Institut Mines-Télécom

DIGITAL TECHNOLOGY:
INDUSTRIAL CHALLENGES AND ECOLOGICAL IMPERATIVES

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EDITORIAL

Odile Gauthier,
Executive Director of IMT.

The centuries-old history of Institut Mines-Télécom (IMT) and its engineering and management schools—some with close ties to French industry dating back more than 200 years—has intimately connected it to the major technological developments and their social and economic implications. As we begin a new decade, the rise of new technology continues and the role of digital technology is increasing, even as ecological concerns and considerations are coming to the foreground in our society. It was therefore only natural that we should question the compatibility between the digital and environmental transitions. In the meantime, the health crisis has accelerated the development of professional and personal uses of digital technology. This has further highlighted the importance of addressing the ecological challenges of digital technology that is seen as a key to resilience. Supported by Fondation Mines-Télécom, IMT has therefore gathered a network of experts from its schools and industrial and academic partners to produce this 12th brochure on the environmental impacts of digital technology.

As you read through this booklet, you will gain a deeper insight into the issues that arise at the point where ecological imperatives intersect with the socio-economic and technical demands companies face.
Through articles written by our scientific journalists, our experts will help readers understand every stage in the life cycle of digital products, offering insight into the specific issues involved in the extraction of raw materials, design, use and recycling of these products. They help provide an understanding of how to adapt the digital sector in the context of a climate emergency,
and how to raise awareness among stakeholders for the future. This insight helps us see that, although reconciling the development of digital technology and sustainable development is a complex task requiring significant efforts, it is still within reach.

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I

HARDWARE IN THE EARTH

Mining is becoming an increasingly important issue as the needs of digital technology for raw materials increase. Projects for new mines are flourishing in areas seeking to regain sovereignty over the production of critical metals. This industrial boom is paired with the growing ecological concerns of our society. This makes the questions raised about the footprint of mining activities extremely complex, because they combine economic, political and scientific interests.

THE MINE, A MULTIFACETED THING

Each mining site is unique, with specific parameters linked to its specific territory. The ore mined, economic means used, and policies applied all help to define the mine and its environmental impact.

2020: smartphones still don't grow on trees. To make them, we must dig deep into the earth in several locations around the world. We have become so used to seeing the streamlined designs of our phones, that we can easily forget their mineral origins. Yet the mine is the first phase in an electronic product's life cycle. Without the extraction of raw materials, there would be no Netflix, no Amazon Prime deliveries, and no Uber. **Rare earths**, tantalum, gallium, lithium, aluminum, gold, copper, etc. The anatomy of our smartphones and computers reveals the presence of some forty different metals. All of these elements are present in rock that must be extracted from the ground.

But what exactly does a mine look like? "It all depends on the resource being mined, the location of the mine, and the investors," explains Jean-Alain Fleurisson, a researcher in geoscience at Mines ParisTech. "The mine seeks optimum efficiency at a set cost," and this optimum must factor in a wide range of parameters. These include regulatory aspects, the nature of the terrain, and political and economic considerations for the territory. This means that for the same ore, two different mines could have very different environmental impacts. "One thing is for sure, there is no such thing as a neutral mine," says Yann Gunzburger, researcher in geoscience at Nancy. "Since its role is to extract material, a mine cannot be sustainable. All that can be done is to minimize its impacts."

Surface or underground?

In countries with weak regulations, without any opposition from local communities, open-air mines can easily be opened. In such cases, the mine has a major effect on the territory. This is due to a fairly simple principle: the mine extracts material from the surface to reach the deposit located below. As the mine digs deeper into the Earth, it must also expand in width to stabilize the ground, which increases the volume of rock extracted that does not contain ore—this is referred to as **mine tailings**. This unnecessary material is usually stored near the mine, creating small artificial hills, and increasing the visual transformation of the landscape.

On the other hand, in countries with strong regulations, with investors who are concerned about their image—and therefore risks—the minimization of impacts can reach a high level of performance. In Europe and North America,

Evaporation ponds at the pilot lithium mine in Salar de Uyuni, in Bolivia. Located 3,700 meters above sea level, it is the largest salt pan in the world, spanning over 10,000 km^2. The lithium mine has 17 lines of 10 ponds, for a total dimension of 1 km in length and 500 m in width. Photo: Cédric Gerbehaye

some high-tech mines are virtually invisible. One such example is the tungsten mine in Mittersill, Austria. A state-of-the-art facility, it is often used as an example of the model mine. The only sign of this underground mine is an entrance to a tunnel in the mountain.

Its advantages are not merely visual, they are also productive. The underground mine does not scrape the surface soil to reach the deposit. It therefore does not need to expand in width. This enables better yield in terms of mined material and generates less in the way of mine tailings to manage. "Surface mines generally produce 350 kilograms of ore per ton of extracted rock," explains Philippe Marion, professor emeritus in geoscience at École Nationale Supérieure de Géologie, Université de Lorraine. "In the case of an underground mine, this amount is approximately 900 kilograms of ore per ton of extracted rock. The idea is to extract as little rock as possible to remove the economic substance."

Moreover, "underground production has a lesser impact than surface mines," explains Jean-Alain Fleurisson. "The risks are related to groundwater management, ground failures and residual seismicity." These last two factors are well managed in mines where advanced technological methods are used. Extensive digital models make it possible to accurately select the most robust areas of the terrain.

"There is no such thing as a neutral mine. All we can do is minimize its impacts."

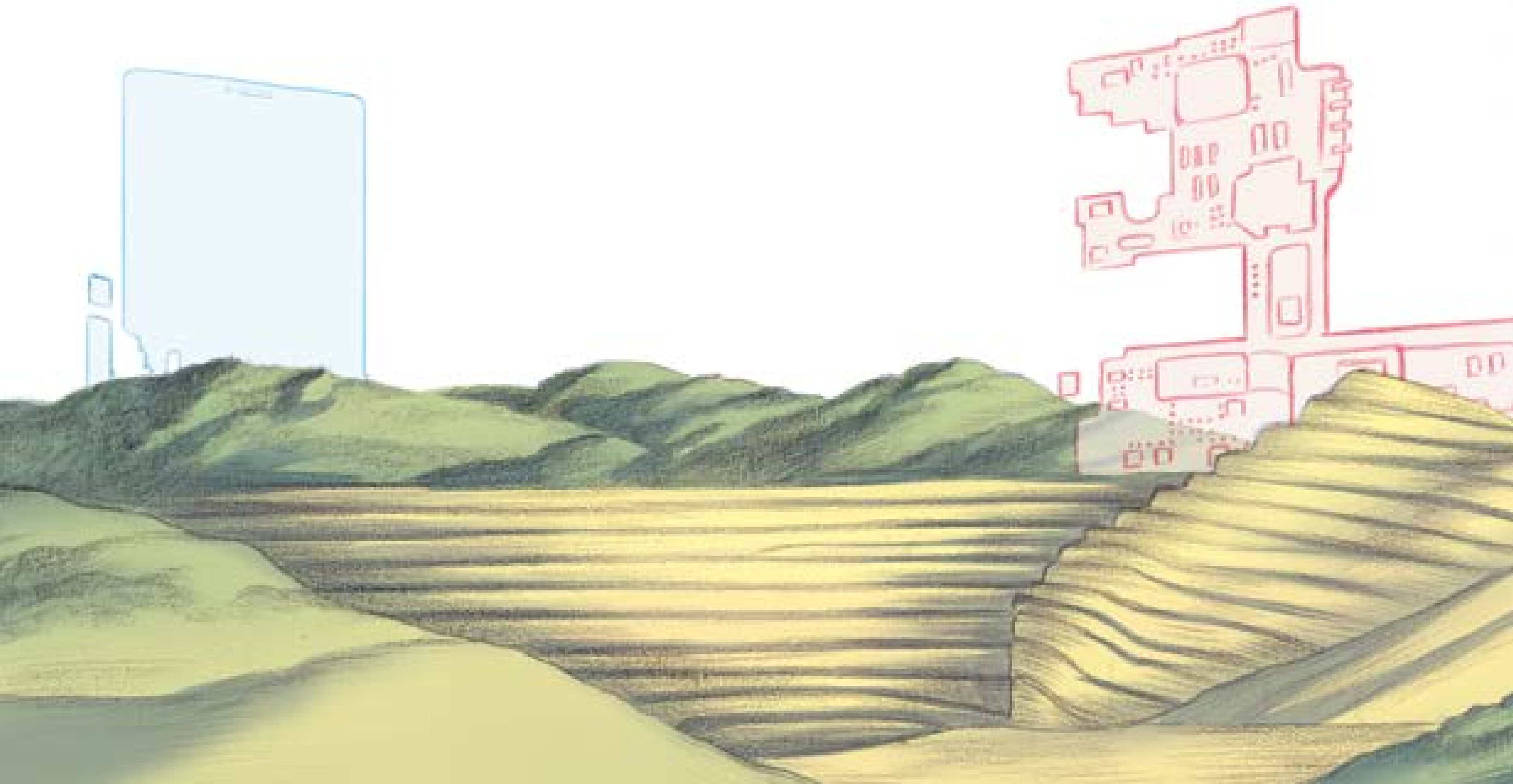
The groundwater issue is more complicated. When ore is exposed to air, the rock is oxidized and generates several products that can contaminate the water. "This is the case with sulfuric acid, resulting in a phenomenon called acid mine drainage," explains Philippe Marion. Good practices can be used to manage runoff by trying to separate them from underground water circuits, or waterproofing the vulnerable areas of the mine. Despite these precautions, "very few sites are able to avoid these phenomena," the researcher says. "It is virtually impossible to waterproof all the areas necessary. This underground volume would be the equivalent of thousands of buildings."

"The mine of the future is also a societal phenomenon."

The weight of the socio-political context

Despite current technological measures, there is therefore a residual impact on the environment that is very difficult to overcome. Therefore, in the words of Yann Gunzburger, "the mine of the future is not only technological or environmental, it is also societal." A responsible mining project is not a project without any impacts, it is a project in which society—especially local stakeholders—negotiate and accept the irreducible risk by adapting it to the territory. This approach is especially effective in geographical areas where the different social stakeholders can use policy instruments to influence territorial policies. A good example is the case of nickel mines in New Caledonia, which included discussions with the Aboriginal community and environmental organizations on the identity of the territory.

Unfortunately, this is not a common occurrence. There are specific cases in which technical constraints and the socio-economic environment do not allow for true integration of environmental issues. Lithium, for example, used to produce the batteries in all of our electronic devices, is primarily extracted from **salars**. These salt pans are formed by large high-altitude likes, primarily located in South America. As the water evaporates, it leaves behind several salts which can be separated, some of which contain lithium. Salars are rare sites, prized by photographers and tourists for the layer of residual water that reflects the sky. "Lithium mines in these areas damage remarkable landscapes," says Michel Jébrak, a researcher in mining engineering at Université



du Québec in Montreal (UQAM). "Furthermore, these facilities require tremendous amounts of water, in geographical areas that sometimes experience shortages." There are few satisfactory alternatives to replace salars. Australia has pegmatite quarries that produce lithium, but in smaller amounts.

The case of lithium is not an unusual one. In fact, underground mines only account for a small share of the extractive industry. "There are four to five times more of these mines than surface mines, but they only produce 40% of global ore tonnage," explains Yann Gunzburger. The reason is primarily economic. While underground mines are the most responsible option, they are also more expensive. Therefore, underground mines are not very popular in areas where mining projects only marginally take account of environmental concerns. However, according to the researcher from Mines Nancy, "volumes mined for the digital market represent small quantities in the mining industry. The trend of underground mining therefore would not be a bad idea, since economic factors become less significant as the volume of the deposits decreases. The only exception is cobalt, which is a by-product of copper and therefore requires significant production volumes."

From artisanal mine to illegal mine

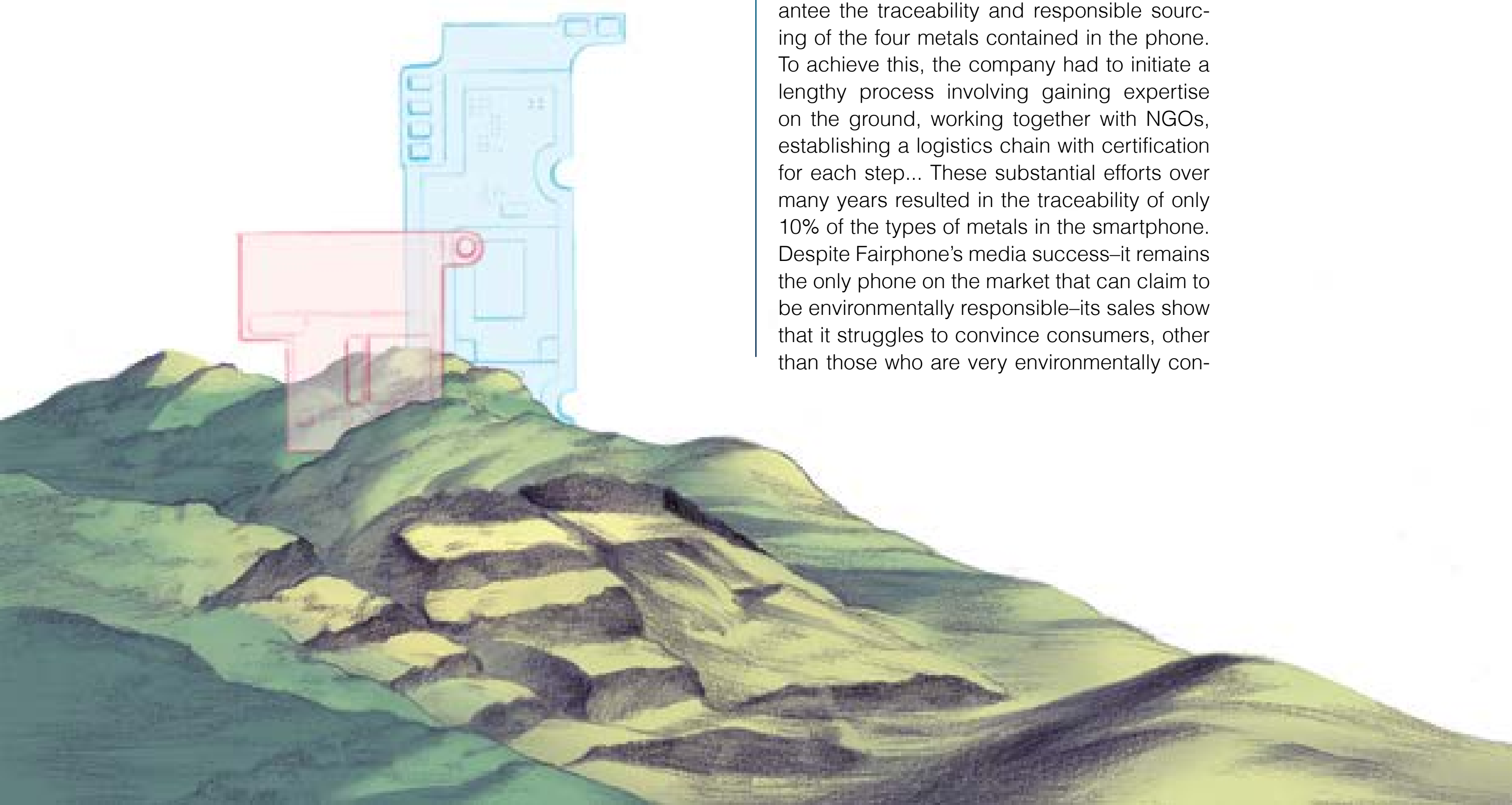
Cobalt, which is also used in batteries, is generally combined with copper and nickel in the deposits. One of the major cobalt-producing regions is the copper belt located between Zambia and the Democratic Republic of the Congo, known as one of the world's largest copper production areas. The relationship with mines is much more complex in this region. "Copper extraction is conducted using artisanal methods," explains Michel Jébrak. "Families carry out this work, and resell it on-site to mining industrialists." Artisanal mining production is far from marginal. "It is estimated that there are at least 40 million artisan miners in the world, as opposed to 8 million industrial miners," says the researcher from UQAM. While the mined tonnage from artisanal miners is certainly not proportional to their number in the minerals market, they must not be

"A more responsible mine is also more expensive."

overlooked. In October 2019, a report by the German Federal Institute for Geosciences and Natural Resources (BGR) estimated that artisanal production represents approximately 15% of all Congolese cobalt exports.

"There are two types of artisanal mines," says Marc Vinches, a researcher in geoscience at IMT Mines Alès currently supervising a thesis on the environmental impacts of artisanal mines in the Niger River Basin. "First there is the legal artisanal mine, for which the operators pay a tax collected by the State. The mayor or traditional chief guarantees that the tax will be paid back to the employees. Then there is the illegal mine, unsupervised by the State and run by the local mafia. The army will not go there because it is too dangerous." Although they are much smaller than large industrial facilities, these artisanal mines can cause disastrous environmental impacts. Without supervision, the deforestation of several hectares is conducted in an uncontrolled manner in order to dig the shafts. "The soil is no longer held together. When the rainy season arrives, large areas of land become unsuitable for farming," says Marc Vinches. Since the miners rely on local agricultural production for food, they move to a nearby area to start over. "Yet the consequences for land surfaces are less significant than the effects on water," explains the researcher. "The rivers become turbid and their toxicity greatly increases." The main reason is that the rocks are processed right near the extraction site, with limited technical means. "At our study site, we observed polluted water with arsenic content 200 to 300 times higher than the legal level for water in Europe."

