The Ecology of Digital Music

Measuring flows to unlock options

By Vincent Lostanlen

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Introduction

In his book *Decomposed. The Political Ecology of Music*,musicologist Kyle Devine explains that since around the year 2000, recorded music is experiencing a third era of materiality: the era of data, which follows the era of shellac (1900-1950) [1] and of plastic (1950-2000). However, Devine insists on the fact that the digitisation (sometimes incorrectly called "digitalisation") of music does not imply its dematerialisation. The technical system that stores and transfers internet packets [2] is indeed a "physical medium" for streaming; except that it is quasi-invisible for the end user. According to Devine, the confusion between digital and the immaterial is a rhetorical trap because it serves to hide that the streaming industry is complicit in multiple environmental and social damage, relating to material resources, human labour, energy, and pollution. However Devine adds that "the details and extent of its complicity are largely unknown." [3]

This article provides an overview of the environmental issues concerning digital music, with particular attention to its distribution method of streaming. Its aim can be summed up as follows: the time has come to renounce the utopian dream in which everyone has access to all music, on-demand wherever, whenever, and at the touch of a button. On the contrary, music streaming is embodied in its objects, limited in its choice architectures, and geographically located. Subscribing to streaming is not reducible to an individual consumption choice. In sociological terms, it is not a "lifestyle" but a "way of life," rooted in a system of values and norms. [4] Thus, the environmental damage of streaming will not be reduced by efficiency gains – for example, like better audio coding algorithms may lead us to hope for. Rather than looking for solutions in technological innovation, it is more useful to implement plausible scenario planning. However, we will see that a survey approach aimed at measuring the impact of music streaming in physical units (volume of material transferred, electrical power, amount of greenhouse gases) comes up against uncertainties of all kinds. For the most part, a way of performing environmental accounting on music today is yet to be invented.

Throughout this article, we will repeatedly take the case of the French company Deezer as an example of a music streaming platform. This should not be understood as a collection of critical and condonable evidence, but simply as a concern for consistency in the argument. Although Deezer is a key streaming player as a leader on the French market, most of our remarks can be transposed, *mutatis mutandis*, to other specialists in the sector (Pandora, Qobuz, Spotify, Tidal), as well as to certain Big Tech products (YouTube Music, Apple Music, Amazon Music).

1. From vinyl to CD (1980-2000): the plastic era

Ecotoxicity of compact discs

On the face of it, songs being made available online, whether by downloading or streaming, is good news for the environment; it made demand for compact discs fall, which explains why their sales figures have been declining since 2000. However, a compact disc contains heavy metals as well as polycarbonate, a plastic derived from bisphenol A (BPA). According to Ademe, the French environment and energy management agency, there is no recycling network for polycarbonate waste in France: "Whether dropped off at a recycling centre or thrown in the bin, CDs and DVDs are disposed of in one of two household waste disposal methods: they are incinerated (most often with heat recovery to produce energy) or buried in a landfill." [5]

It takes about a million years for polycarbonate resin to decompose, and the European Chemicals Agency now classifies BPA as a "substance of very high concern" for animal and human health. [6] There is a real risk of BPA entering into the biosphere and, while waiting for a biotechnological solution to polycarbonate's ecotoxicity, [7] we must contemplate the future of all the compact discs which collect dust on our shelves. According to a 2007 estimate, two hundred billion compact discs would be in existence, all uses combined. [8]

The rebound effect of plastic

To understand the challenges that await streaming today, it would be instructive to take a look back over the history of the transition from analogue (vinyl) to digital (CD) discs. While it is difficult to estimate the number of records and audio cassettes in circulation on the global market, the US market can be measured using data from the Recording Industry Association of America (RIAA). [9] By knowing the mass of plastic contained in each format, [10] the quantities placed on the market can be converted into kilotons of plastic, which can then be grouped into three categories: vinyl, cassettes and compact discs. Figure 1 shows the resulting total mass of plastic.

We then see that the U.S. recording industry increased its efficiency. Between 1975 and 2000, it doubled the number of units sold, all formats combined, while halving the amount of plastic needed for engraving on audio formats. But this improvement conceals another historic disruption. For the most part, cassettes and compact discs were not packaged in cardboard sleeves, unlike vinyl records: they were packaged in rigid polystyrene boxes, called jewel cases. [11] We can then update the first set of figures to include the estimated mass of packaging (see figure 2).

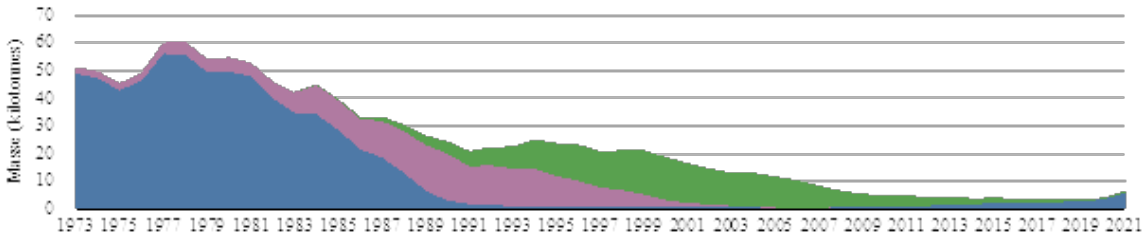

Figure 1. Mass of plastics contained in vinyl records (blue), cassettes (purple), and compact discs (green) placed on the US market each year. Estimate excluding packaging. Source: RIAA

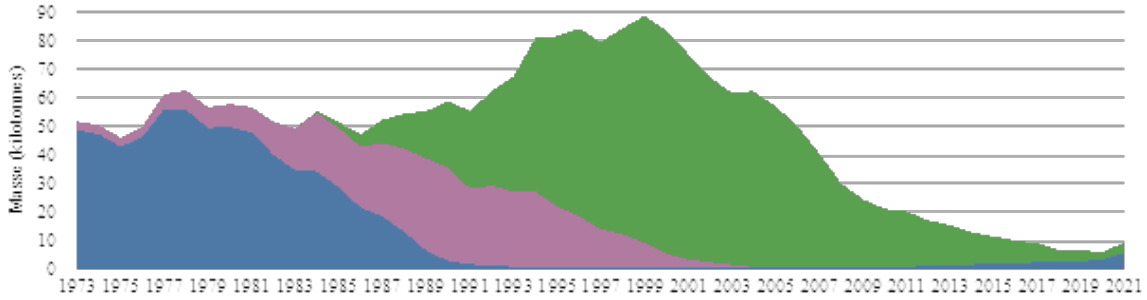

Figure 2. Mass of plastics contained in vinyl records (blue), cassettes (purple), and compact discs (green) placed on the US market each year. Estimate including packaging. Source: RIAA.

Even if the figures obtained are only estimates, due to unidentified variations in the packaging, there is a distinct shape to the curve. From 1986, the total mass of plastic consumed rose again until it approached 90 kilotons in 2000, during the peak of CD sales. This resulted in what economists call a "rebound effect," or Jevons paradox: the efficiency gains (use of plastic) made possible by a new technology (compact disc) have been lost by the sectoral transformation (use of cardboard sleeves discontinued). Here lies the paradox of the recorded music industry, in that it has never distributed so many fossil-based plastics as it did in so-called "compact" formats, such as discs or cassettes.

2. From CDs to music streaming (2000-2020): the data era

The digital music player: a media object with high embodied energy

A retrospective study on the transition from vinyl to CD should alert us to the presence of possible hidden factors in the environmental impact of streaming. It is undeniable that the mass distribution of MP3 files from the year 2000 put a stop to the dispersion of harmful plastics (mainly polycarbonates and PVC) contained in discs – despite the "vinyl revival" around 2010 and a possible "CD revival" in 2021. But meanwhile, the availability of

unlimited internet packages has profoundly transformed the French population's way of life. When it comes to music, this new way of life is embodied in one particular object: the digital music player, with the Apple iPod (2001) as the most iconic model.