From a broader perspective, the political and economic complexity of the mining industry make it difficult to offer simple solutions for reducing its environmental impacts. Steps must be taken to bring together the responsibilities of final customers, manufacturers of electronic devices, public authorities in producing regions and major consumer areas... This amounts to holding the entire market accountable, after decades of established power dynamics. The Fairphone, a smartphone produced by a company of the same name, created in 2013, is emblematic of this comprehensive change in approach. In 2016, shortly after the launch of Fairphone 2, the company was able to guarantee the traceability and responsible sourcing of the four metals contained in the phone. To achieve this, the company had to initiate a lengthy process involving gaining expertise on the ground, working together with NGOs, establishing a logistics chain with certification for each step... These substantial efforts over many years resulted in the traceability of only 10% of the types of metals in the smartphone. Despite Fairphone's media success–it remains the only phone on the market that can claim to be environmentally responsible–its sales show that it struggles to convince consumers, other than those who are very environmentally con-

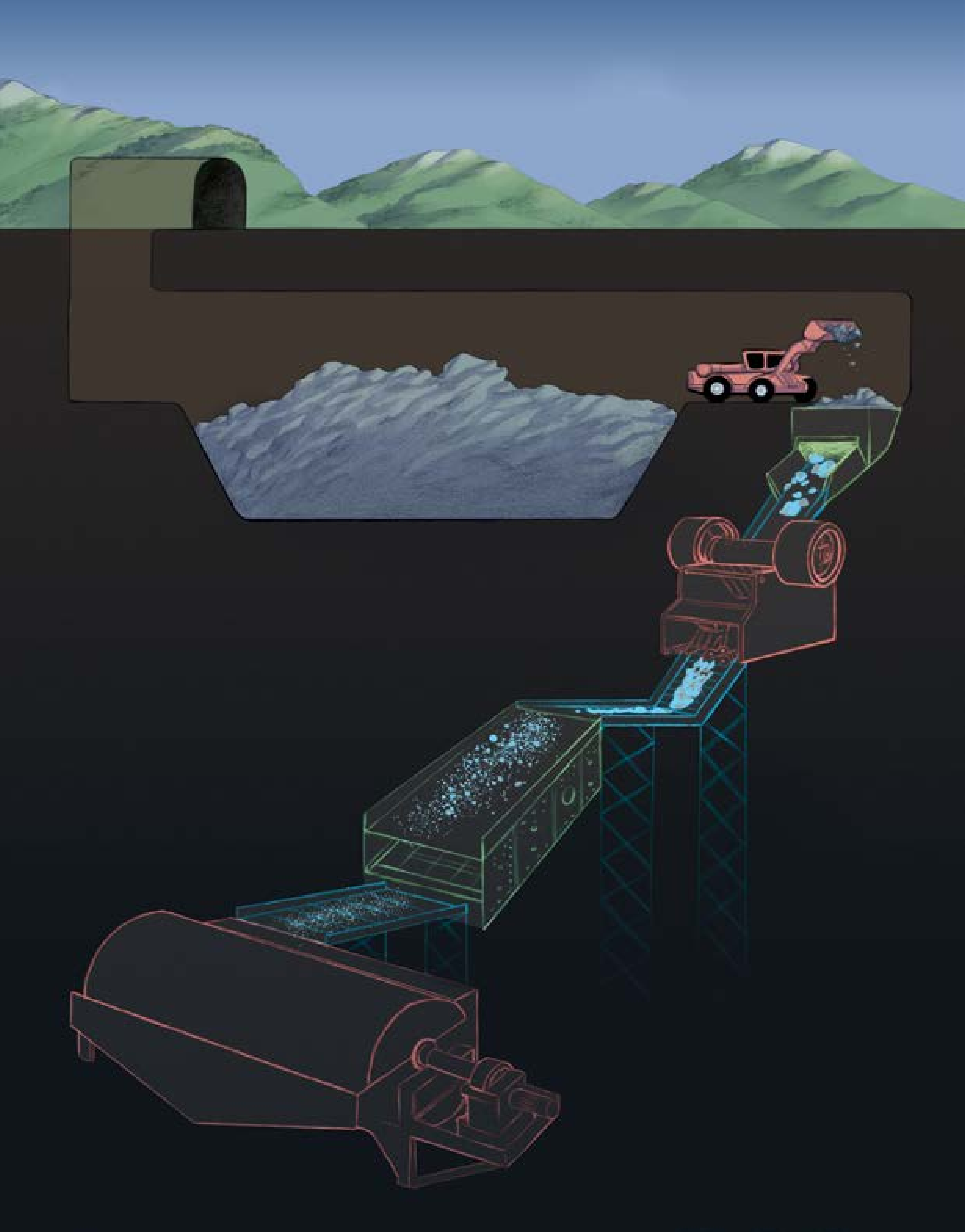


scious. While the smartphone is exemplary, it also shows how difficult it is to impose new standards of responsibility in the market. Without any economic pressure on local mineral production from the final customer at the end of the chain, it will be difficult to introduce the value of responsibility in the mines least concerned about environmental impacts.

"It is difficult to impose a standard of responsibility."

THE MINE OF THE FUTURE: UNDER THE SEA OR IN THE SKY?

As more and more industrialists are looking to the abysses for undersea deposits of rare earths, some projects have set their eyes on space and the minerals of asteroids. In both cases, these projects must use very advanced technological means to reach the desired elements. Given the enthusiasm in this area, Michel Jébrak, researcher in mining engineering at Université du Québec in Montreal, recalls the principle of a deposit: "It is an economically exploitable resource. The word 'economically' is paramount, because if it is not profitable, no one will want to extract the mineral." In the midst of the initial excitement, it is therefore important to question the industrial reality of the underlying projects. Successfully bringing a few kilograms or even a few tons of ore up from the abyss does not necessarily mean that it will be possible to scale up to extracting thousands of tons of rock per day, as is the case for existing mines.



EXTRACTION, THE OFF-SITE IMPACTS

The mine is only one discrete part of the extractive industry's environmental footprint. Once the ore has been removed from the ground, the storage and processing phases have more significant consequences on the environment than extraction. These indirect impacts are often neglected in analytical studies of ecological consequences, often due to a lack of appropriate tools.

"When it comes to the quality of ecosystems, the overwhelming majority of the mining industry's impact occurs outside the mine itself," explains Miguel Lopez-Ferber, researcher in environmental engineering at IMT Mines Alès. Since 2015, his team has been working on the assessment of the extractive industry's footprint. The main difficulty involved in this task is the integration of all the activities related to the mine, not only extraction. Once it has been removed from the earth, the ore must be stored and processed before being sold. These steps are generally carried out at other sites, away from the mine, and involve indirect impacts–as compared to the direct impacts of the mine site. "Our research has shown that the indirect impacts are significantly higher than the direct impacts," says the researcher.

For example, the initial stages of grinding and concentrating the ore can account for up to 70% of the total water consumption for the entire extraction and processing phases. This is true for copper as well. In 2016, a report for the Chilean Copper Commission estimated the consumption of freshwater for its processing phases at 10.6 cubic meters per second. Predictions for Chile–one of the world's largest copper producers–anticipate stable consumption of freshwater over the next ten-year period, despite an expected increase in production. New processes are incorporating the use of sea water when it is accessible in order to limit the use of freshwater. In Chile, consumption of sea water is expected to increase fourfold by 2026, and move from 2.5 to 10 cubic meters per second.

> **"The overwhelming majority of the mining industry's impacts occur outside the mine."**

Philippe Marion, professor emeritus in geoscience at École Nationale Supérieure de Géologie, Université de Lorraine, agrees on the indirect impacts: “This is where significant progress can be made, including in the storage of tailings. With unregulated storage and unsafe storage practices, there is considerable room for improvement.” The current storage limits are economic as well as technical. From a technical perspective, the construction of sites must ensure chemical and physical stability. Storage facilities for tailings generated by concentration operations are generally surrounded by dams. Some ponds can hold hundreds of thousands of cubic meters, requiring the construction of dams over 100 meters high. Exposed to the air and rain, the storage ponds must be able to withstand the mechanical constraints of the terrain.

“The problem arises when uncertainties exist concerning a project’s economic viability.”

In countries where health and industrial authorities have the necessary means of action, the structures are inspected and the projects subject to technical studies. “With the latest developments in the field, industrialists can sustainably encapsulate the chemicals by creating ‘soil sandwiches’ composed of several materials,” says Philippe Marion. “The problem arises when uncertainties exist concerning a project’s economic viability or political stability.” In these cases, the storage phase is not always integrated as it should at the start of the project, which results in problems later. If the mine becomes profitable, and extraction increases relative to the initially estimated level, “the updates to the facilities are sometimes not executed as well as the initial project.” The storage area can therefore be undersized, which increases the risk of tailings dam failures or leaks into the environment. On the other hand, if the project is quickly abandoned, there is an increased risk of a lack of financial means or commitment by stakeholders to manage the tailings.

“Governance is the most important factor.”

In the worst cases, the poor management of storage areas can lead to major natural disasters. The most well-known in Europe occurred in Baia Mare, Romania, in 2000. More recently, in 2015 and later in 2019, two tailings dam failures in the state of Minas Gerais in Brazil drew attention to the importance of effective management of these sites. When these events occur, the sludge is released into surrounding waterways and land soil and has long-term impacts on the ecosystems. “Governance is the most important factor in ensuring the security of these sites,” says Philippe Marion. “They must have a legal, political and economic framework that enables the regular and long-term monitoring of these sites.” Yann Gunzburger, researcher in geoscience at Mines Nancy, also emphasizes this pressing need: “Accidents occur even after the site closes, once the operator has left. Monitoring aspects are therefore of primary importance. Post-mining security responsibility, whether it is attributed to the operator or State, must be defined at the outset of a project.”

Storage management is a central issue for the mining industry. Surface deposits—the most accessible—are the most commonly mined, and are reaching maximum production capacity. In order to meet demand and find the increasingly rare materials needed to manufacture new technologies, it is now necessary to dig deeper into ore that is less rich in the desired element. In the near future, the mining industry will therefore be required to produce and store more waste rock, and process larger quantities of ore to recover the same amount of metal. It is therefore essential to improve the security and monitoring of storage infrastructure. At the same time, solutions must be found to manage the tailings. "One solution that is becoming increasingly popular is to use them as backfill in the mines," says Yann Gunzburger. Both surface and underground mines leave large empty cavities behind after mining operations. Most of the time, these holes are filled with water, creating artificial lakes. The use of tailings as backfill is an alternative that could also help restore the stability of soil that has been weakened by mining activities. "Another approach is to find an industrial use for these tailings," says Philippe Marion. "Some rocks can be used as road aggregate. Unfortunately, they are rich in sulfide, which is not a welcome addition in concrete. This has therefore hindered the recovery of tailings in this area."

Calculating every parameter

The storage and processing stages involve a wide range of parameters to take into account when calculating the footprint of mineral production. The shaping of the territory, stress on local water supply, and energy consumption–which depends on the local production methods–are all aspects that must be integrated into the environmental impacts.

> **"It is now necessary to dig deeper into ore that is less rich in the desired element."**

However, impact studies conducted prior to the start of mining projects rarely integrate this information on indirect impacts. Miguel Lopez-Ferber: "When an impact study is conducted, it focuses on what is happening on the land to be used for the mine. Will the facility disrupt a nearby river? What effects will it have downstream? But the study never takes into account whether it is necessary to construct an off-site ore processing plant, tens or hundreds of kilometers away."

The main reason for this lack of thoroughness is the amount of data that must be included in the assessment as soon as indirect impacts are added. Conventional **life cycle analysis** methods cannot integrate that many parameters. At the actual mine site, things are very clear. It is usually easy to determine the water and energy sources.

> **"Conventional life cycle analysis methods cannot integrate that many parameters."**

But what should be done when the copper and cobalt are separated, each metal stored in a different location, sometimes at different sites, and sent to several processing plants around the world? For each entity, local production methods must be integrated, as well as the share of local energy consumption used for the ore from the given mine (thus ensuring traceability throughout the entire chain). "And that is only for the first cycle of consequences," says the researcher from IMT Mines Alès. "If we want to integrate every employee's mode of transport at all the sites, or the footprint of the machines at each plant, we end up having to calculate the footprint of all the human activity." Yet, for economic reasons, no mining project can afford such an extensive impact study.

New tools must therefore be invented to better assess the overall footprint, taking both direct and indirect impacts into account. "We have started researching this," says Miguel Lopez-Ferber. The idea is to make it easier to integrate the entire geographical scope, including new environmental parameters, such as damage to aquatic environments, the fragmentation of ecosystems, and spills of metals into the environment. Eventually, these new techniques for impact studies should provide better insight for policy makers and local communities right from the outset of mining projects.

"New tools must be invented to better assess the overall footprint."

For the researchers from Alès, this is also a matter of providing final information that is easy to understand, with impact categories and assessments that are easy to read. This is an absolute precondition for including as many of the stakeholders involved in mining projects as possible, both at the mine sites, and in areas affected by the indirect impacts.

RECONCILING EXTRACTION AND ENVIRONMENTAL PROTECTION THROUGH LAW

Several years ago, a reform of the French Mining Code was initiated but never finalized. The goal was to bring this code for the extractive industry into line with the Environmental Code. The underlying legal issues question the fundamental principles of managing mineral resources in France. Stéphanie Reiche-de Vigan, researcher in sustainable development law and new technologies at Mines ParisTech, is analyzing this ongoing reform in her work. She presents key issues in providing a framework for extraction activities and the management of natural resources from a comparative perspective, in order to highlight current shortcomings in the French mining model.

Which regulation governs mining activities in France?

Stéphanie Reiche-de Vigan: In France, the exploration and exploitation of mineral resources is regulated by the **French Mining Code** enacted by Ruling No. 2011-91 of January 20, 2011 on codifying the legislative section of the Mining Code. This section was codified on the basis of existing legislation, meaning that no significant changes were made to the existing law dating back to 1956. The fundamental principles of that law were taken from the Napoleonic law of April 21, 1810 on mines, mining operations and quarries.

How does this regulation work?

SRdV: The French Mining Code is based on an original feature: the legal concept of "mine". It has nothing to do with industrial techniques of mining or oil industries, or the reality of the subsoil. All the foreign legislation studied, unlike French law, uses the term "mine" or "mining" to refer to all that relates to the mining industry alone, thereby excluding the oil and gas industries and any other uses of the subsoil, such as for storage or geothermal energy. This French exception served a purpose in the past. It was intended to create a new form of legal property, the mine, governed by the State, as an exception to the Civil Code, and to extend ownership into the depths of the ground. It now

appears to be outdated and sorely lacking any relevance to current environmental, economic and industrial issues, and the concerns of citizens.

In this case, how can the regulation of resources and extraction be updated?

SRdV: The French "Mining" Code should be renamed and the scope broadened to improve its social acceptability and intelligibility. Instead of a code limited to regulating the exploration and exploitation of mineral resources and the subsurface, it should become a code for the management of mineral resources. This code would exclude subsurface uses that are unrelated to the exploration and exploitation of resources, such as for storage or geothermal energy. Another approach could be to rename this code the Subsurface Use Code, which would include all these other uses. In both cases, the new code would integrate a resource protection and conservation system. France is very much behind in integrating the general interest of mineral resources for their non-economic and non-strategic value. Unlike most other foreign legislation, French law only considers the general interest of mineral resources and the subsurface in the context of mining and processing these resources. Legislation must include protection and preservation of mineral resources and underground sites. This could take the form of what could be called a national policy for the management of mineral resources and subsurface uses.

Why has the French mining code been in the revision process for years?

SRdV: The Mining Code reform is part of a national and European strategy for the security of strategic supplies as well as a sustainable development strategy. Reform of the Mining Code has been initiated multiple times without success. The latest project, a bill aimed at adapting the Mining Code to environmental law, submitted on November 23, 2016 by Bruno Le Roux, and voted on in first reading in the National Assembly on January 25, 2017, did not pass. The level of social acceptability for extraction activities in metropolitan France and in overseas territories is very low. In light of the French national context, especially in terms of the country's history and social environment, mining activities will only be able to grow in France—especially in mainland France—if the reform integrates the environmental concerns of citizens and the demands of Aboriginal groups living in French territory. The code focused only on exploration and exploitation must change to become a code ensuring the sustainable, balanced and sound management of mineral resources and possible subsurface uses, as is the case in most foreign legislation.

"The level of social acceptability for extraction activities in metropolitan France and in overseas territories is very low."

You use China and North America as examples, yet the management of mining activities in these countries is strongly criticized.

SRdV: That is true, but the environmental damage caused by extractive industries are the inevitable consequences of these activities. They are more the result of political will than of a legal reality. Both Chinese and U.S. Federal law, to take but two examples, are very clear regarding the rational use of the subsurface and its resources, and acknowledge the harmful consequences of mining activities. Under Chinese law, the 1982 Constitution requires that the State ensure "the rational use of natural resources". Under U.S. Federal law, the Federal Land Policy and Management Act of 1976 establishes a multiple-use management policy for federal land in order to best meet the present and future needs of the American people, including the production of mineral resources and the protection of fauna and flora. This Act is based on the principle of the "harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and environmental quality." Differences exist between private land and federal land, but the law in this area is much more complex that certain French analysts suggest. A desire to deny the intrinsically destructive nature of mining activities, as seen in the current French Mining Code and the draft reform, will not increase the social acceptability of mining activities nor reduce local opposition to the projects. It would be wiser to work in consultation with public and local authorities to establish a long-term plan aimed at meeting national needs, which would identify the potential areas for mine sites and areas that would be entirely off-limits given their ecological value or fragility. Planning based on the U.S. Federal model or Spanish model is a valuable tool for meeting national needs while also improving the social acceptability of mining projects and thus reducing legal uncertainty for operators. This phase could include consultation with the public and local authorities and an environmental impact study.