We have since entered an era of "media-object consumerism," i.e., repeat purchases of high-tech objects likely to give us access to the same cultural content. [12] However, to incorporate the energy cost of these objects, the energy required for manufacturing, transporting and potentially recycling them must be included. Regarding digital formats, this intrinsic energy, or "embodied energy," represents nine times the amount of energy consumed in electrical form when the device is used. [13]

To date, a number of so-called "connected" or "smart" objects are capable of downloading and then decoding MP3 data, and therefore of serving as a streaming terminal. In 2021 as part of its extra-financial reporting, the French streaming company Deezer wrote:

Deezer also offers a free, ad-supported service for consumers. Anyone with internet access can access Deezer's entire music catalogue and most of the app's existing features. Deezer provides a seamless experience to its users thanks to more than 80 hardware partnerships, which allow its users to listen to their favourite content on smart speakers, voice assistants, smart watches, smart TVs, connected cars, smartphones, laptops and tablets. [14]

On initial reading, this approach seems laudable, because it implies that the user does not need to purchase specific equipment: they can use a device they already own. But, in reality, it is unthinkable to subscribe to a streaming service and use the same playback device *ad vitam aeternam* – like a first-generation iPhone (2007). For good reason, apart from streaming platforms, the entire consumer digital sector is preoccupied by a commercial strategy of obsolescence. The leading item of this strategy, the use of which controls all others, is the smartphone.

The smartphone: at the crossroads of obsolescence

Philosopher Jeanne Guien's book, *Le consumérisme à travers ses objets*, [15] devotes a whole chapter to the smartphone as a pivotal commercial digital device. According to her, "brands put the rapid renewal of models at the centre of their business model." In fact, 63% of smartphone owners in France have an almost new device which is less than two years old. [16] This figure rises to 69% amongst bundle package customers, whose contracts combine the price of a handset with a mobile communication plan. Apple's business model, which offers a similar package ("iPhone Upgrade Program"), "is not designed to support customers for the continuous time they use their phone, but in the sequenced time of a phone repurchase," writes the author. [17]

Jeanne Guien nevertheless deplores that the debate on obsolescence in France has become bogged down in "an avalanche of false problems," starting with that of trying to produce exhaustive categories of problems, like "functional obsolescence" (technological innovation develops a new product that better meets the needs) against "style obsolescence" (the

product suddenly seems unfashionable). [18] These categories date back to least to the 1960s and to sociologist Vance Packard's book, *The Waste Makers*. [19] However, the smartphone trade is subject to multiple obsolescence strategies, both technical and psychological, which intertwine and mutually reinforce one another. The most conspicuous strategy is to release frequently new numbered models (34 iPhones to date, pending the iPhone 15), with added superlatives (Plus, Max, Pro), and ever-changing sizes and colours.

The frequent repurchasing of smartphones is not only for aesthetic reasons. When new hardware is launched on the market, it endorses regular compatibility breaks, especially with regard to operating systems. For example, the current version of Deezer's mobile app (9.29.1) can only be installed on an iOS 15 or Android 6 operating system. However, iOS 15, released in June 2021, can only be installed on any iPhone newer than an iPhone 6s, released in September 2015. Conversely, those who own an iPhone 2G up to the iPhone 6, available new from June 2007 to September 2018, see their devices rendered obsolete. A similar reasoning could be carried out for Android devices. Here is an excerpt from Deezer's support forum, which is quite representative of content delivery platforms' rhetoric as a whole:

"Why do I receive emails/messages to update my app?"

– To make the most of your Deezer app on your mobile, we may prompt you with a message or email asking you to update your app. We always encourage you to use the latest version to improve the overall security and performance of the Deezer app.

"What if I'm not able to update my app because my device is old or not supported?"

– You will still be able to use older versions of the Deezer app already installed on your device. However, they may have limitations such as reduced audio quality.

Warning: Only the latest version of Deezer will be shown in your app store. You will not be able to find or rate older versions of the Deezer app, and as a consequence, if you uninstall an older version, you will not be able to restore it. [20]

Listeners are therefore urged to get up to speed with "security and performance improvements" by purchasing a new device.

Post-Digitisation, waste a likelihood

The proof is in: unlike offline MP3 players such as the iPod, and *a fortiori* record or CD players, streaming has shortened the life cycle of playback devices. Of course, smartphones offer a wide range of uses beyond simply streaming music. Thus, this makes it difficult to say what part of a smartphone's environmental impact should be attributed to the music sector. But the fact that streaming – a software technology that has been maturing for more than fifteen years – declares compatibility breaks on devices that have sold in their billions signals a weakness in the sustainability of the digital audio industry as a whole.

Earlier, we saw how the CD era increased overall plastic consumption compared to vinyl, particularly due to packaging. Likewise, it is feared that the streaming era will be one of throw-away hardware and wasted effort. Not that the format itself is more polluting, on the contrary: since a motor is no longer needed for spinning the disc, the use of MP3-type files represents a gain in efficiency, *ceteris paribus*. But streaming, in its modern form, steers us towards more expensive behaviour (downloading the same content over and over), towards regular device repurchases (to "make the most of" the service or simply because devices are easily breakable and difficult to repair); and, consequently, towards an obscuration of the environmental and social damage caused by the recorded music industry.

A recent study by the Ademe which conducted a life cycle analysis (LCA) for digital goods in the cultural industry concluded that "if some recent equipments can be lighter and less energy consuming (e.g.: connected speaker which represents impacts than the hi-fi system), the multiplication of equipments (smartphone coupled with headphones, a speaker, a hi-fi system, etc.) necessarily leads to an increase in impacts." [21] We therefore find the issue of media-object consumerism at the core of the ecology of audio data flows.

3. Digital music: a complicated industry

Geopolitical tension over "rare metals"

The French population is insufficiently informed about digital technology's involvement in the environmental crisis. [22] In the case of digital music as in many others, this involvement is rather complex: far from being a simple service, digital technology is based on an economy of high-tech goods that involve heavy industrial processes. In 2013, the battery for a Nokia smartphone featured thirty-four different metals. [23] However, a recent study by the Fraunhofer Institute predicts that, for eleven of these, current production will not be sufficient to cover the demand generated by certain emerging technologies by 2040. [24] For example, lithium is used to manufacture smartphone batteries, as well as so-called "solid electrolyte" batteries for electric vehicles. Another prime example is ruthenium, which is used in giant magnetoresistance (GMR), a quantum technology for reading hard disks with high information density. The aforementioned study predicts an annual demand for ruthenium of 630 tonnes in 2040, compared to an annual production in 2018 of 12 tonnes.

In *La numérisation du monde*, philosopher Fabrice Flipo explains that "the mining sector's responsiveness is low," which increases the risk of shortage. [25] Moreover, given the existing tensions with regard to access to certain rare metals, [26] restructuring the electronics markets as a whole seems therefore inevitable, even if the role to be played by audio-visual industries is yet to be determined. If this restructuring is poorly anticipated, the sudden shortage will cause compatibility breaks and therefore accelerate the

obsolescence process. This is why the issue of the rare metals market is crucial to understanding the digital sector's environmental challenges, particularly for streaming platforms.

The LCA of a digital object reveals that its environmental damage does not begin when the object is first used, or even in the microelectronics industry's semiconductor foundries, but rather during the mining process. According to the non-profit The Shift Project, the volume of material moved to acquire these metals is 40 times greater than the volume of the final product, [27] which involves severely disrupting biogeochemical cycles over long time scales. For example, for connected speakers, most microphones and loudspeakers need "rare earth" materials such as neodymium and dysprosium. Likewise, audio connectors are plated with precious metals such as palladium, platinum and gold.

4. Mining extractivism, conflict minerals and basic human rights

Another chemical element in high demand by the electronics industry is tantalum, which is used to build ultra-small capacitors for smartphones. However, current production is mainly based at columbite-tantalite (coltan) mines in the Democratic Republic of Congo. On this topic, Jeanne Guien writes:

During the Kivu conflict, all the parties involved engaged in mining coltan, tin or gold, to put them on the mobile phone market and to supply themselves with weapons. Since then, mining has remained militarised and labour often forced. Following field research and hundreds of interviews in Kivu, the NGO Free The Slaves reported in 2011 and 2013 that the markets for coltan (tantalum), wolframite (tungsten) or cassiterite [sic] (tin) were based on various forms of adult and child slavery: debt slavery, forced labour, sexual slavery, peonage. [...] The NGO also reported cases of slavery in Ghanaian gold mines. [28]

Thanks to the work of NGOs such as Free The Slaves and Gouvernance et Paix, [29] the European Parliament voted a regulation "laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores and gold originating from conflict-affected and high-risk areas." [30] This came into force on 1 January 2021.

We see here that investigations into the environmental issues of a certain technology (music streaming) progressively reveal political and social issues from which they are inseparable. It is the whole meaning behind a "technocritical" approach in social science to report the continuities between the defence of non-human living beings and the defence of human life regarding the technical organisation of work.