In your legal analysis of the draft reform of the Mining Code, you recommended including certain principles, including the sustainable and rational management of natural resources. What does this involve?

SRdV: The exploration and exploitation of mineral resources must be seen from the broader perspective of the sustainable and rational management of natural resources, which includes choosing not to outsource impacts to other countries. In terms of mineral resources, this fundamental principle must ensure the balance between using underground space for mining, injection and storage purposes, and preventing the use of underground space in order to protect natural resources. This principle must also allow for the development of a national mineral resources and subsurface use policy based on fundamental principles. These include use planning, State management of mineral resources, the integration of environmental, economic and social impacts, proportionality, the respect of adversarial proceeding principles, consultation and participation of the public and local authorities, and sustainable management of the environmental impacts of exploration and exploitation projects.

"The exploration and exploitation of mineral resources must be seen from a broader perspective of sustainably and rationally managing natural resources."

A thorough reform should simplify and clarify current law by removing the outdated legal concept of the mine. New law should be based on the principle of the sustainable and rational management of mineral resources, meaning management that is economically efficient, socially just and environmentally sustainable.

To learn more:

- *Des Mines en France ? Une controverse entre technique et territoire*, I'MTech, 2018, www.imtechnews.fr
- *New Caledonia: a mine challenging democracy*, I'MTech, 2017, www.imtechnews.fr
- Michel Jébrak, *Quels métaux pour demain ?*, Dunod, coll. UniverSciences, 2015, 256 p

II

CORPORATE RESPONSIBILITY

Singled out for their bad or good practices, companies are often on the front lines when it comes to environmental responsibility for digital technology. They must therefore learn to adapt in order to integrate their customers' concerns and those of their employees. Yet given the complex nature of these process changes, combined with a lack of tools for effectively assessing environmental footprints, societal pressure from inside and outside organizations, this is no easy task.

1 WITHOUT VISIBILITY, NO IMPACT ASSESSMENT

2 ECODESIGN, THE CONVERGENCE OF SUSTAINABLE AND SOCIAL INNOVATION

3 RAISING AWARENESS FOR THE FUTURE

WITHOUT VISIBILITY, NO IMPACT ASSESSMENT

Inside companies, managers and staff members are seeking solutions to reduce the impacts of digital technology. New environmental expert positions, such as Green IT managers, are being created in organizations. The goal is to better understand the environmental cost of the entire production chain in order to determine means of action to prioritize.

It is no longer simply a matter of assessing a product's footprint. Companies must now be able to integrate the indirect impacts of their services and products into their environmental performance. They must therefore take into account the power supply for the infrastructure used for data storage and computing, since companies in every sector now use digital technology. This holistic approach to footprint calculations is difficult to implement. Miguel Lopez-Ferber, a researcher in environmental engineering at IMT Mines Alès, explains that "while indicators are used to control the consumption of data centers in France and certain Western countries, this is not the general practice."

Perrine Tiret, Head of the Green Company for BNP Paribas employees is currently conducting the assessment of their digital carbon footprint. They are using **PUE** (**Power Usage Effectiveness**) indicators that assess the relationship between the company's need and the data center's consumption to measure its effectiveness. "This allows us to closely monitor the management performance of our servers and make sure the techniques used to cool the servers are effective", Perrine Tiret says.

But not all companies have their own servers–many rely on suppliers. "Under certain conditions, a few suppliers ensure the maximum consumption of their server," says Miguel Lopez-Ferber. But again, this is not general practice. "The concept of server consumption certificates is gaining ground, but the process will need to be standardized," he adds.

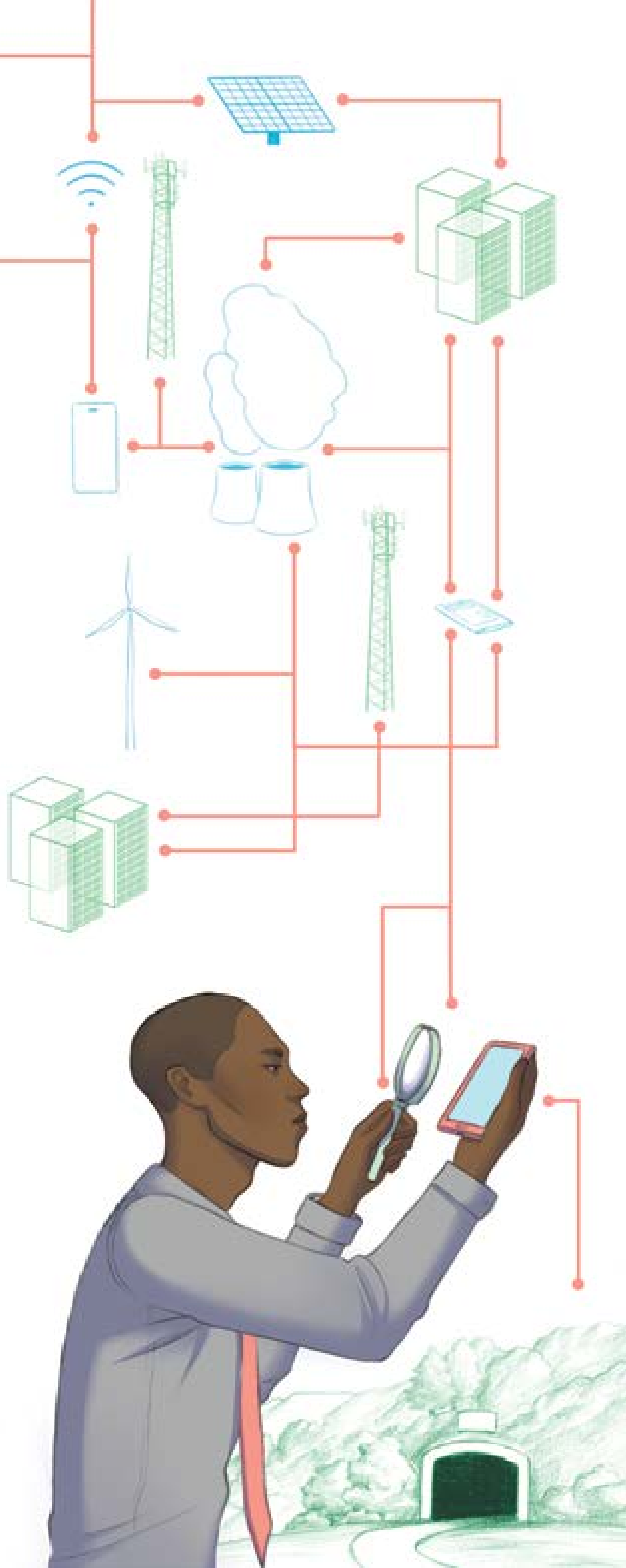
> **"How can we tell where the servers are when we use cloud services?"**

Tracking virtual machines

Then comes the main problem: cloud services. "In France, we are powered by nuclear energy, which is low-carbon, but for China and Germany, which rely on fossil fuels, the environmental cost is higher for the same amount of energy consumption. How can we tell where the servers are when we use cloud services?" Miguel Lopez Ferber asks. Since the servers are virtualized, companies lose visibility and are unable to estimate the impacts of their data storage and computing activities themselves.

Emmanuel Laroche is the **Green IT** manager for Airbus Group, and a member of INR (Institut du Numérique Responsable), the French institute for sustainable digitalization. He testifies to the difficulties that arise in assessing the environmental impacts of digital activities due to **virtualization**: "**Life cycle analysis** relies on databases that measure the impacts of different families of equipment, such as servers, data centers and network equipment. In the case of cloud computing, it is very difficult to enrich databases with data from cloud providers. It is just as difficult to obtain greenhouse gas emissions reports from these vendors." Greater transparency must be established between providers and the companies using their services in order to enable the environmental assessment of cloud activities. This could, for example, mean requiring virtualized service providers to monitor their own consumption and communicate this information to the companies.

Emerson Picq, the agile development manager at EDF, stresses this limitation to the use of virtualized machines: "We have **data centers** on one side and users on the other. We must find coherence between the two." His colleague, Olivier Lefebvre, strategic director of agile development at EDF, explains that the goal is being able to say: "I can open my application and identify the end-to-end value of all that has been consumed, from the user terminal to the server that hosts the application, in order to address the entire service chain." The colleagues both agree that today "no tool on the market meets this need." There is therefore a need to develop coherence throughout the entire chain and transparency between the different stakeholders.



A need for transparency

This need for transparency extends beyond cloud service providers to all corporate staff members. Perrine Tiret explains that one area that could cause problems in identifying the right means of action for the ecological transition "will probably be the collection and sharing of the necessary data." This transparency is not a given. Partners can be reluctant to share data which likely has strategic value. Some therefore prefer to protect it by means of professional secrecy.

"Establishing transparency means first establishing trust with industry stakeholders on how we will use this data," says Samuli Vaija. "They want to make sure it will truly be used to analyze the environmental cost and that we will not use it for other calculations, such as searching for financial savings by checking the price of what is paid." Along with Marc Vautier, he is part of a community of experts with Orange Group. They are both in charge of product life cycle analysis issues. "We are not an industry. We are an operator service. When ordering a product, it is hard to tell which components are used and in what quantities, and it's often difficult with industrialists who do not necessarily want to share this information," explains Marc Vautier. These measures used to be taken internally, but their policy has changed. They now ask industrial contractors to carry out this analysis directly on the products provided.

The standardization of life cycle analysis practices would be a good starting place for encouraging subcontracting companies to perform the analysis themselves and share the information with the rest of the chain. "This environmental analysis principle must percolate into the industries and become a habit. Basically, there must be more sharing between the different stakeholders," explains Samuli Vaija. Marc Vautier add that "ideally the industry producing the wires should share information with the one installing the chip, and so on. That way all the data would follow the product and be added to the entire life cycle."

"Trust must first be established with industry stakeholders."

But this also requires commitments to be obtained from companies on the entire cycle of the product or service they offer. This involves pressuring them become accountable for the upstream manufacturing processes and downstream consumption. Otherwise, some key aspects for reducing the environmental impacts of digital technology could be overlooked. "Before, when we installed a decoder for a customer, it would consume energy every day. It was not the company's issue because the cost of electricity only affects the customer. But if operators are held accountable for the products installed in their customers' homes, they will promote solutions to reduce this cost, such as installing a standby mode," Samuli Vaija and Marc Vautier explain.

ECODESIGN, THE CONVERGENCE OF SUSTAINABLE AND SOCIAL INNOVATIONS

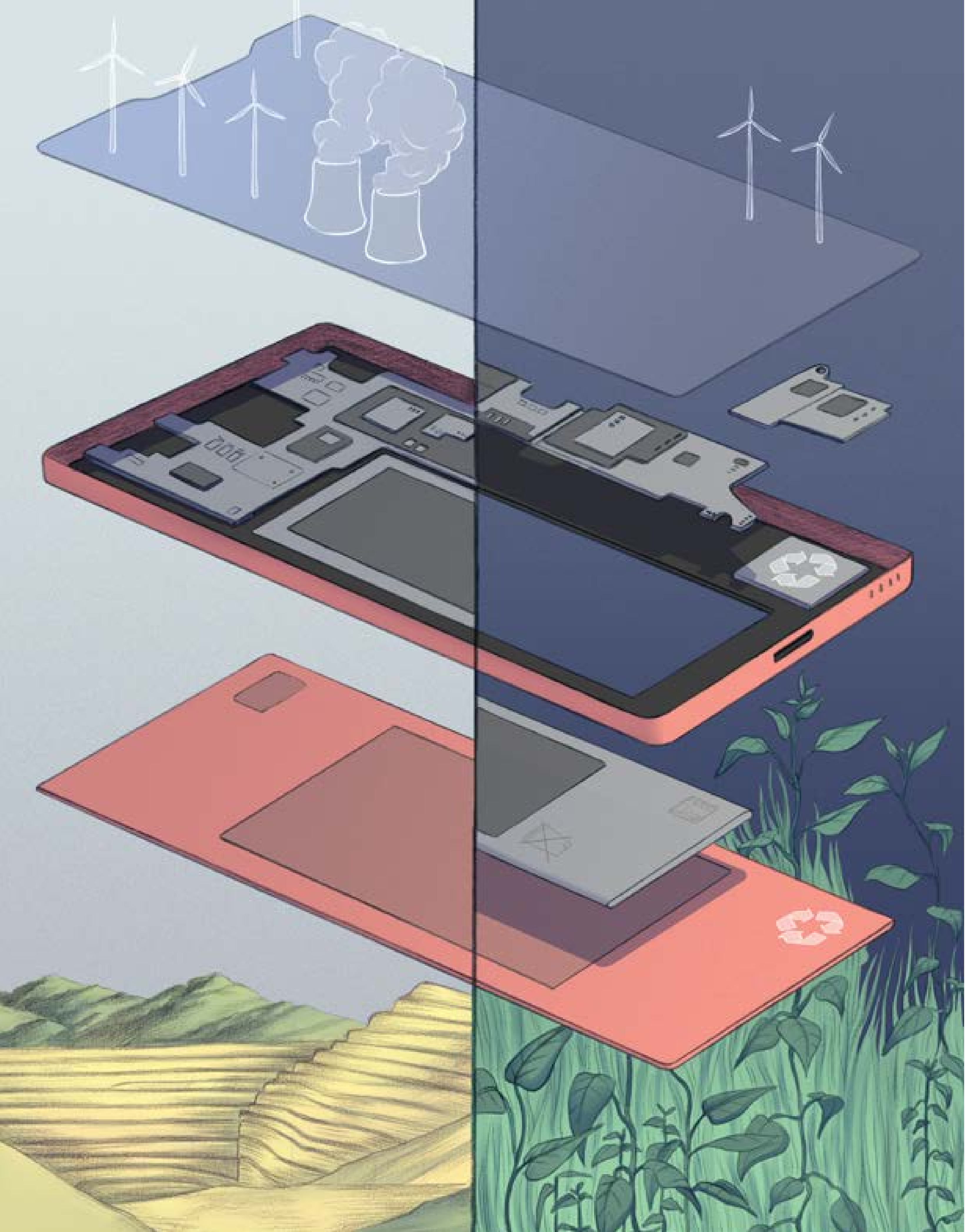
Ecodesign is becoming unavoidable for companies increasingly concerned about their environmental impacts. It allows them to develop sustainable products and services. Despite its name, it is not limited to design. Ecodesign is a call to thoroughly rethink the company's organizational structure and all its relationships with socio-economic players.

For companies, the development of ecodesigned materials, designed to reduce their environmental impact, often creates fears of increased production costs and thus increased sale prices. According to Samuli Vaija, product life cycle analyst at Orange, "by changing the materials used, we can simply be faced with more expensive products. We can also have materials with the same value per kilogram that are sold for a higher price per unit due to higher demand."

Historically, certain materials have been promoted without taking into account their environmental impacts. Other materials, with similar prices but better environmental performance, are not sufficiently developed to replace the old materials. "If we need a lot of material to replace all the Orange decoders and the new production chain is not used to such high demand, we can be faced with economic absurdities," says Marc Vautier, who is also a product life cycle analyst at Orange.

Smart ecodesign

The economic factor is obviously very important for businesses. The experts explain that what is needed "is to make a smart **ecodesign**, for example by improving refurbishment possibilities. It's a life cycle optimization that also represents cost savings." Olivier Lefebvre, strategic director of agile development at EDF, adds that there will likely "be a necessary investment involved in initiating changes in standards, but we see potential gains in the future. Having to replace equipment less frequently and developing servers that are less energy-intensive is also helps generate gains."



However, this does require companies to rethink their strategies. They can no longer rely on a novelty value approach. "There is serious reflection on value creation practices, and what this means for employees and customers. It is primarily through this economic means that ecodesign was introduced in companies," says Sandrine Berger-Douce, researcher in responsible management and innovation at Mines Saint-Étienne. This is not simply a matter of optimizing materials and performance, but also of working on uses, by offering relevant products without "extravagant uses", that are light and low-energy.

These questions challenge the economic models. "Many companies are embracing the concept of a circular economy, for example," says Sandrine Berger-Douce. "This is important for innovation in its broader sense because companies need to find ways to innovate differently." Cédric Gossart, researcher in social innovations at Institut Mines-Télécom Business School, also raises the issue of systemic obsolescence, with the use of components that are inexpensive but do not last long. "This is a trend based on the responsibility of users and legal responsibility. A law to increase the duration of warranty periods, for example, would require companies to design products that last."

"There is serious reflection on value creation practices, on what this means for employees and customers."

Radical corporate change

Ecodesign practices in companies must be integrated far in advance, in reflection phases, with the involvement of all the relevant stakeholders. In general, optimizing a product's refurbishment involves developing an entirely new design that features spare parts and is easy to repair.