Human obsolescence as the factory floor strategy

In the smartphone production chain, violations on human dignity are not only in mineral extraction. The Taiwanese company Foxconn, officially known as Hon Hai Precision Industry Company, is a subcontractor of Apple through its subsidiaries iDPBG and iDSBG. Its largest "factory city," the Longhua Science and Technology Park, is located in Shenzhen, near Hong Kong. Back in 2010, sociologists Jenny Chan and Pun Ngai investigated a spate of employee suicides at the company's premises. They write that these "suicides as protest" are a sign that "leading international brands have adopted unethical purchasing practices, resulting in substandard conditions in their global electronics supply chain." [31] To substantiate Chan and Pun's claims, the student-led non-profit SACOM (Students and Scholars Against Corporate Misbehavior) collected accounts directly from workers, some of which were recently translated into French in the anthology *La machine est ton seigneur et ton maître.* [32]

Another concept which can be added to the technical and psychological obsolescence of digital music is "human obsolescence," a concept studied as early as 1956 by the technocritic philosopher Günther Anders. [33] Commenting on SACOM's reports, Guien states that "the importance given to the launch date of a new model implies that there is very tight schedule for orders," hence "the feeling of being dominated by the speed of the machines and not by human labour standards [...]." [34] According to Vicky Xiuzhong Xu, [35] a journalist affiliated with the Australian Strategic Policy Institute (ASPI), the discourse on the obsolescence of digital objects is used to persecute Turkic and Muslim minorities in the Xinjiang province, including Kazakhs, Uzbeks, Kyrgyz, Tatars and Uighurs. Guien summarises the ASPI report as follows:

Huawei, Apple, Samsung, Sony, Nokia, Xiaomi, HTC and even LG are accused of purchasing and/or being supplied by Chinese manufacturers who benefit from [their] forced labour. It is estimated that between 2017 and 2019, at least 80,000 Uyghurs detained by the Chinese state in "re-education camps" were sent to work across China, in textile, automobile or electronics subcontractor factories [...] In addition to this system of "extrajudicial detention," the Chinese government has set up "poverty alleviation" and "industrial Xinjiang aid" programmes which involve displacing part of this region's population, especially young rural Uyghurs, to work under military-style management for very low wages, or sometimes even for nothing, as "rural surplus labourers" and "government-sponsored workers." [...] In state, academic and media discourse, a people described as "backward" and "poor" is called to join "modernity" and "material values" through "re-education" and "training" processes as factory work. Other official documents, however, explicitly accept that forced labour transfers make it possible to "reduce labour costs." [36]

Kyle Devine shares the same analysis: as early as the 1950s, "music (via radio) was a key player in establishing the ideas of planned obsolescence and death-dating in the consumer electronics industry." [37] He draws a comparison with the present time: "digital [musical] devices come and go at an even faster rate than their elders. The accelerated temporal logic of contemporary electronics devices is rooted in an industrial-cultural conjuncture that

demands constant software updates and which insists on constant newness." [38] Thus, he considers that the Foxconn case "is only the most infamous example of a much larger problem." [39] Based on the research of Jack Linchuan Qiu, professor at the University of Singapore, he concludes: "If the factory floors of record pressing facilities in the shellac and plastic eras were sites of social inequality and exploitative labor, digital electronics assembly in places like China is truly chilling." [40]

5. Flow productivism

When B2B joins B2C

Meanwhile, streaming platforms deny the extent of their involvement in the current damages and future risks relating to the digitisation of cultural content. As part of its extra-financial reporting, Deezer states: "While our group's activities have inherently only a limited impact on the environment, environmental considerations are nevertheless at the core of our thinking when defining our strategy and managing our day-to-day business operations." [41] Ethically speaking, this sentence demonstrates a concept of consumption that could be described as instrumentalist, in that it reduces the existence of technical objects solely to the time they are used. This concept is lawful, of course, from the point of view of the service's terms and conditions: "Deezer Service" (free or premium), it reads, "consists of the website and its apps for desktop, tablet, and mobile." [42] But it poses a problem more globally when it comes to the environmental planning of a country like France. For good reason, it makes the "subscriber" entirely responsible for greening the enormous material infrastructure that connects them to the "service." Here is article 3 of the premium service terms and conditions:

The use of the Service requires a high-speed internet connection for personal computers and an internet service for mobile devices. These connections are not provided by DEEZER, therefore the Subscriber must first subscribe to a high-speed internet and/or an internet for mobile offer in order to use the Service. A connection to internet for mobile through a third- or fourth-generation (3G or 4G) mobile technology norm is highly recommended. [43]

The company therefore recommends not only a list of compatible devices, but a certain wireless telecommunications standard; and this, while limiting its legal and financial responsibility to developing a "website" and an "application."