Marc Vautier explains that the process of developing a decoder made from recycled plastics involves discussions with academics to find the right materials, with manufacturers in the early design phases, and discussions with the various company departments. "The marketing department wanted an elegant, white design but it was too difficult to make with recycled plastics," he explains. Sandrine Berger-Douce highlights the social and cultural issues that come into play in interactions between stakeholders from different organizations. "Not everyone speaks the same language and gaps must be bridged to facilitate cooperation, complementary reflection and, ultimately, to make ecodesign a reality." With this goal in mind, Sopra Steria Group has gathered a group of nearly 250 staff members, on a voluntary basis, to learn to speak the same language in terms of **CSR** (**corporate social responsibility**) and environmental responsibility.

This requires targeting sustainable development challenges and identifying strategies for meeting them by integrating these challenges into innovation strategies. This takes into account environmental and social aspects, ecodesign issues and working conditions. It is then necessary to identify the right means of action from among all the company's strategic priorities. The transformation must be designed in cooperation with the various company departments, with the involvement of as many people as possible. Emerson Picq, agile development manager at EDF, adds that it is also important to think "in terms of accessibility rules, for employees and customers, for those with disabilities. The goal is to establish a guide of best practices that ensures accessibility for all users."

Need for cooperation

"This task of combining energy performance, CSR and sustainable development principles is a perilous one, especially for SMEs," says Sandrine Berger-Douce. It entails having a dedicated department and resources, and companies do not all have the same level of business maturity. "We are entering a world where incorporating ecodesign issues will be unavoidable," says Emerson Picq, who suggests that we could "create measuring points to quantify and encourage efforts that have been made."

"Public action also has a role to play in setting standards and regulations to encourage companies to move in the right direction."

For the most part, this would mean supporting companies by guiding them in the right direction, and potentially proposing labels or standards used to quantify efforts made. "There is a need for public initiatives to support these projects, these environmentally responsible initiatives," says Cédric Gossart. "Measures must be taken to promote these initiatives, such as an additional tax on those who do not integrate these issues, or an environmental bonus system, for example."

Public action also has a role to play in setting standards and regulations to encourage companies to move in the right direction, "the Europe zone can also strengthen these aspects," says Samuli Vaija. "Regulations have a snowball effect, causing other organizations and standardization bodies to follow suit. Regulations will allow us to encourage our standards internally. Our goal is to stay a step ahead of legal requirements in order to develop joint projects with manufacturers and plan ahead for 2050 in keeping with the **Paris Climate Agreement** (2015)."

This also shows that some companies are further ahead on these issues than others. It is therefore important to develop mutual assistance between companies in order to direct decision-making. In addition to his role as **Green IT** manager at Airbus, Emmanuel Laroche is a member of Institut du Numérique Responsable (INR), "which aims to help develop a more responsible and resilient digital world." He believes that developing cooperation between the different stakeholders is essential in order to "share feedback that will help people avoid difficulties others have experienced, and prevent the rebound effects that are so common in digital technology."

It sometimes happens that projects intended to reduce environmental impacts actually have the opposite effect, creating new environmental impacts, or generating gains that enable the funding of another project with negative consequences. Like INR, many organizations, including The Shift Project, institutions like ADEME (French Agency for Ecological Transition) and organizations such as the WWF (World Wide Fund for Nature) provide tools intended to guide decision-makers towards the best means of action. Discussions between organizations, working groups and companies are crucial in bringing common solutions to light.

"We benefit from this effect, which did not previously exist, and the proliferation of ideas that we can build on, and feedback that is essential in determining which initiatives had a major impact in order to direct new efforts," says Olivier Lefebvre.

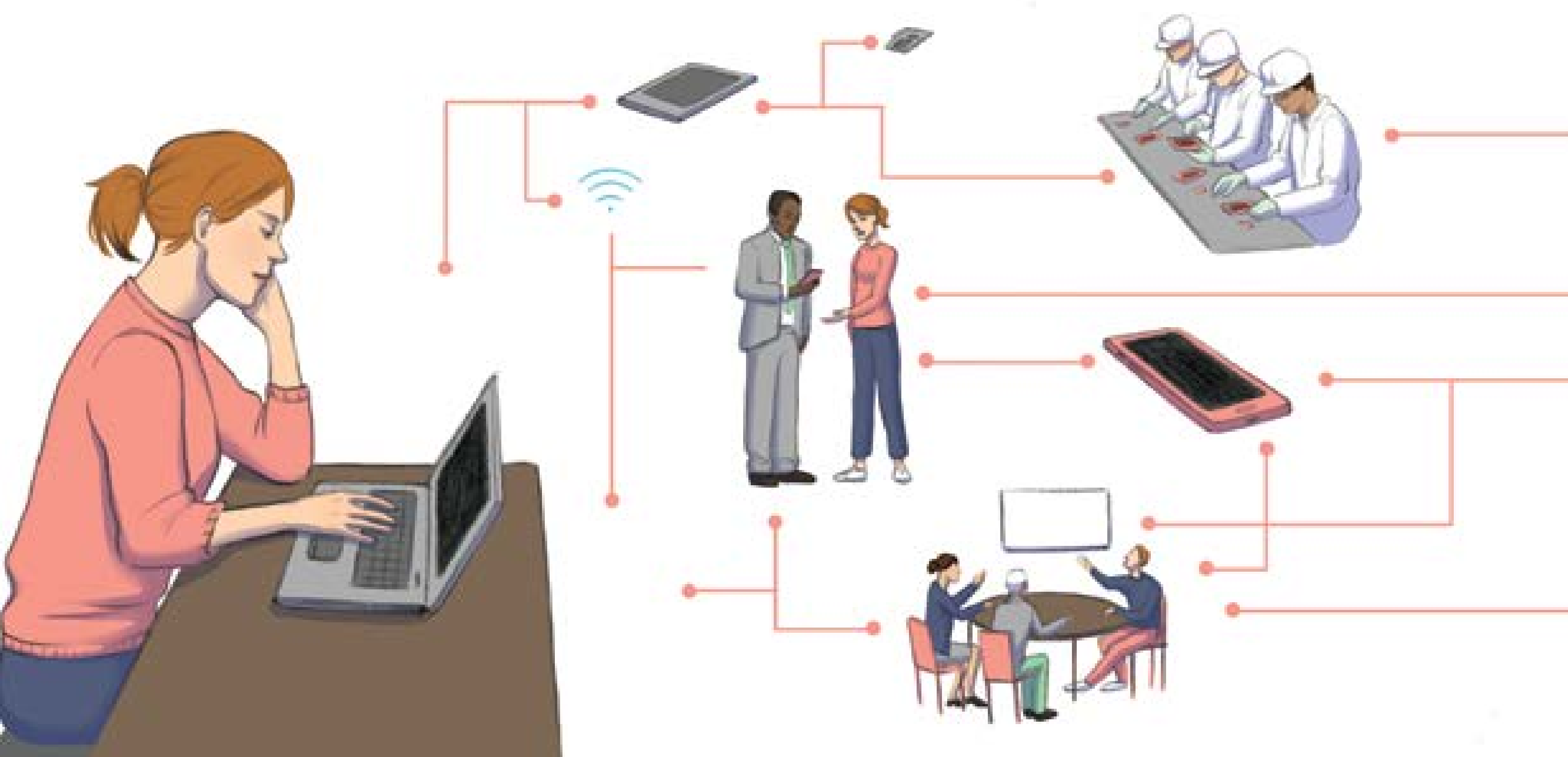
"Some companies are further ahead on these issues than others."

RAISING AWARENESS FOR THE FUTURE

Efforts to raise awareness are an essential step in the quest for responsibility and best practices. It is vital for engineering schools and companies to offer training and promote a culture that leads to an understanding of the complexity of environmental issues.

“We all have a role to play in changing this focus on novelty value. This includes companies, the academic world and consumers,” says Sandrine Berger-Douce, researcher in responsible management and innovation at Mines Saint-Étienne. Samuli Vaija, product life cycle analyst at Orange, agrees with her: “People must be ready to get involved. Engineers must be able to understand life cycle analysis constraints and know where to intervene.” His colleague, Marc Vautier, adds “it is also up to industries to take up this issue, recruit people and position them higher in the system of priorities.”

Therefore, future engineers must also be trained on these issues. According to Emerson Picq, agile development manager at EDF, “when we look for service providers, we will look for people who are familiar with these concepts, who really understand the subject.” Integrating current environmental and social



issues into engineering education is therefore an essential step in this transition.

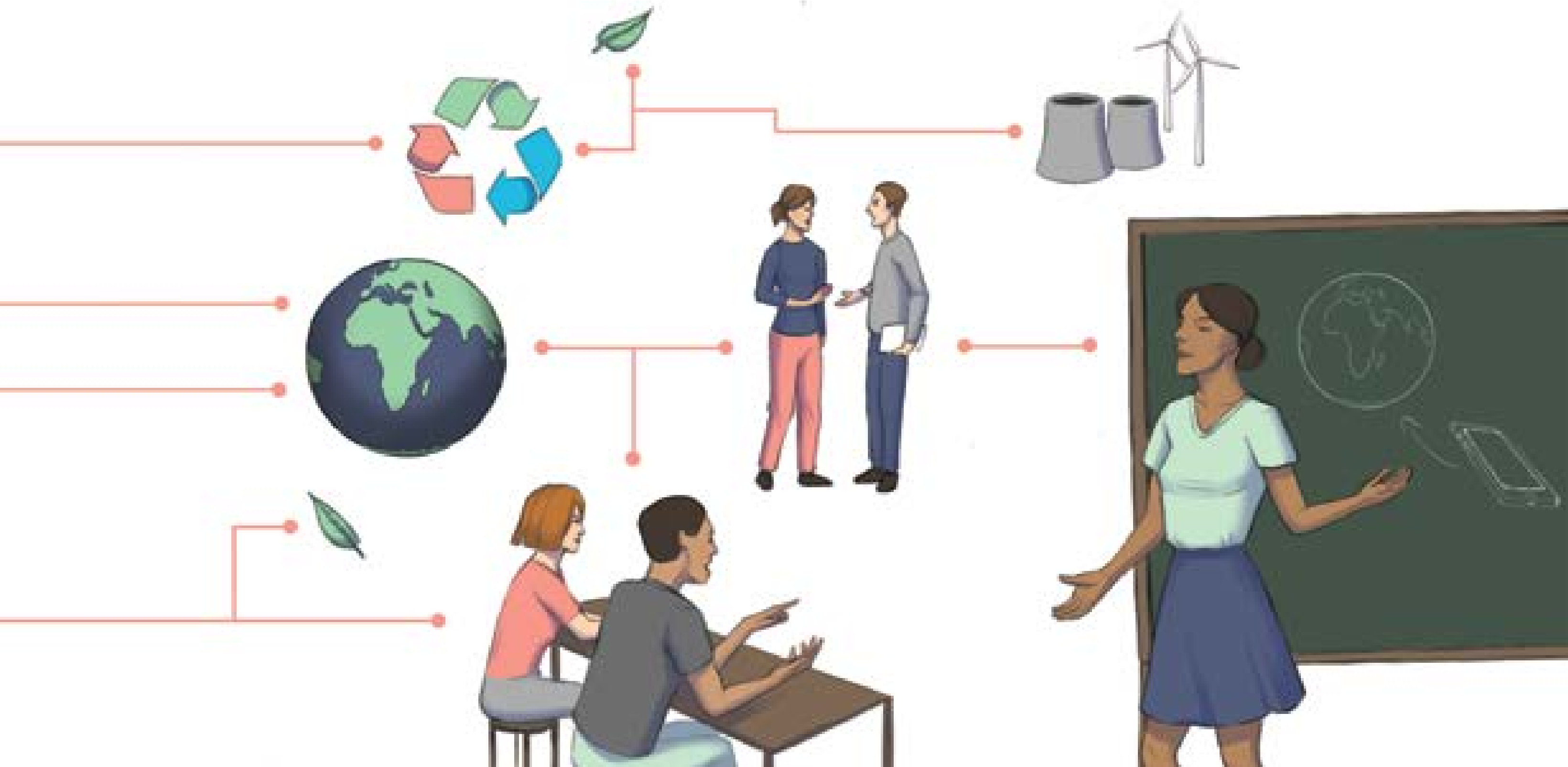
Engineers of the future

"They are as rare as unicorns," says Marc Vautier, referring to the fact that current candidates are either engineers who need training in life cycle analysis, or people who have received life cycle analysis training who need to learn about electronic culture. "There is sometimes a misconception that we need to find people who are sensitive to environmental issues. We need to realize that this requires both skills in micro-electronics and environmental expertise. This is a complex combination of expertise and we must find the right balance."

It is for this reason that Télécom SudParis has launched the "Digital Engineering & Environmental Transition" teaching chair and IMT Atlantique has created a new training program for the start of the 2020-2021 academic year on the digital transformation of industrial systems for industry of the future. "The goal is to combine cross-disciplinary teaching in industrial engineering and social sciences in order to comprehend the effects of digitalization on work, skills and environmental sciences," explains Sophie Brétésché, researcher in sociology at IMT Atlantique and co-director of the training program along with David Lemoine, researcher in computer science at IMT Atlantique. The program is developed in partnership with industrial stakeholders in order to match their needs. It is designed as a work-study course. "There's nothing like going out into the field, into factories and laboratories, and learning by doing, to discover tips and the industrial process," says Samuli Vaija.

"We must train engineers in life cycle analysis."

This program aims to meet the need to train engineers with strong skills in computer science and industrial engineering, who also have cross-disciplinary expertise. "Environmental, energy and social aspects are all essential skills in addressing the key challenges of the industry of the future," says Sophie Brétésché. Engineers will need to work in a complex world, taking many different parameters into account, of which they must be aware. "Engineers must be familiar with environmental legislation in order to implement relevant solutions," she explains.



The research professor stresses the need to remove barriers between disciplines by promoting interdisciplinary training and building bridges between industry and the academic world. “Companies must meet together and process their reflection. As academics, we must lead students by example by engaging in collaborative reflection in multidisciplinary settings,” she says.

Emmanuel Laroche, **Green IT** Manager at Airbus and member of Institut du Numérique Responsable (INR), explains that this can also be communicated by initiating theses on these issues, on the topic of cloud architecture, for example.

> **“There is a pressing need to raise awareness in terms of digital uses, to create an understanding of this environmental cost.”**

Raising the awareness of current teams is also of critical importance. “At INR, we are working on a MOOC intended to raise awareness among our teams and improve their skills. This will enable them to identify the major environmental impacts of digital services accurately and choose the most effective means of action,” he adds.

And companies are not always well-informed when it comes to labels, and standards for ecodesign and **CSR** (**corporate social responsibility**). “There is still a need to provide information about standards and awareness-raising processes, to let people know how they can get involved, make a difference and contribute to ecological transition,” says Sandrine Berger-Douce. She also observes that “raising awareness on these issues will require the involvement of stakeholders from the economic, academic, public and nonprofit sectors.”

There is also a pressing need to raise awareness in terms of digital uses, to create an understanding of this environmental cost. “Imagine that I use a device to search for something on the internet,” says Miguel Lopez-Ferber, researcher in environmental engineering at IMT Mines Alès. “We can easily understand the cost in terms of electricity, but we cannot see the impacts of the infrastructure. It’s invisible, virtual, and doesn’t cost us anything. It’s hard to attribute an environmental impact to something we can’t see,” he says. It is therefore necessary to raise awareness of the cost involved, and required by, our digital habits, and suggest good practices in this area.

To learn more:

- Natacha Gondran, *How eco-design earned its place in the corporate world*, I'MTech, 2018, www.imtechnews.fr/en/
- *Innovation: to be or not to be responsible?*, I'MTech, 2018, www.imtechnews.fr/en/

III

ENERGY: FUEL OF THE DIGITAL INDUSTRY

The entire digital chain of usage requires energy. Whether it be data storage, network infrastructure, or users' fixed and mobile devices, environmental and energy footprints are inseparable. Despite significant growth in digital uses, next-generation technologies in all of these areas are helping to reduce pressure on our common resource: energy.

DATA CENTERS: CENTERS OF ATTENTION

**Data centers have a bad reputation as energy hogs.
While they undeniably account for a significant proportion of digital energy consumption, there is still room to maneuver in reducing their environmental impacts. Two potential areas of action exist: the servers' demand for electricity, and server room cooling requirements.**

In the media, they represent digital energy consumption. **Data centers** are often criticized for the amount of electricity needed to power and cool their servers. However, for several years now, stakeholders, including researchers, companies and organizations, have been working to develop solutions aimed at limiting their environmental footprint. It should be noted from the outset that consumption, in absolute terms, is not the only indicator to monitor. The goal is also to improve the effectiveness of data centers, described in terms of the **PUE**: **Power Usage Effectiveness** indicator.

This value is defined as the ratio between the total energy consumed by the data center and the energy consumed by the servers alone. In an ideal world, the PUE for a center would be 1. That would mean the entire electricity supply would be used for the computer equipment only. In reality, however, other components, such as cooling systems, need energy too.

Thanks to recent technological advances, this indicator has moved much closer to its optimum level. Fifteen years ago, it generally remained between 2 et 4. In other words, for every 100 W consumed, only 25 to 50 were consumed by the servers. Today, the majority of data centers have a PUE indicator of around 1.5.

> **"How can we improve the energy efficiency of data centers?"**

A recent problem

How can we reduce the consumption of data centers and improve the PUE indicator? Jean-Marc Menaud, researcher in the energy efficiency of distributed systems at IMT Atlantique, has been interested in this subject since 2006. “At the time, the energy consumption of computers was not an issue,” he recalls. “This scientific topic only took on greater importance starting around 2010.” The researcher initiated a first thesis in this area at the time, aimed at optimizing the operation of servers.