In 2021, Spotify reported greenhouse gas (GHG) emissions of 353 kilotons of CO_2 equivalent. Furthermore, 99% of these emissions are indirect ("Scope 3"), located in the company's supply chain: marketing, end use, goods and services, cloud and capital goods. Despite an increase in emissions, Spotify continues to maintain its "net zero" target before 2050. However, its impact report remains unclear as to how it will achieve this: "We continued to work together with our partners to improve cloud efficiency, establish

stronger procurement around environmental aspects for our suppliers, and investigate the emissions from audio streaming." [44]

At this point, it is worth noting that a streaming company's business model is not based purely on contracts with consumers (B2C, or business-to-consumer), but also with businesses (B2B, or business-to-business). This is the case for Deezer, for whom about a quarter of their turnover results from 45 B2B partnerships. The latter include internet service providers (ISPs) such as Orange – whose subsidiary is an 8% shareholder of Deezer –, SFR, Bouygues Telecom, T-Mobile (Austria), TIM (Brazil) and A1 Telekom (Austria). When it comes to ISPs, the partnership consists of providing streaming access to the subscriber at a preferential rate. This is what economist Gérard Pogorel calls a "content aggregator strategy," a concept already highly developed in the United States: [45] AT&T is a customer of Spotify, T-Mobile a customer of Tidal, Verizon a customer of Apple Music, and so on. Conversely, the "content acquisition strategy," which involves going into a B2B partnership with a record company (for example, Neuf Music with Universal in 2007) is less common today.

Asymmetric relationship between content providers and access providers

However, ISPs' venture into the recorded music market is not without environmental impact. To understand why, it is worth remembering certain technical elements relating to the BGP (border gateway protocol) inter-domain routing. Stéphane Bortzmeyer's book, *Cyberstructure*, offers an excellent introduction to the socio-technical issues of the contemporary internet, in particularly on the concept of asymmetric traffic:

In theory, the internet is a peer-to-peer network. All machines are equal, all send and receive traffic. In practice, a distinction is often made between "content providers" and "eyeballs." The evolution of the Internet has created a gap between specialist content hosting and service providers (such as Facebook and YouTube) and those specialised in providing internet access. It is the latter who refer to their subscribers as mere "eyeballs," whose only vocation is to consume. [...] From a financial point of view, this distinction between content or service providers and ISPs has significant implications. This is because content providers send bytes, eyeball ISPs receive them. The traffic will therefore be asymmetric, which will influence the debate, such as the one on net neutrality. [46]

If the synecdoche [47] of "eyeballs" were replaced with that of "eardrums," what is true of video on demand is also true of music streaming. The first consequence of such asymmetry is that, in the B2C market, eardrum ISPs do not communicate directly with the streaming platform, but through a content delivery network (CDN). CDNs, such as Akamai or Edgio, are relatively unknown to the general public, however they play a key role in the internet's physical infrastructure: they are networks of servers distributed around the world, each maintaining a partial local copy of the platform's content. By paying for a CDN, the platform indirectly gains a point of presence (PoP) at many internet exchange points (IXP), as well as at "carrier hotels." It is at the level of these PoPs that BGP interconnection

agreements are negotiated between the CDN and other autonomous systems (AS): local ISPs and long-distance operators.

To attract B2B customers, a CDN must have low latency, be fault-tolerant and be resistant to denial of service attacks (DoS). As such, CDNs invest heavily in building data centres, located as close as possible to their PoPs with the most data-intensive ASs. Hence an excessive concentration of the data centres themselves, as part of peering or transit agreements. In her book *À bout de flux*, the historian of architecture Fanny Lopez describes this asymmetry as having a "magnet" effect:

The data go where the data are, like magnets attracting each other. […] With a rebound effect, because the increase and acceleration of flows and interconnection in urban hubs promote simultaneously the increase in data centres for storage and redundancy in the middle of nowhere […]. The contiguity and proximity of data centres are not an obstacle to business development, on the contrary. They're an accelerator. [48]

Redundancy intensifies further with the hybrid model combining B2C and B2B. In the content aggregation strategy, "eardrums" pay their ISP directly to access the streaming service. The aggregator ISP then pays the platform and negotiates private peering with its AS – or with the AS of its host if it does not have an assigned AS. By doing so, it avoids intermediary fees for transit providers, IXPs and CDNs. But the ISP still has infrastructure costs on its own network, between the platform-side access point and the eardrum-side collection routers. It will therefore set up regional proxy servers, specialised in cached storage of the service provider's content. Thus, the ISP becomes a *de facto* CDN: a telco CDN indicates this convergence between delivery and content.