“The problem is caused by the fact that the rooms are often designed to absorb peak loads,” Jean-Marc Menaud explains. “Therefore, most of the time, the computers aren’t doing much.”

“It’s a little like a big game of Tetris.”

The initial research therefore focused on improving the design of data centers by adapting them to more closely match users’ needs. This made it possible to turn off computers that were not being used at given time, thus reducing the structure’s overall energy consumption.

It may sound elementary. “The idea is simple, but the technical implementation is complicated,” says the researcher form IMT Atlantique. This type of solution is in fact extremely complex. The first thesis was based on “dynamic consolidation”, which involves concentrating a maximum of applications on a minimum number of physical servers. “It’s a little like a big game of Tetris,” Jean-Marc Menaud explains. “The applications are the different shaped pieces and they must be grouped together, ensuring that they take up as little space as possible.” This type of solution has now been widely adopted and is an important means of reducing the consumption of data centers.

Availability constraints

However, in some companies, the oversized capacity for absorbing peak loads is linked to internal constraints. At EDF, both of the group’s data centers were designed with four-tier architecture due to the critical applications and sensitive data hosted on their servers. This classification system for computer centers, established by Uptime Institute, includes four levels. The highest level, Tier IV, involves significant equipment redundancy aimed at minimizing the unavailability of the services provided under any conditions.

“Reducing energy consumption is more than an environmental concern. It is also a financial advantage.”

Compliance with the requirements associated with this classification system enables theoretical availability of 99.995%, the equivalent of 27 minutes of downtime per year. This imperative necessarily limits the computer rooms’ energy efficiency.

It does not, however, prevent Tier IV infrastructure from developing initiatives to help reduce energy consumption for both environmental and financial purposes. Even as an energy producer, EDF’s electricity bill for data centers is a major cost: 20–25% of the operating budget for the centers, before energy consumption reduction processes.

Cooling systems account for such a large proportion of data center energy consumption that some companies choose to build their infrastructure in countries with cold climates. When this is not possible, they must find other ways of optimizing the cooling systems.

Cécile Boulnois, a data center efficiency engineer for the group, explains the measures that have been taken to reduce consumption, while ensuring compliance with Tier IV requirements. “First, it is important to note that the consumption of our equipment used for management computing is very stable over time,” she says. This means that, regardless of their load, data centers always consume roughly the same amount of energy. At EDF, the priority is therefore not to limit the use of the applications hosted in computer rooms, but to choose more efficient machines when the time comes to replace the older ones.

However, according to Cécile Boulnois, this is not enough: “The key question we must answer is, how can we use the least equipment possible?” Part of the solution comes from the **virtualization** technique, which involves running several systems on the same machine as if they were on different physical machines. At the end of 2019, EDF’s virtualization rate was 89% for servers and 60% for network equipment, which significantly optimized their use.

Cooling optimization

Computer equipment is not responsible for all of a data center’s energy consumption. Cooling systems also account for a significant proportion, 25% for EDF. This highlights the value of optimizing air conditioning systems for the rooms.

Jean-Marc Menaud has studied this subject as well. The first issue his teams raised was that the data centers lacked uniform cooling. The equipment located near the air conditioning unit received a greater benefit than that located further away– a difference that is far from trivial. “Our objective from the outset was simply to reduce the number of servers switched on, regardless of their location,” he explains. “The idea now is, if we want to turn off servers, we may as well choose those benefiting least from the cooling system.”

“Cooling is not uniform in data centers.”

EDF was able to adapt the cooling setpoints based on the machine loads. “The cooling needs are directly proportional to the servers’ electricity consumption, and therefore their use,” Cécile Boulnois explains. “We therefore monitor this consumption in order to regulate the number of air conditioning units running and adjust the operating setpoints for our equipment.”

And the IT load is not the only factor that must be taken into account. EDDC (Efficacité Dalkia Data Center), the Dalkia subsidiary in charge of the operating and maintaining the technical infrastructure equipment for EDF’s data centers, has implemented a procedure that constantly adapts the number of cabinet air conditioners running to the machine use and the outside temperature. Natural cooling is therefore used to cool the servers as necessary in order to limit the use of hardware solutions. In total, these measures enabled a 28% reduction of the cooling equipment energy consumption.

What were the results of these optimizations for the entire infrastructure? According to Cécile Boulnois, the data centers’ electricity consumption was reduced by almost 15% between 2015 and 2019, even as the number of servers hosted nearly doubled and the computing capacity installed on the supercomputers hosted more than doubled. The PUE indicator for both sites also decreased, dropping from 1.75 to 1.64 for one and from 2.28 to 1.94 for the other. They remain higher than average, but this is due to the Tier IV classification and the necessary resiliency measures.

Test environment

Further progress will require experimentation and equipment that can test solutions outside of the industrial infrastructure. IMT Atlantique teams therefore worked with Orange in order to develop complete modeling of a server room. The goal is to be able to carry out simulations and estimates of energy consumptions even before a data center is built. This assistance will guide companies in their choice of hardware and in the general architecture–including the air conditioning system. In the same vein, EDF recently worked with one of its subsidiaries to develop a digital twin of one of its cooling facilities. “This will allow us to identify optimal operating points for our cold production and distribution systems and identify any excess energy loss from the hardware,” says Cécile Boulnois.

Yet this is not enough. In general, the computer models are difficult to implement and are resource-intensive, which is paradoxical given the objectives. Three years ago, IMT Atlantique initiated SeDuCe, a project to build a server room equipped with airtight servers, covered with power and thermal sensors. Built at the end of 2018, it is the ideal setting for studies. SeDuCe is powered by solar panels.

It can therefore be used to prototype real solutions while minimizing its own environmental impact.

Are data centers and renewable energy compatible?

The possibility of powering industrial data centers with electricity from renewable sources is also being considered. Yet renewable energy has a major drawback: intermittency. Solar energy, for example, can only be used to power the equipment during the day, and its production fluctuates depending on the weather. A new thesis underway at IMT Atlantique aims to adapt the operation of the servers to this intermittent energy. The research is seeking to modify the applications behavior based on users' needs and the energy production.

"Renewable energy has a major drawback: intermittency."

"Take the example of routes suggested by an application like Google Maps," says Jean-Marc Menaud. "Currently, when Google servers are overloaded, the tool can only suggest one route, instead of the usual three or four. We can imagine the same scenario with renewable energy: when it is not available, the service could simply be reduced."

But, of course, there are limits to this type of system. In the case of solar power, energy production stops completely during the night. We therefore remain dependent on the traditional electrical system. "There is still a lot of work to be done when it comes to data center autonomy," says the researcher from IMT Atlantique.

NEXT-GENERATION NETWORKS: NEW ENERGY CHALLENGES

The advent of 5G is rekindling concerns about the consumption of mobile networks. While they may be less visible in the digital energy footprint than data centers, these networks are major consumers of electricity. 5G is synonymous with new network deployment, and must bring with it a set of technological innovations to enable better management of network consumption.

They may be less visible than **data centers**, but mobile networks also contribute to the overall environmental impacts of digital technology. According to GSM Association, which brings together hundreds of key players from the digital sector, network energy consumption accounts for 20–40% of operators' maintenance expenses. Fixed networks currently represent a larger portion than mobile, but this trend is expected to be reversed in coming years. This should especially be the case with the deployment of networks in areas with little coverage, and the advent of 5G.

The next generation of mobile networks poses the question of environmental impact. Will it be an energy guzzler? "Honestly, there is no clear answer to this question," says Loutfi Nuaymi, researcher in telecommunications at IMT Atlantique. It is important to note that the concept of energy efficiency was taken into account for this standard right from the development stage. The standard includes new energy saving features and aims to improve energy consumption per bit. "Right from the design phase, the standard imposed constraints in this area," explains Dalia-Georgiana Popescu, research engineer at Nokia. Furthermore, while 5G is intended to eventually cover as much of the territory as possible, it will begin by relying on existing 4G infrastructure before installing new antennas.

However, the advent of this fifth generation will bring with it new uses, with multiple connected objects (sensors, Industry 4.0). Operators are therefore expecting an increase in energy consumption. For Orange, this increase is estimated at 5-10% by 2025 for total energy costs, depending on the initial scenario and calculation base. "But these figures are immature and change quickly based on data from the builders and deployment projections for standby functions," says Azeddine Gati, coordinator of the Green research program at Orange Labs. It is also necessary to account for the fact that certain uses exist already, regardless of whether we remain in 4G or move to 5G. For the same uses, consumption increases would be more significant if we remained in 4G." Yet this does not prevent academics and industrialists from implementing procedures for limiting the impacts of this new technology.

Optimizing based on demand

For the past ten years, Loutfi Nuaymi has focused on the energy consumption of wireless networks, especially 4G and now 5G. He specifically works on network access, made up of tens of thousands of base stations–or antenna sites–which accounts for 70–80% of all electricity used by the network.

Some of the techniques used to reduce the networks' energy footprint resemble those used for data centers. "A telecom network is designed to handle peak hours. The issue of energy consumption was not an initial priority. We were not really worried about optimizing energy during off-peak periods. But now, we cannot afford to run the network in its full capacity during off-peak hours."

However, as is the case for data centers, implementing these types of solutions is far from trivial. Certain constraints complicate this equation, including the need for continuity of service, the possibility of making emergency calls, and rules imposed by standards. Networks currently use sleep mode techniques for small cells, which is made possibly by 4G and 5G standards.

Nokia, one of the main manufacturers in the market, takes this issue of network optimization seriously. "Take, for example, an area consisting primarily of offices and another with housing," says Dalia-Georgiana Popescu. "The load transfer on the network can be used to better allocate resources where they are most abundant." It is however important to ensure continuity of service and maintain network responsiveness, which explains the need for algorithms.

"With 5G, operators are expecting an increase in energy consumption."

5G in all its forms

Turning off base station antennas is not the only option, especially since this can lead to significant lag times, which reduces the quality of service. Base stations can also be put into sleep mode in several different ways. "One of the scientific challenges facing networks is the ability to enter sleep mode and then wake up before the user even makes a request" says Azeddine Gati. Different sleep modes have been introduced for 2G, 3G and 4G, resulting in energy savings ranging between 10 and 30%.

But, there's a problem. The protocols for previous generations of mobile networks required the transmission of a continuous signal used only to maintain the connection with a telephone and enable the display of signal strength bars on the device.

"The wireless network must adapt and learn."

"But this signal is not useful, it doesn't carry any valuable information," the engineer from Orange Labs explains. 5G has helped to overcome this constraint. Dalia-Georgiana Popescu explains: "5G enables the addition of a state that is especially useful for connected objects or sensors used for industry or agriculture. In this intermediate state, devices can continue to send data from time to time, while consuming much less energy."

Renewable energy and AI

Another solution, also similar to those explored for data centers, involves powering base stations with renewable energy. "At Orange, our goal is to become 100% carbon free by 2040 and reach 50% renewable energy in our **energy mix** by 2025," says Azeddine Gati. Once again, there is the challenge of intermittency. "Since renewable energy is not constantly available, we need to use batteries," says Loutfi Nuaymi. Today, those most frequently used are lithium batteries, which are best suited to base station activities. However, these systems also involve constraints in terms of usage time and charge and discharge cycles.

Within this context, the operation of the cellular network integrates new parameters, in addition to more conventional ones like user behavior and position, and services used. "The wireless network must adapt and learn to make the best decisions, such as when to transmit a signal and at what power level, and which base stations to turn off," says Loutfi Nuaymi. His teams at IMT Atlantique have implemented automatic learning methods in order to solve this complex problem. Research is aimed at optimizing the performance of **5G networks**, which add still more constraints to take into account, such as connected objects and industrial uses.

Nokia also uses automatic learning techniques, a branch of artificial intelligence, to adapt its networks to user requests. “In the long term, artificial intelligence should make it possible to design customized networks, which will help reduce the energy footprint,” says Dalia-Georgiana Popescu. “The use of machine learning provides greater flexibility in the development, modification and improvement of algorithms, which reduces the need to change electronic components dedicated to a single function.”

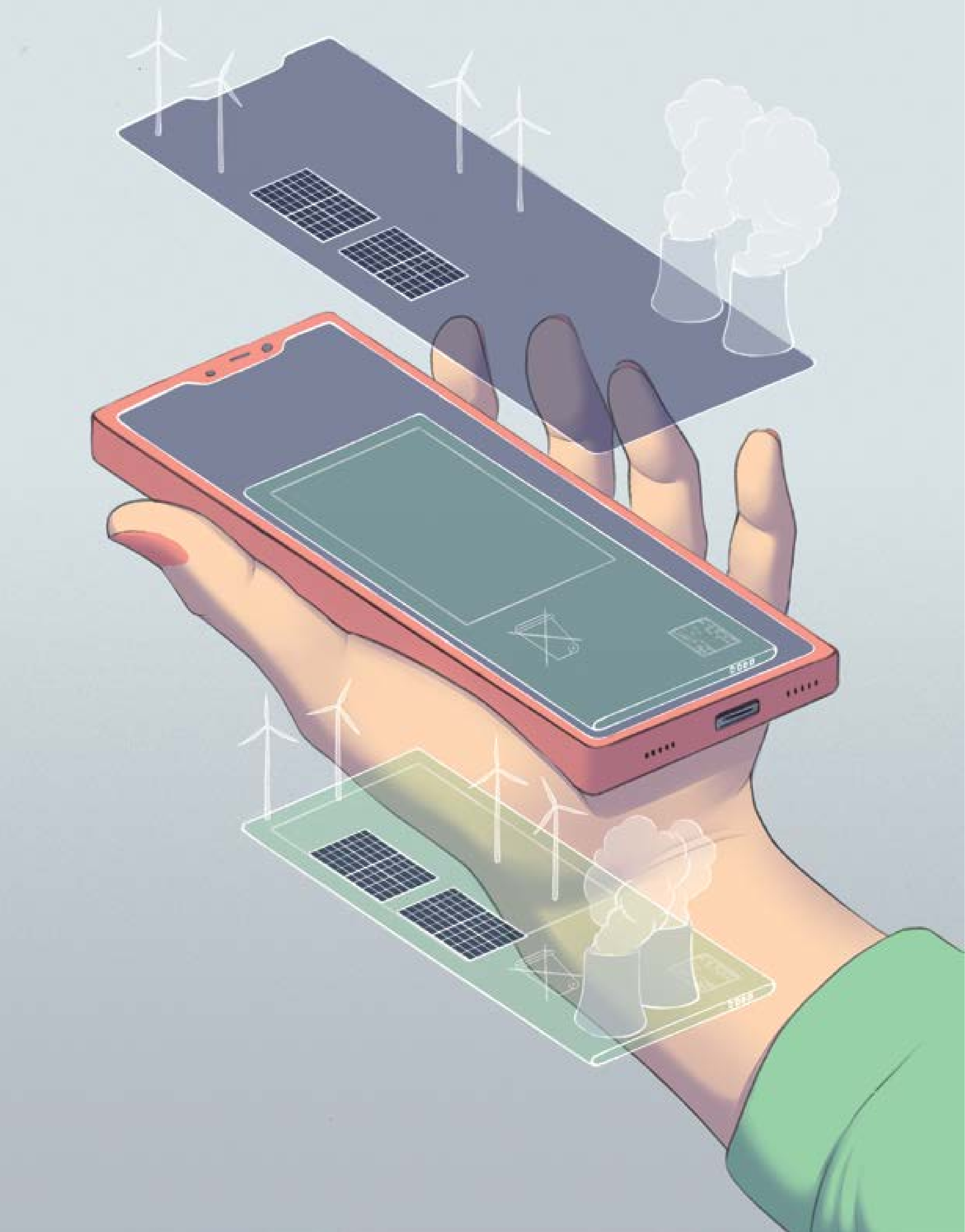
Promising early results

At IMT Atlantique, the algorithms have been tested via simulations. “In some favorable cases, we observed energy savings ranging between 10 and 50%, with maximum savings during off-peak hours,” says Loutfi Nuaymi. These results were mainly for 4G. The researchers currently lack accurate 5G models needed to analyze the impacts of the algorithms this type of network.

But observing a decrease in energy consumption is not enough. The network must also maintain sufficient quality of service. The team from IMT has therefore been studying average delays. “If the network disconnects regularly, this leads to longer delays, which is usually due to transmission latency,” says Loutfi Nuaymi. “This can disrupt some services, for which response times are critical.” The researchers are therefore striving to find the best compromise, ensuring energy savings while maintaining acceptable delays.

At Orange, the figures show that energy consumption was reduced by 3% for the group over the past two years. This was thanks to the previously mentioned solutions, as well as other measures, including a reduction in the number of data centers, operator infrastructure sharing, and equipment replacements.

“Observing a decrease in energy consumption is not enough.”



IN OUR POCKETS: THE TERMINAL CONSUMPTION OF DIGITAL TECHNOLOGY

Terminals are the last link in the chain of energy consumed by digital technology and they are not the least. Multiple avenues exist for reducing their footprint from next-generation batteries to code optimization. In some cases, the batteries could simply be eliminated..

How can terminal energy consumption be optimized? The first research area focuses on a major environmental issue: batteries. To improve their characteristics, changing the materials used might seem like a good place to start. "It now seems unlikely that we could find a revolutionary material that would achieve a tenfold increase in the performance provided by lithium," says Thierry Djenizian, a researcher in microelectronics at Mines Saint-Étienne, who is working on devices measuring only a few square centimeters. He believes that improvements can still be made, but that the future lies in research on battery design.

This starts with interface optimization. Batteries are composed of three elements: two electrodes–anode and cathode–separated by an electrolyte. Their performance depends directly on the electrochemical reactions that occur on the surface of the cathode and the anode. "It is therefore important to ensure the best possible contact between each electrode and the electrolyte," the researcher explains.

> **"The future of batteries lies in research on their design."**

Gradually, as the battery is used, unwanted layers can be deposited on the electrodes, due to side reactions, and negatively affect the component's capacity. One solution used to combat this inconvenient occurrence is the addition of a very thin layer of alumina on the electrodes. "However, since we work with 3D materials at the nanoscale, it is very difficult to uniformly distribute a very thin layer over the surface of the structure," says Thierry Djenizian. Due to this constraint, the teams at Mines Saint-Étienne turned to high-precision techniques, such as the deposit of thin atomic layers and electroplating. These processes succeeded in doubling the capacity of the batteries in the long-term.

Thierry Djenizian's work has a specific focus: the storage of energy for transportable electronics, such as medical patches, using micrometric batteries. This work does not pertain to components for smartphones, computers or electric cars. The results obtained could possibly be used for other applications, but this would require some adaptations. In any event, the research seems to focus more on optimizing the capacity than on energy savings.

"Are batteries essential for terminals?"

Battery-free technology: RFID

But do terminals really need batteries? François Gallée, researcher in electronics at IMT Atlantique, is conducting work that makes it possible to overcome this constraint, in some cases. The goal of one of his projects was to monitor the development of corrosion in concrete structures, using wireless sensors that are directly integrated in the material. Given that corrosion-related physico-chemical processes can last a very long time (several decades) and the integration occurs in inaccessible environments (such as concrete), a battery-free solution seemed appropriate, since it would offer unlimited autonomy and therefore a longer lifespan. The scientists therefore chose to use **RFID** (**Radio Frequency Identification**) technology to power the device.

This method offers the advantage of enabling the transmission of information, without requiring an outside energy source to emit the signal from the sensor. "The energy is supplied by the reader, the equipment that will collect the data transmitted by the sensor," explains François Gallée. When the reader is positioned in front of the sensor, the sensor will recover the energy emitted to power itself in order to process and transmit the data from the physical corrosion sensor."

"RFID has interesting benefits in terms of autonomy and lifespan, but it comes with a major limitation: its range."

It uses backscattering: the signal emitted by the reader is reflected and modulated by the sensor in order to transmit the data. The goal here was to monitor the reaction of a metal alloy in order to monitor the development of a corrosive environment inside the structure.

However, although RFID has interesting benefits in terms of autonomy and lifespan, it comes with a major limitation: its range, typically of 5 m. "We could possibly gain a few meters, but not much more," says the researcher. This research remains limited to specific needs, such as preventive or predictive maintenance, for example, monitoring corrosion in buildings.

These research activities were initiated in the context of a local partnership in Brest between Université de Bretagne Occidentale and Institut de la Corrosion. The research is now continuing in the framework of a European in partnership with the Swedish research institute RISE.

Code optimization

The research on batteries is therefore not primarily for the general public. However, other initiatives, like code optimization, could alter the energy footprint of digital terminals.

This practice involves improving the effectiveness of a computer program, with the goal of reducing the associated energy consumption. Marc Vautier, product life cycle analyst at Orange, began studying this subject in 2013. At the time, the operator's developers were not very enthusiastic about this approach. They were already subject to a wide range of constraints and not always aware of the impacts of their software. "One of them said to me at the time: software is just ones and zeros–that doesn't consume energy," he recalls.

In concrete terms, how can a computer code be optimized. First step: the choice of the language. "I believe it's a little like a religious war," says Marc Vautier. "Some will favor one language over another, but other aspects come into play. If one proves to be more energy efficient, is it also as powerful or flexible?"

He believes it would be wiser to make a better choice of "library". In programming, this term refers to sets of functions that are already coded and ready for developers to use, which prevents them from having to rewrite it all. The idea is to be pragmatic, in selecting only those specifically adapted to the work in progress. However, some have a tendency to turn to those they are most comfortable with, even when they are adapted to much greater needs.

Finally, according to the expert, a crucial aspect of code optimization is the provision of tools used to measure the energy consumption. Orange also partnered with Greenspector, a French start-up that develops this type of solution. They also conducted experiments on an Internet of Things application. The teams and company observed they could reduce the program's energy consumption by 10–15% by eliminating a very energy intensive library.

Today, Marc Vautier still regrets that code optimization is struggling to gain support in companies, partially due to a lack of tools. Greenspector offers one of the few solutions available on the market. It has begun to be accepted, but there is still some way to go before it is widely integrated into teams.

> **"Software is just ones and zeros–that doesn't consume energy."**

He believes that in order to obtain convincing results, it is necessary to return to the earliest stages by directly addressing the features the software offers. This would mean developing applications that strictly meet user requirements, and enhancing them later as necessary.

The cost of charging a smartphone for one year is €1 in France. Savings from next-generation batteries are therefore generally more visible for larger devices that consume more energy.

Teaching digital sobriety

His position can be summed up in two words: digital sobriety. In fact, he was part of the working group that produced the report "Towards Digital Sobriety" for The Shift Project. He therefore emphasizes the need for collective awareness of this issue, especially among users, in order to curb the "**rebound effect**" phenomenon. "When we improve energy efficiency, there is a tendency to increase the use, he says. Limiting this rebound effect therefore requires working to address sobriety in the areas of both supply and demand."

> **"When we improve energy efficiency, there is a tendency to increase the use."**

Jean-Louis Dirion shares this view. He is a researcher in process engineering at IMT Mines Albi and head of the Energy and Digital Transition option. Teaching currently focuses on how digital technology can promote the creation of energy transition policies. Jean-Louis Dirion would like to enrich the content by further integrating the concept of environmental impacts. The option would then reflect the change in mentality witnessed on campus.

"In the last few years at IMT Mines Albi, students have seemed increasingly concerned about environmental issues," he says. "They created an environmental organization (UNITA) at the school." They would be very interested in courses that examine these issues in depth. It is therefore up to the school to follow the lead of its students, who are "ahead of the institution," according to the researcher.

The future engineers therefore appear to be leaders in environmental issues. "But have they fully integrated the impact of digital technology and identified it as a priority?" wonders Jean-Louis Dirion. He intends to have them work on assessing the digital energy footprint. This could include questions like "What is the environmental cost of sending an email to your entire class?" The goal would be to make them think about the consequences of their own uses. This is a first step in higher education towards raising awareness of the benefits of digital sobriety.

MACHINE LEARNING: A CHANGE IN APPROACH TO SAVE ENERGY

Machine learning was developed with performance in mind—without a concern for environmental impacts. Today, given growing concerns about the energy cost of digital technology, learning tools are being adapted and even redesigned. Stéphan Clémençon, a researcher in machine learning at Paris Télécom, bears witness to this trend in the research community.

Is energy consumption a parameter that is included in the development of machine learning tools?

Stéphan Clémençon: With the rise of big data, techniques were initially focused on the efficiency of data processing. In order to increase speed, improve reliability, and avoid the memory limit difficulties inherent in the machines, the most efficient approach is to cut and replicate the data in several places, and distribute the computations. The entire framework for the algorithm is therefore based on this approach. It turns out that the approach avoids computations on the terminals, which would be too energy-intensive, and even impossible for smartphone batteries to handle. However, many tools are based on a redundancy level and protocols for intensive communication between the network nodes that are not really necessary and could offer a way to reduce their energy consumption.

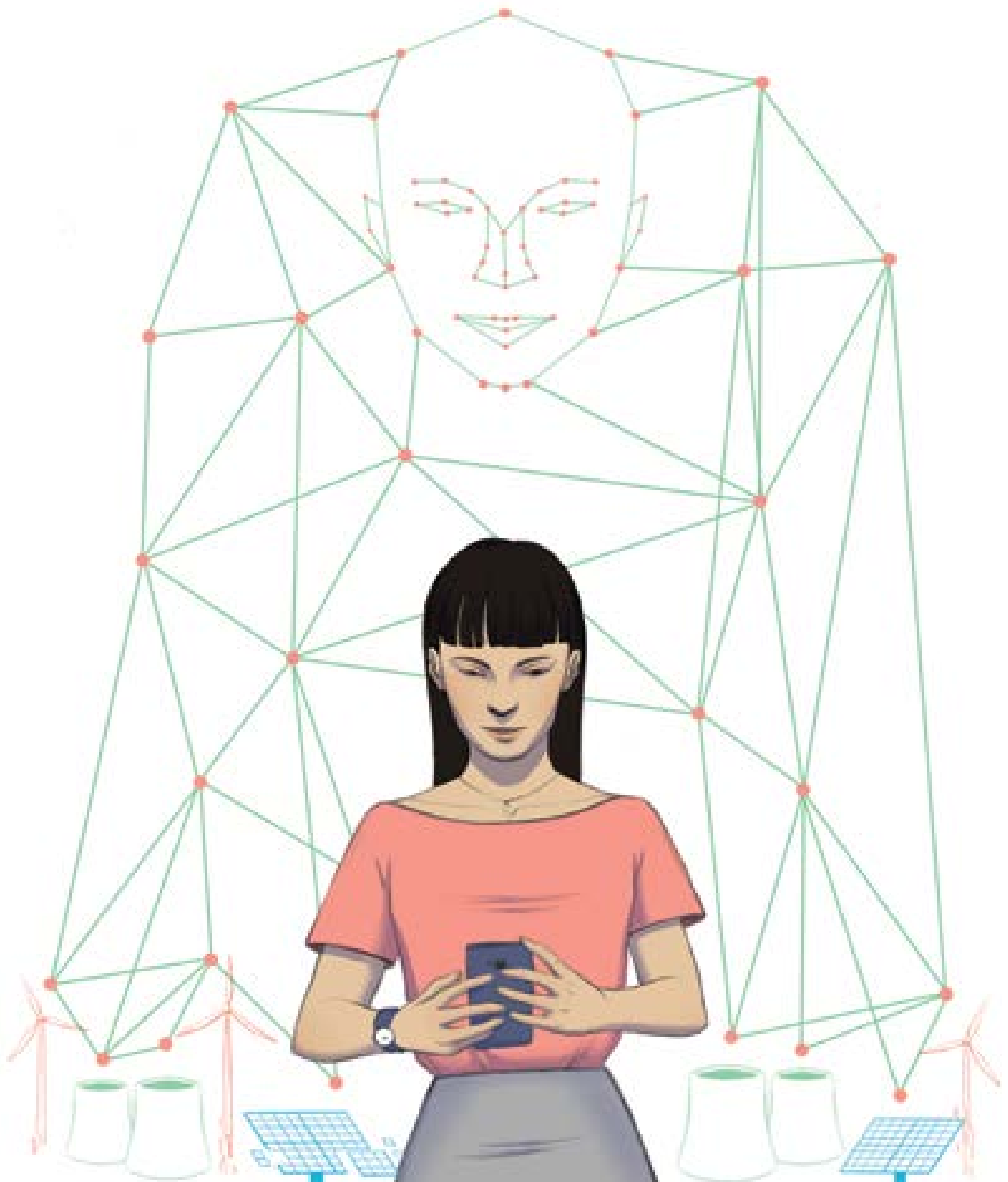
How would it be possible to save energy on machine learning tools?

SC: In the algorithm prediction phase, the main possibility would be to simplify the architecture of the algorithms, which is sometimes too complex. When we look at some of the current neural networks used, for example, in the field of computer vision, certain neurons or connections are not necessarily useful. They are present because they were inherited from an approach that prioritized flexibility, without any concern for energy savings. By simplifying the architectures, without compromising the predictive performance, we can reduce the computations and thus the energy consumption.

In the learning phase, the methods for improvement include integrating constraints in the algorithm that force it to adapt the data and computation communications, and the complexity of the model it learns, to the difficulty of the predictive task.

Could prioritizing the energy efficiency of algorithms over their robustness negatively affect their overall effectiveness, and therefore their value?

SC: For some uses, the loss of this redundancy does not involve a lot of risk. For exam-



ple, image recognition is one of the tasks that require the most energy in machine learning. When facial recognition is used in an airport with a biometric passport, you need a high level of reliability, and therefore computationally intensive algorithms. On the other hand, when you need to unlock your mobile phone with facial recognition, the task is less critical. You can have a lower level of precision and therefore an algorithm that requires less energy. It is important to take this approach of adapting an algorithm's complexity to its use. A false positive would clearly not have the same effects in the case of an online banner ad poorly adapted to a user as it would in the case of an aircraft maintenance prediction. The idea is to reduce energy consumption where we can.

This solution aims to optimize existing tools. Are there any more radical approaches?

SC: Imagine we reach a bottleneck, in which existing solutions offer little room for maneuver. If we want to be more energy efficient, we must find new approaches. As academics, it is our role to explore new solutions. However, since this work is linked to the applications and requires compromise, we cannot do it alone. Even if we develop very energy-efficient methods, we must ensure they will meet the needs of engineers and industrialists, and be consistent with consumer usage. We can help to inform these compromises, but cannot make the final decisions.

Are companies aware of this need for cooperation with academics in exploring the issues of responsible digital technology?

SC: The entire machine learning community is realizing the need to revise our approaches in the area of energy consumption. This is true for both scientists and companies. One illustration of this trend is the new center for artificial intelligence that we are creating in partnership with companies. In this context, one of the objectives we share with our industrial partners is to reduce the digital energy footprint.

To learn more:

- Fabrice Flipo, *The worrying trajectory of energy consumption by digital technology*, I'MTech, 2020, www.imtechnews.fr/en/
- *Datafarm: low-carbon energy for data centers*, I'MTech, 2020, www.imtechnews.fr/en/
- Report "The unsustainable use of online video", The Shift Project, 2019, www.theshiftproject.org

IV

WHAT HAPPENS AFTER USE?

What do we do with our telephones and computers at the end of their life cycles? Multiple possibilities exist—recycling, refurbishment, the sale of spare parts—but they are not all equivalent. New strategies and policies aimed at giving a second life to digital products must take into account the complex structure of the industries and markets, as well as the willingness of industrialists and consumers.

RECYCLING THE CONCEPT OF RECYCLING?

Recycling is the standard-bearer for giving products a second life after use. Yet the different channels are struggling to structure their activities and face numerous obstacles. Technology, the economy, and international policy intermix and continue to largely hinder the development of recycling as a viable solution for managing electronic waste.

What do 4,500 Eiffel Towers and all the airliners ever built have in common? They can both serve as an illustration of the 50 million tons of waste from electrical and electronic equipment (**WEEE**) generated throughout the world in 2018. Computers, mobile phones, and household appliances are all examples of WEEE. These complex waste sources primarily consist of metals, plastics and specific chemical compounds, which makes them difficult to process. And if our consumption of electronic products remains the same, a tsunami of 120 million tons of WEEE will be unleashed in 2050.

Given these predictions, investing in recycling appears essential for the electronics industry. Yet only 20% of WEEE is actually recycled. Why? Grazia Cecere, a researcher in economics at Institut Mines-Télécom Business School, can list only two drivers of research activities on recycling this waste. The first is the introduction of new regulations–including by the European Union in the 2000s–which successfully boosted research in this area as far away as China. The second driver is economic. Recycling costs more than extracting the raw materials. “Certain equipment will be recycled more if the prices of metals used in electronics (gold, silver, and copper) increases. Economic influences always trump ecology,” says Grazia Cecere.

“Economic influences always trump ecology.”

Waste worth its weight in gold

Around the world, the geopolitical issues of recycling electronic materials are prominent concerns. In 1992, the former paramount leader of China, Deng Xiaoping, stated “the Middle East has oil, China has **rare earths**.” Resources are indeed unevenly distributed around the globe. The European Union became aware of the strategic importance of the minerals required for digital technology in the 2000s. Japan’s shortage in the supply of rare earths, orchestrated by China in 2010, could also occur with other nations. “We analyzed factors such as the state of reserves, substitutability, and the recycling rates for eighteen groups of materials in order to assess Orange Group's exposure to resources. Gold and silver, which are widely used in microelectronics, have appropriate recycling rates and can be supplied by several countries, unlike rare earths," says Samuli Vaija, product life cycle analyst at Orange.

"Recycling is still underdeveloped and does not offer a short-term solution equal to the task of treating WEEE. "

Although China has access to these critical resources, it also recycles the most WEEE in the world, because it has invested in its development. Considering that there is more gold in a ton of mobile phones than in a ton of ore, many countries have an urban mine right within reach. Countries who tap into this waste would limit their demand for raw materials and promote a circular economy model.

Complexity and recycling do not mix well

The resources are there, but the techniques for accessing them must be developed. Current innovations in electronics seek to add more and more features to small devices that can contain up to 1,000 different substances. The wide range of elements present in small quantities in these devices turned waste generates an ore that is difficult to treat and therefore to recycle. For example, Europe's best recycler is Umicore, a Belgian organization that can recycle 17 of the more than 60 elements from the periodic table contained in a smartphone. The margin for improvement is therefore significant, but the sector is not attracting as many investors as it is products to be recycled.