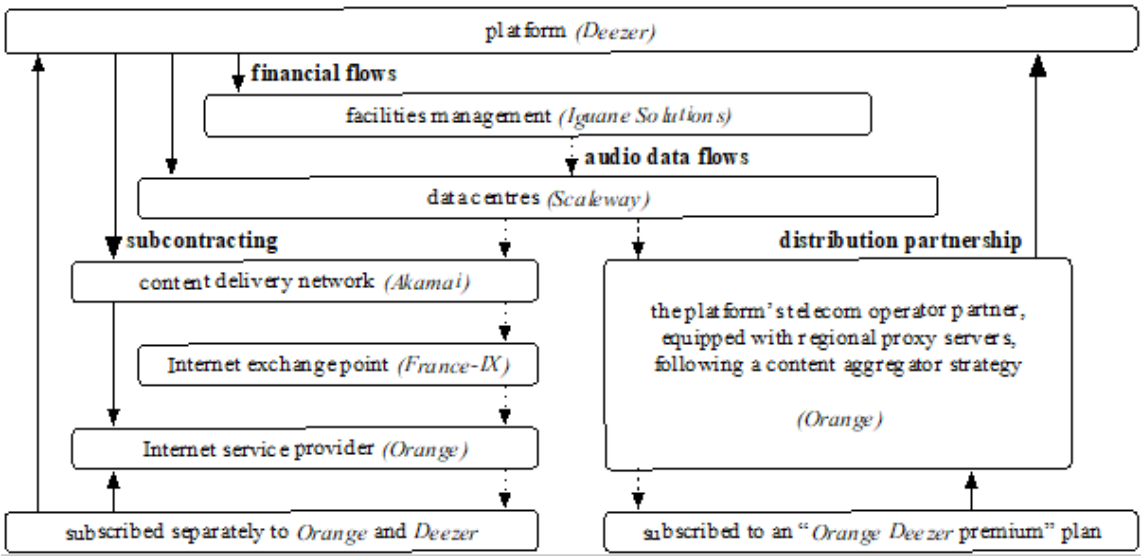

Figure 3. Audio data flows (blue) and financial flows (green) for an online music service.

The terms in italics (Deezer, etc.) are examples of companies fulfilling the role described in the box, but are not necessarily associated in reality. CDN: content delivery network. IXP: internet exchange point. ISP: internet service provider. Left: B2C model. Right: B2B model

Concretely speaking, the emergence of telco CDNs means that two neighbours in the same building, listening to the same song on the same streaming platform will require very different material resources depending on who their internet access provider is. These neighbours may be on the same local loop and make the same HTTP request, but their IP address is different, hence the different routing. For example, one neighbour will listen to a stream from the platform's CDN *provider*, while the other neighbour will listen to a proxy from its platform's ISP *client*. The diagram in Figure 3 illustrates this phenomenon.

With so-called "anycast" routing, the situation becomes even more opaque, because the same CDN or proxy IP address can be configured in several places. It therefore becomes very difficult to assess the throughput of the service as a whole; and this, regardless of whether it is a platform, ISP, CDN, or a regular citizen.

The amount of GHG emissions that Spotify reported in 2021 includes 81 tonnes classed as "end use" and 46 tonnes classed as cloud use (and again, surprisingly, 100 tonnes of marketing), without it being clear as to what these categories cover. This is why we must remain critical when Spotify proclaims that "we attribute the increase [in our GHG emissions] to factors including enhancements to our GHG emissions calculations methodology, growth of our business to new markets, and increased employees and monthly active users." [49] When environmental accounting is carried out with such little precision, it cannot fall back on a causal explanation.

Does measuring the energy consumption of streaming make sense?