Which techniques have proven successful? Supporting research on recycling means exploring new processes for grinding and extracting the rare earths and minerals present in our devices. In France, hydrometallurgy is the most commonly used process, because it also dependent on the nuclear industry. Other, very different, possibilities are being studied throughout the world, ranging from controlled-temperature grinding to biological recovery methods using microorganisms (fungus, bacterium) called bioleaching. The most promising solutions will likely rely on a combination of several techniques, rather than on a single method. "Developing industrially viable solutions takes time. Recycling is still under-developed and therefore does not offer a short-term solution equal to the task of treating WEEE," says Fabrice Flipo, researcher in philosophy of science and technology at Institut Mines-Télécom Business School.

The limits of recycling

Although Europe has established guidelines for the treatment of WEEE, each State is responsible for implementing these guidelines in its territory. In France, eco-organizations, governed by distributors and producers, collect and treat the waste. In addition, "Since 2010, France has been the only country to introduce **eco-modulation** in WEEE channels in order to promote ecodesign. This had already been introduced for packaging," explains Helen Micheaux, researcher in management science at AgroParisTech. Incentive criteria were established, including the prohibition of certain substances, access to spare parts, the integration of recycled plastics, and connection standardization. If producers satisfy the criteria, they benefit from a reduction in the contributions they must pay for the given product. If not, they must pay a penalty and their contributions increase.

But there's a problem: establishing long-term eco-modulation criteria is difficult due to the fast pace of technological innovation. While the European community is closely following this French experiment, the WEEE sector suffers from a lack of overall coordination. At the global level, large amounts of waste are illegally exported to underdeveloped countries despite legislation banning their exportation. It took China closing its door to Western waste in 2017 to reveal the flaws of the recycling industry.

“France is the only country to have introduced eco-modulation in WEEE channels in order to promote ecodesign.”

Finally, there is still a major obstacle to recycling waste in the right conditions: today’s WEEE is yesterday’s equipment. It is therefore difficult to meet tomorrow’s needs for the raw materials of increasingly innovative products with today’s WEEE. Is the circular economy model in the context of electronics truly the best solution for the exponential growth of waste in this sector? Especially since recycling has no effect on accelerated obsolescence or growth in equipment for individuals and businesses, for which demand is increasing at an approximate rate of 2-3% each year. Recycling would only reduce the strain on extraction and its consequences. As long as the policy of increased production dominates the market, recycling can only remain one supply source among others.

GIVING A SECOND LIFE TO DIGITAL PRODUCTS

If recycling channels are struggling to absorb the amount of electronic waste generated, what are the alternatives? The general approach could be to find ways to offer used products a second life. From refurbishing used products to selling spare parts, new economic models are emerging.

Let's pretend the circular economy is a game with a circular board. The waste from digital technology would be pawns that need to travel around the board once before taking on a new form and continuing the game. But wouldn't it be possible to change the rules to make the game last longer? By creating durable equipment, promoting reuse, and developing new markets for components, devices could continue their journey without having to leave the market. Longer life cycles would reduce production and give recycling and other channels time to make progress without having to run to catch up. What's the situation on the ground?

Durability: from ecodesign to repairability

An initial approach to fighting the increase in waste from digital technology is to extend product life spans. "Recyclability is difficult to take into account in long-term time scales since recycling channels and technology develop so quickly. That's why our main focus is on a long life span and products designed to be maintained in operational condition for as long as possible in order to reduce their environmental impacts," says Julien Weber, head of **ecodesign** at Airbus Defence and Space. Satellites, for example, have a theoretical lifespan of 15 years. This technology is not recycled, but the satellites in low Earth orbit (altitude of up to 2,000 km) are designed to disintegrate during atmospheric re-entry. However, the manufacturer is still conducting research aimed at reusing the satellites and repairing them in orbit.

In the case of smartphones, the manufacturing phase has the greatest environmental impacts. In the case of network equipment—like servers—with continuous power supply and a long lifespan, it is the use phase that is most crucial in terms of environmental indicators. It is possible to reduce these effects by ecodesign techniques that increase product lifespan and promote repairability. One example of alternative design is Fairphone: a telephone that is easy to repair, made with interchangeable sub-assemblies in order to facilitate repairs. Yet this concept faced major challenges upon the launch of the first models. "There was pressure on the market for LCD (liquid crystal display) panels and, because they needed smaller volumes than the major market stakeholders, they were not the first served," says Samuli Vaija, product life cycle analyst at Orange. Despite these implementation challenges, this concept of modularity is gaining ground.

For two years now, ADEME (French Agency for Ecological Transition) has been working to develop a repairability index. This rating system, expected to be released in 2021, should take into account factors such as the price of spare parts and ease of disassembly. The goal is to reach a 60% repair rate for electrical and electronic devices in France within five years, as opposed to the current rate of 40%.

In the case of smartphones, the manufacturing phase has the greatest environmental impacts.

Rental: a model promoting refurbishment

Various business models, such as the servitization of products, encourage manufacturers to ensure the optimal use of resources during a device's life cycle. Some companies, like EDF, have adopted leasing systems. EDF leases all of its computer equipment–approximately 80,000 computers renewed every 4 to 5 years–from a supplier. The producer or lessor directly handles the end-of-life management for the devices.

On the other hand, Orange leases its equipment (routers, TV decoders) to users. The company therefore integrates future refurbishment needs into the initial product design. This step encourages the rotation of equipment, which is returned by one customer, refurbished, then rented to another customer. "Research on refurbishment is key. It enables us to reduce the overall impact and thus improves cost-effectiveness, with products that are easily refurbished and therefore last longer," says Samuli Vaija. In 2018, for example, the company refurbished 2.9 million routers.

An open door to new markets

The rotation of equipment has its limits, however, due to marketing realities. New offers on the market, intended to attract new customers, require the removal of older equipment whose technical specifications are no longer in line with market demands. In light of this situation, Orange considered several other options for reusing its routers that could not be refurbished, without finding any ideal solution. For example, selling the routers outside the Orange group would require the removal of the group's logo, making this option too expensive. What about the sale of spare parts, like in the automotive sector? The resale of electronic components is not currently sufficiently developed to offer industrial goods a second life. Ultimately, these markets could play a key role in the ADEME repairability index.

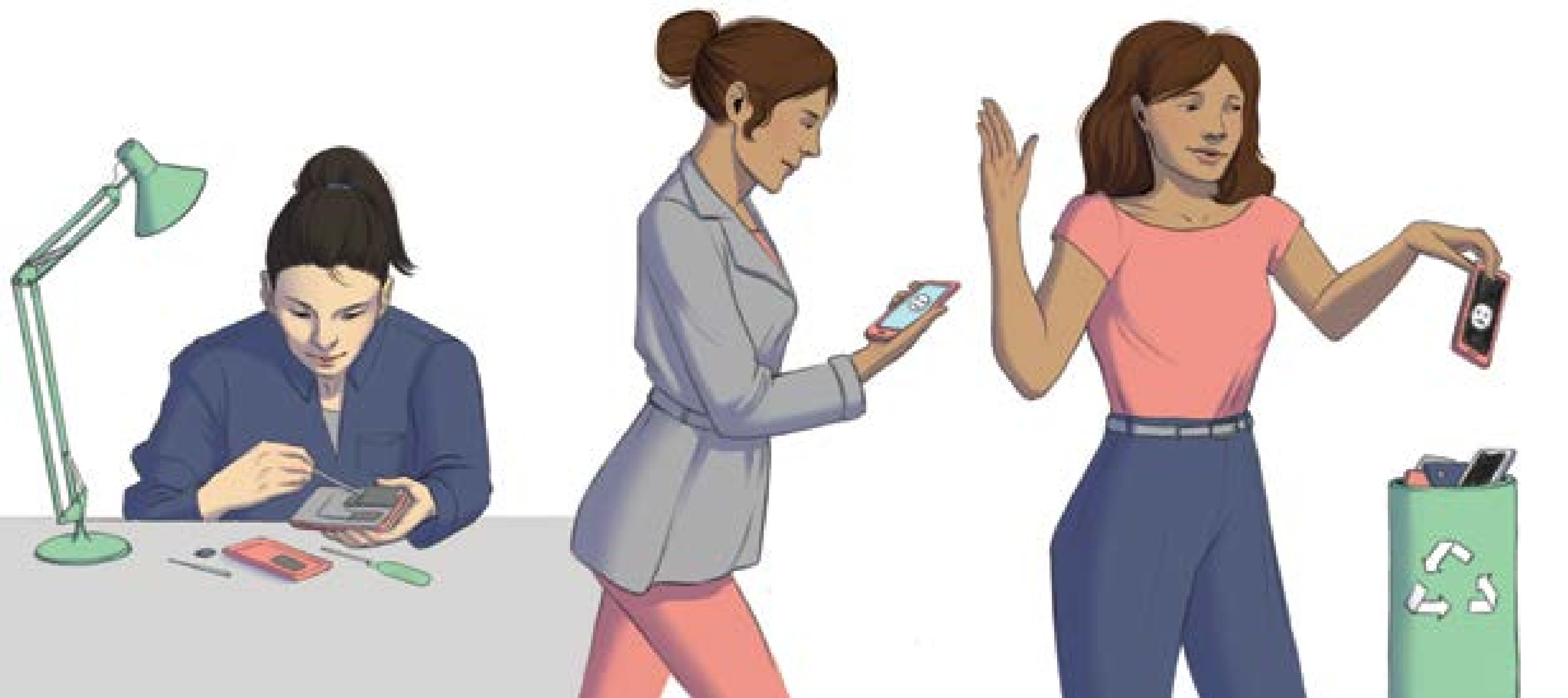
Furthermore, more solutions emerge when fewer goods are available. EDF uses the services of a broker–an intermediary who purchases the equipment and resells it to other users with lower performance requirements. Depending on the amount of equipment sold, a company may be able to negotiate a right to monitor the management of its former property.

Finally, another under-developed channel is that of donation. "A public policy, like the policy for food waste, should be developed in France. It could, for example, state that a certain percentage of devices replaced by major companies will be redistributed to schools," says Grazia Cecere, a researcher in economics at Institut Mines-Télécom Business School. Often, equipment that has become obsolete for companies would not be too outdated for other users. There is no requirement for self-regulation either. Companies could promote certain measures without public policy intervention. So far, the economic value of recycled goods has outweighed their reuse.

> **"The resale of electronic components is not sufficiently developed."**

Can keeping devices become a hazard?

Does product longevity mean product safety? Data centers use lead batteries that are known



to be stable and easily recyclable due to the maturity of the sector. However, lead poses health and environmental problems if not properly treated in end-of-life disposal. Furthermore, the replacement of these batteries represents a strategic decision for companies. Some replace them at the end of the 5-year warranty period. EDF changes them every eight years based on its experience and performance levels. The longer a user keeps batteries, the lesser the environmental impact. On the other hand, the risks increase over time. In the best-case scenario, the battery will no longer work. In the worst case, it may oxidize and explode. The solution is therefore to regularly replace these tools to ensure their reliability.

At the same time, lithium batteries are known to be more powerful and last up to 20 years in the case of data centers. The problem is that they are much less stable than other batteries! In light of the advantages and disadvantages of each type of battery, the waste issue is replaced by that of risks in the industrial process. "As much as we want to find virtuous waste solutions, we always face the constraints of the technology's performance and life cycle. Lithium batteries have only been available for data centers for two years. We therefore do not have much feedback and do not know how to recycle them, as opposed to lead batteries, which remain a safe bet for now," says Raphaël Jamet, head of data center operations for EDF.

MANAGING ELECTRONIC WASTE: A GLOBAL PROBLEM

Multiple actors share responsibility for managing waste from digital technology. On the one hand, States have the responsibility to increase border controls in order to manage the waste stream better and avoid exportation to developing countries. On the other hand, manufacturers of electronic devices must assume their role by facilitating end-of-life management for their products. As for consumers, they must become aware of the consequences of their habits that are "invisible", because they have been outsourced to other countries.

In order to understand how waste from electrical and electronic equipment (**WEEE**), is managed, we must turn to the Basel Convention of 1989. This multilateral treaty was originally intended to manage cross-border movements of hazardous waste, to which WEEE was later added. "The Basel Convention led to regional agreements and national legislation in many countries, some of whom prohibit the export or import of WEEE," says Stéphanie Reiche-de Vigan, a researcher in sustainable development and new technology law at Mines ParisTech. "This is true for the EU regulation on waste shipment, which prohibits the export of WEEE to third countries." However, EFFACE, the European research project dedicated to fighting environmental crime, estimated in 2015 that approximately 2 million tons of WEEE illegally leave Europe each year. How can that much electronic waste secretly cross the borders? "A lack of international cooperation hinders efforts to detect, investigate and prosecute environmental crimes related to the trafficking of electronic waste," says the researcher. Therefore, even if an international agreement on WEEE was established, it would only have a small impact without the true determination of the countries generating this waste to limit its shipment.

"Approximately 2 million tons of electrical and electronic waste leave Europe illegally."

This is compounded by the fact that electronic waste trafficking is caught between two government commitments: that of punishing environmental crimes, and that of promoting international trade in order to regain market share in international shipping. In the interest of competitiveness, the London Convention of 1965 on Facilitation of International Maritime Traffic improved the transfer of vessels, goods and passengers to ports. "As a result, customs procedures were simplified to promote competitive transit between the ports and distortion of competition between the ports developed countries with the minimum implementation of regulation on cross-border waste shipment and in particular controls by border and port authorities," says Stéphanie Reiche-de Vigan. The European Union observed that the companies exporting and importing WEEE tended to use ports where the enforcement of the law was weakest and therefore least effective.

"Companies exporting and importing WEEE use ports where the enforcement of the law is weakest."

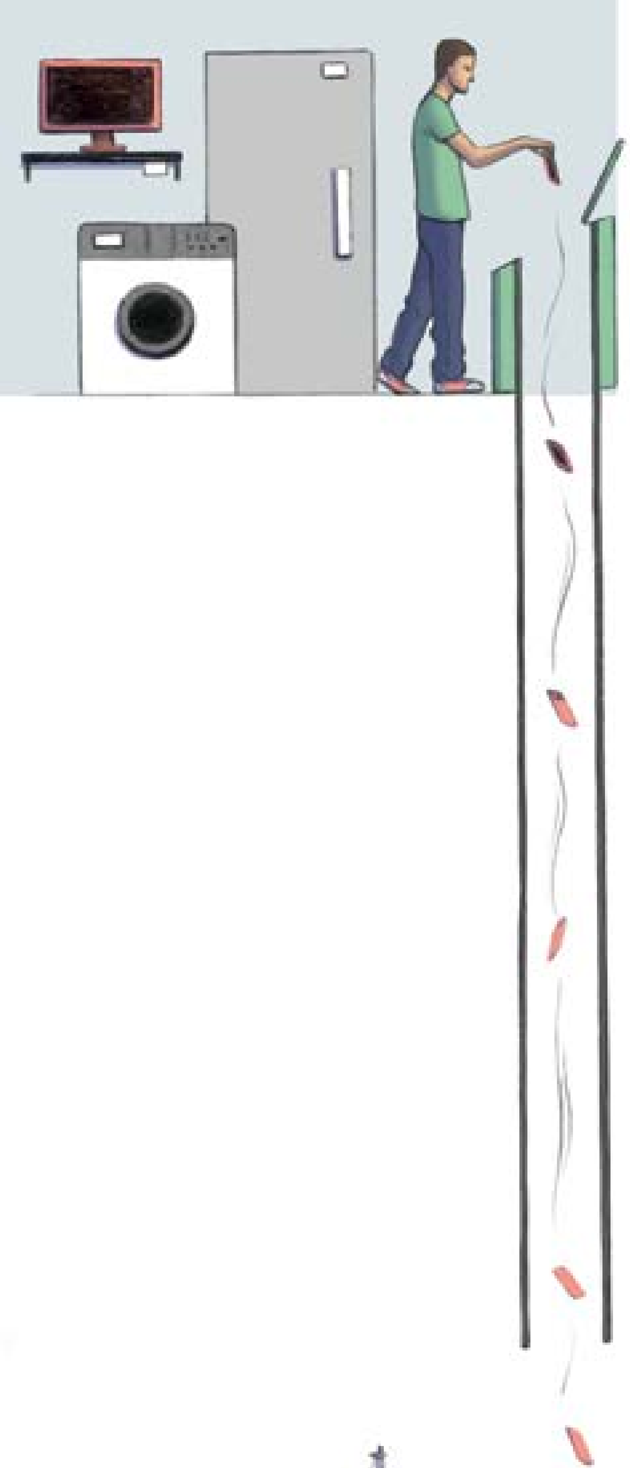
So how can we break this cycle of international trafficking? "It is essential that the International Maritime Organization examine this issue in order to promote the sharing of best practices and unify control procedures," says the research professor. It is up to states to strengthen their controls at ports to limit these crimes. And technology could be play a major role in helping with this task. "The mandatory installation and use in ports of an X-ray scan of the container contents could help to reduce the problem," says Stéphanie Reiche-de Vigan. Currently, only 2% of all of the world's sea containers are inspected physically by the customs authorities.

The responsibilities of digital companies

The chain of digital technology is made up of different links: mining activities, manufacturing, marketing and recycling. The different life stages of an electronic device are therefore isolated and disconnected from the each other. Therefore, producers do not have an incentive to partner with recycling channels. "As long as producers of electrical and electronic equipment have no obligation to limit their production, contribute to recycling costs, or improve the recyclability of their products, the electronic waste stream will not be able to be managed," says Stéphanie Reiche-de Vigan. Addressing this issue would require reconnecting the links of the chain in a **life cycle analysis** of the electric and electronic equipment and redefining corporate responsibility in this area.

Rethinking corporate responsibility would require pressure to be put on the giants of digital technology, but developed countries seem incapable of doing this. However, they are the ones who bear the costs of sorting and recycling waste. So far, this awareness has not been enough to implement concrete actions that in the end seem more like recommendations. National digital technology councils in Germany and France have established road maps for digital sobriety. They propose possible future regulations, such as extending the lifespan of devices. However, this is no easy solution, because a device that lasts twice as long means production would be cut in half for the manufacturer. "Investing in a few more companies to be in charge of device refurbishment and extending product lifespan is not enough. We are still a long way from proposing viable solutions fort he environment and the economy," says Fabrice Flipo, researcher in philosophy of science and technology at Institut Mines-Télécom Business School.

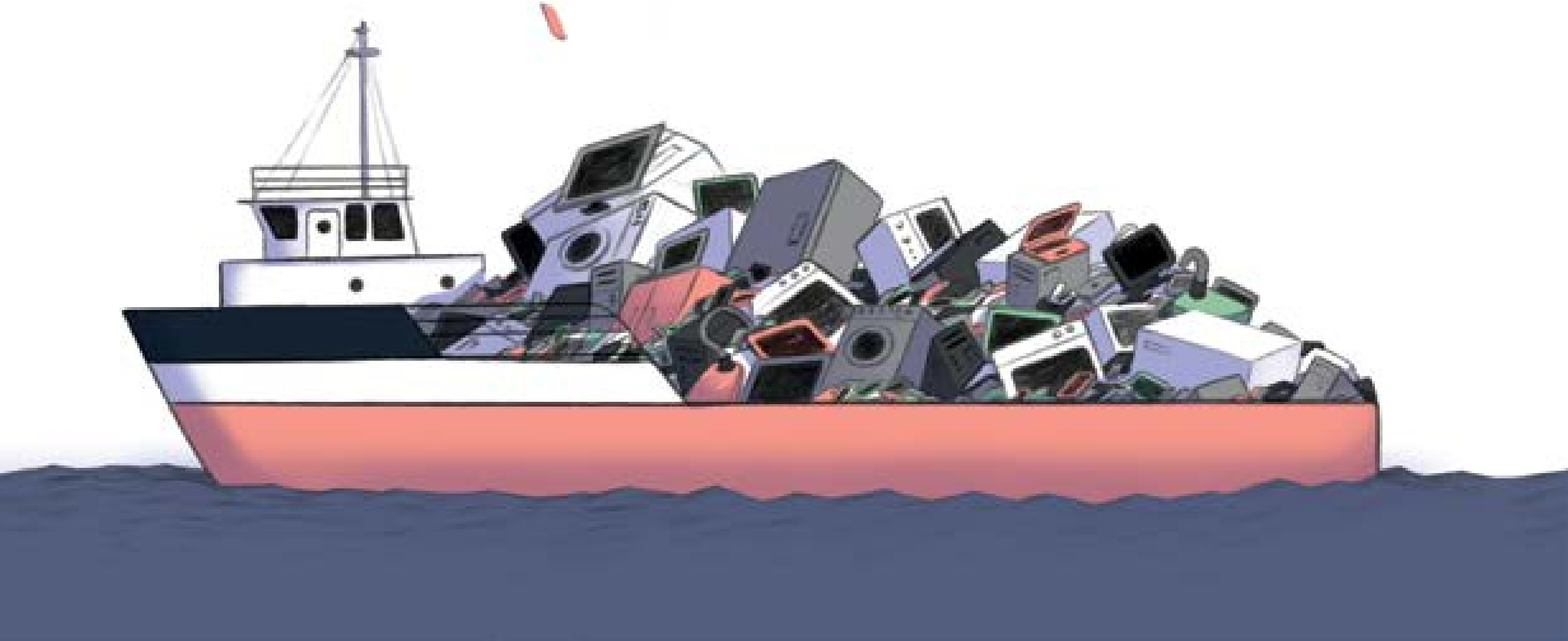
Countries are not alone in confronting the powerful top digital technology companies. "At Orange, beginning in 2007, we tried to implement an environmental notice system to encourage customers to buy phones with the least impact on the environment," says Samuli Vaija, product life cycle analyst at Orange. Beforehand, this approach sought to encourage manufacturers to integrate environmental practices into their ranges of products. When it was presented to the International Telecommunication Union, the initiative from Orange



was quickly stifled by opposition from American companies (Apple, Intel) who did not want to display carbon footprint information on their devices.

"The life stages of an electronic device are disconnected from each other."

There is still the possibility of civil society efforts, including those of NGOs, inspiring a change in political will. The major obstacle there is that citizens in developed countries are not, or not sufficiently, aware of the environmental impacts of their excessive consumption of digital technology tools, because they do not experience them directly. "All too often we forget that there are also human rights violations behind the digital tools on which our Western societies are based, from the extraction of the resources needed to manufacture the devices to the shipment of waste they generate only a few years later. From the first to the last link, it is primarily people in developing countries who suffer the consequences of the consumption of those in developed countries. The health effects are not visible in Europe because they are outsourced," says Stéphanie Reiche-de Vigan. Could it be that digital technology in wealthy countries has been isolated within



an informational bubble containing only its benefits? The importance attributed to digital technology should not come at the expense of ignoring its negative aspects.

According Stéphanie Reiche-de Vigan, “it is also the responsibility of universities, engineering schools and business schools to train students in environmental issues right from the start of their undergraduate studies and integrate **life cycle analysis** with a concern for human and environmental impacts into their academic programs.” This training ultimately means providing the companies who will design the tools of the future and the administrations that will supervise them with individuals well-versed in these issues.

A REALISTIC LOOK AT DIGITAL SOBRIETY

The mad rush for data leaves in its wake an immense trail electronic carcasses—and they're not virtual. The enormous amount of electronic waste raises questions about the current vision of growth embraced by the digital technology sector. What if the solution was entirely different? This is the question raised by the concept of digital sobriety.

While technological progress can help save on energy, materials and thus costs, it also facilitates an increase of uses and irreversible environmental impacts. This is the **rebound effect**. This excessive consumption by developed countries calls for a change in practices. It involves understanding how users operate and coming to the realization that more is not better. "For two years now, we have been working on the concept of digital sobriety and how a company can adopt this concept. There is an entire collective imagination to be developed that moves away from consumption," says Marc Vautier, product life cycle analyst at Orange. Could the solution lie in a new marketing approach? An approach that must integrate new values that do not advocate the constant quest for more features. Instead, it could perhaps promote more freedom and less dependence on technology. "There are very simple things that can be implemented, such as reintroducing no-data plans, which are no longer offered," says Marc Vautier.

The current approach to digital offers is based on a concept of unlimited access, which encourages unrestrained use. "These practices are misleading on the whole," says Francis Jutand, Deputy Executive Director of IMT. He emphasizes the need to clarify the actual content of the offers. "The fact that we pay for the cost of our phone in the monthly plan, under the pretext of unlimited network use, does not encourage responsibility in the frequency with which we replace our smartphones." Similarly, video on demand offers encourage the excessive consumption of movies and series for roughly ten euros a month. "Serious reflection is needed on price-quality ratio of use," Francis Jutand says.

> **"The current approach to digital offers is based on the misleading concept of unlimited access."**

A change in economic model would raise issues that are extremely complex. Digital services currently have no obligation to provide consumption indicators. This means no information on the consumption of carbon dioxide, water, or, more generally, the overall energy consumed when watching a series online. "Energy is a common good–one we consume without realizing," says Francis Jutand in response to this lack of public awareness. But would products sell just as well if their harmful nature was displayed? Fabrice Flipo, researcher in philosophy of science and technology at Institut Mines-Télécom Business School, adds: "Providing more complete consumer information conflicts with corporate objectives to facilitate sales as much as possible. It also conflicts with the financial requirements of having a "competitive" infrastructure, and therefore a large group of consumers to use and finance this infrastructure."

A number of regulations can be used to inform consumers. They could include indicators, certifications or labels the user can recognize. For a more rigorous form, "companies could have an obligation to conduct environmental impact studies for their services and make them available for consumers," says Francis Jutand. "Finally, a more legally binding form would involve prohibiting certain irresponsible pricing or commercial practices."

Fabrice Flipo also proposes that companies be required to make the ecological implications of their overall strategy publicly available.

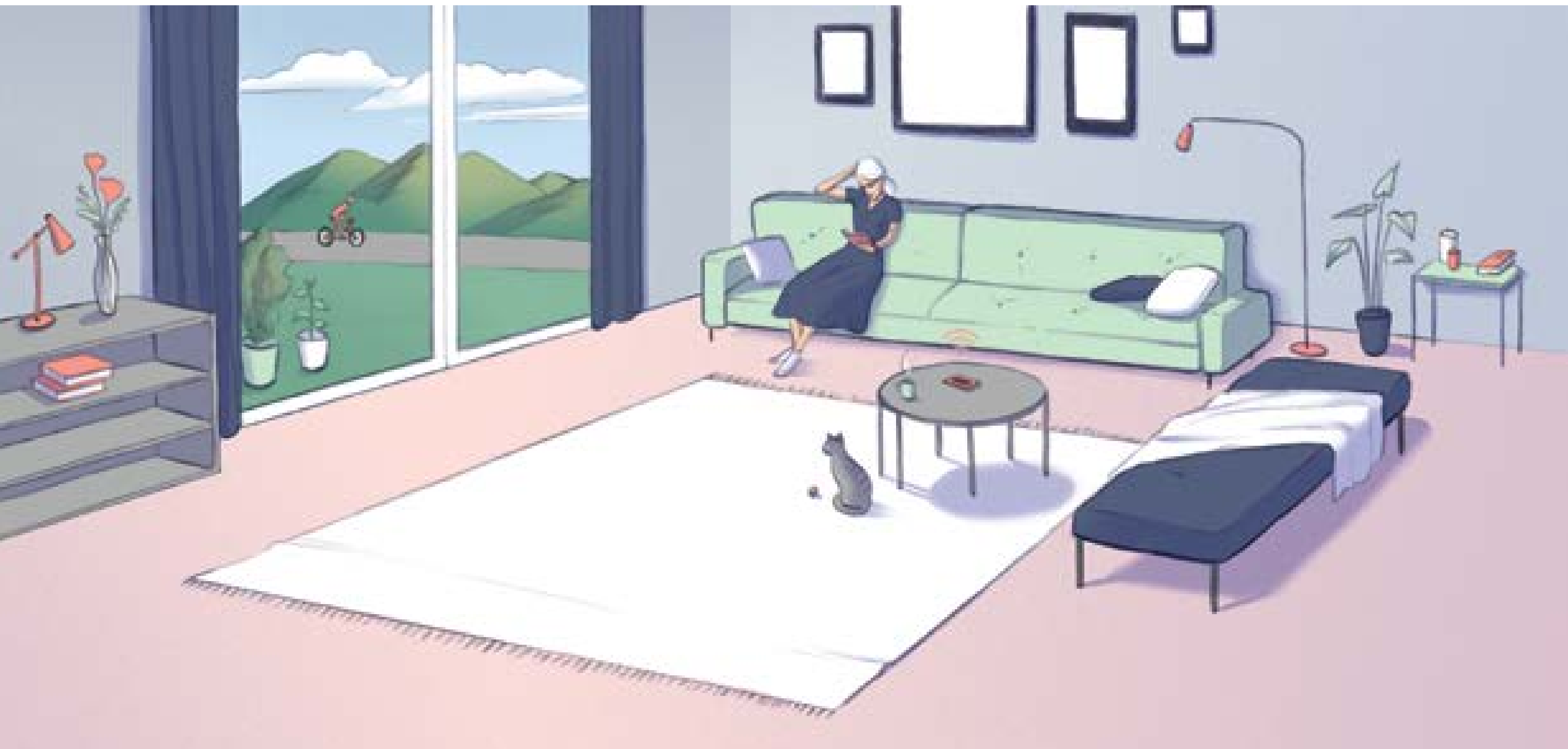
> **"Energy is a common good–one we consume without realizing."**

A carbon-sober digital transition

In addition to establishing frameworks for marketing and consumer offerings, digital sobriety seeks to raise deeper questions about the societal value of the sector's products and services. The Shift Project, a French public interest organization, published a report in 2018 warning against the impacts of digital technology in the context of the energy transition. The organization's network of experts proposes collective and public debate on the true value of the energy-intensive technologies deployed. In their sights they have 5G, autonomous cars, connected objects and video bitrates (HD, 4K, 8K). "5G is expected to transfer even more data at faster speeds. This should only increase the digitization process and device turnover," says Fabrice Flipo. Autonomous cars, on the other hand, will require the significant transformation of road infrastructure. This questions the automobile sector's concern for the reduction of greenhouse gas emissions. Fabrice Flipo sees here the opportunity to establish a digital policy worthy of the name for a more resilient industry. Europe's dependence on China and the United States requires quick action. It will need to initiate ambitious exploratory projects and take risks.

Innovations in State sovereignty

Beneath these debates lies the issue of limiting the consumption of resources in order to protect the environment and preserve the fundamental benefits for society. "This is clearly the heart of the problem. We must not ignore the French people's basic needs, including both physiological and security aspects, which includes the environment," says Axelle Delagoutte, environment expert at Airbus Defence & Space. Reducing resource consumption



would mean risking the creation of a technology gap with countries with which we are in competition. However, this does not mean a rejection of digital sobriety: “We must increase our digital technology capacities, while also finding ways to integrate environmental protection objectives to compensate for its effects,” she says. Rejecting the technological development that is available only makes sense if its made in the context of a global decision. Yet economic and political issues make this scenario unrealistic. If Europe chose

“We must increase our digital technology capacities, while also finding ways to integrate environmental protection objectives.”

to pursue low-carbon 5G, it could not require the same of China. Furthermore, technology has implications in defense and space developments. If taken to the extreme, reducing innovation would affect the country’s economic development and reduce the performance of its companies in international competition. Technological innovation plays a key role in promoting state sovereignty. There is no easy answer to this problem. If a solution exists, it must be found at the point where diplomatic, economic, societal and scientific issues intersect, with global governance to face a global emergency.

To learn more:

- Helen Micheaux, *Responsabiliser pour transformer : des déchets aux mines urbaines*, Presses des mines, 2019,178 p
- Rapport intermédiaire “Déployer la sobriété numérique”, The Shift Project, 2020, www.theshiftproject.org
- *Feuille de route sur l’environnement et le numérique*, Conseil National du numérique, 2020, www.cnnumerique.fr
- Rapport d’information n° 555 sur l’empreinte environnementale du numérique, Commission de l’aménagement du territoire et du développement durable, 2020, www.senat.fr

GLOSSARY

1. **Paris Climate Agreement —** International climate agreement established in 2015 following negotiations held during the Paris Climate Change Conference (COP21). The agreement establishes the objective of keeping global temperature rise below 2°C above pre-industrial levels by 2100.

2. **LCA: Life cycle analysis —** Tool used to assess the overall environmental impacts of a product or service over its entire lifespan, taking into account the maximum inflow and outflow of resources and energy during this period.

3. **Mining Code —** Legal code from 2011 regulating the exploration and exploitation of mineral resources in France, founded on principles from the Napoleonic law of 1810.

4. **Data centers —** Infrastructure housing the equipment required for the operation of an IT system, including hardware to store and process data.

5. **WEEE —** Waste from electrical and electronic equipment — Any waste from products which are dependent on electric currents and contain electrical or electronic components.

6. **Ecodesign —** An approach used to design a product or service while limiting its environmental impacts and using the least amount of non-renewable resources possible.

7. **Eco-modulation —**A financial bonus/penalty system for companies based on their compliance with good environmental practices. It is primarily used in the area of waste collection and management to reward companies concerned with the recyclability of their products.

8. **Environmental Responsibility (or Eco-responsibility) —** Behavior of a person, community or company aimed at taking action to comply with sustainable development principles.

9. **Rebound effect —** An increase in use following an improvement in environmental performance (reduction in energy consumption or use of resources).

10. **Green IT (Information Technology) —** IT practices that reduce the environmental footprint of the sector's activities.

11. **Responsible innovation —** A way of viewing innovation with the purpose of meeting environmental or social needs, while giving thought to the research and development methods used for the innovation itself.

12. **Energy mix —** The combination of energy sources used by a region, including both renewable and non-renewable sources.

13. **PUE: Power Usage Effectiveness —** Ratio between the total energy consumed by the data center and the energy consumed by the servers alone.

14. **RFID: Radio-frequency identification —** A short-range communication method that relies on micro-antennas in the form of tags.

15. **CSR: Corporate Social Responsibility —** A voluntary approach adopted by companies with the goal of integrating social and environmental concerns into their commercial and partnership activities.

16. **5G Networks —** 5th generation of mobile networks, following after 4G, the networks improve mobile data rates and open mobile network uses up to new sectors.

17. **Salar —** High-altitude salt flats, sometimes submerged under a shallow layer of water, containing lithium, which is sought after for use in batteries and electronic devices.

18. **Mine tailings —** Part of of the rock left over after mining activities due to insufficient amounts of the material being extracted.

19. **Rare earths —** Group of 17 metals, several of which are used in the digital industry for their unique properties.

20. **Virtualization —** The dematerialization of a computer action, usually performed by a service provider, in order to save on IT equipment costs.

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