In recent years, the question surrounding music's environmental impact has been the topic of numerous articles in the press. When interviewed by Time Magazine, Kyle Devine said: "One to one, streaming is a much more efficient use of resources. [...] If people started listening to records as much as they do streaming, vinyl would be much more carbon intensive." [50] Thus, the rebound effect holds a major place in journalistic discourse, as reported in *The New Statesman*: "Music streaming has a lower carbon footprint than any physical format, but the huge growth in our music consumption more than outweighs those savings." [51]

As such, there is a temptation to present streaming as the lesser of two evils. A *digital* Scylla preferable to the *analogue* Charybdis? This is how Deezer seems to present itself in its extra-financial reporting, presenting the increase in its energy consumption as "irremediable":

Our music streaming platform operates based on an infrastructure mainly comprising of two data centres located in the Paris region which belong to external service providers, as well as a portion of cloud services linked to our activity. As this infrastructure represents one of Deezer's main environmental impacts, in 2021 we implemented a system to monitor energy consumption at our data centres and cloud services, as well as the level of greenhouse gas emissions and their carbon footprints. We are aware that given the continuous growth of our activity, it is irremediable that our energy consumption will

continue to increase in the future. By implementing a monitoring system, which will be effective during the 2022 financial year, this will allow us to follow the evolution of the relevant indicators in order to understand better our consumption and, if possible, reduce it. [52]

Although Deezer's willingness to be transparent about its service providers' energy consumption is applaudable, the figure that will appear for the 2022 financial year risks being of little ecological use, for at least three reasons: because most of the energy consumed is "embodied," or rather, its intrinsic to a device; because in B2B, streaming does not only involve platform providers but also consumers; and because in the era of renewable energy solutions, what matters is not so much total consumption, but rather peak demand. Despite all this, Kyle Devine details how that, up until now, it has been easier for him to investigate how records and cassettes are manufactured, rather than streaming:

We can know that a cloud server requires "deadly 4,000V DC submarine cables, 96 tonnes of batteries, thousands of liters of diesel fuel, millions of miles of last-mile cabling" and an electricity bill that "comfortably reaches five figures" every month. Yet database providers and streaming services are not forthcoming about their actual energy consumption, making it difficult to compare streaming with earlier formats. How does streaming compare, for example, to the fact that in a single year, 1946, one Columbia Records plant used nearly 12,000 tons of coal, over 8 million kilowatt-hours of electricity, and over 840 million liters of freshwater – enough to fill more than 330 Olympic swimming pools – to operate its presses? How does the proliferation of digital listening devices today compare to the fact that manufacturing 13 million radio-phonographs in 1941 required 280 tons of nickel, 2,100 tons of aluminum, 10,500 tons of copper, and 70,000 tons of steel? Is it possible to find concrete grounds of comparison? [53]

The extract above can be compared to the concept of *continuum électrico-numérique* (electro-digital continuum), which Fanny Lopez develops in *À bout de flux*:

Today the Plaine Commune digital hub is reaching saturation point in terms of land availability and electricity. The distribution networks and source substations that bring the electricity needed to operate the "*armoires numériques*" ("digital larders") are worn out. […] Tomorrow, all major digital metropolises will have monofunctional digital zones, i.e. some 200 hectares of land with and at [a] minimum 1 GW dedicated to it. [54]

The three authors mainly cited in this article (Kyle Devine, Jeanne Guien, Fanny Lopez) highlight that the rebound effect is in no way "irremediable"; no more than software obsolescence, network asymmetry or human rights violations. In the words of *The New Statesman*, the increase in "our music consumption" – whether expressed in hours, gigabytes, joules, or kilograms of CO_2 – is not without cause. It is intertwined in an existing and more general digitisation process, itself a contemporary of lifestyle changes, including beyond human-machine interactions alone. Therefore, it is not enough to attest that "streaming has transformed the way we listen to music," [55] only that we must also understand what maintains this culture of immediacy.

Conclusion

The generation born in 2000 has the highest rate of negative judgments towards digital technology. [56] At the same time, less than 15% of French people believe that the issue of climate change can be solved through technological solutions. [57] As this study draws to an end, we understand that the links between music and ecology should not only be thought of in terms of responsibility, but also in terms of constraints: on materials, flows, energy sources, waste, and, ultimately, imaginaries. In return, it can be said that sobriety is synonymous with freedom. As Fabrice Flipo details in *La numérisation du monde*:

What is sobriety? It is neither a mere "critique of consumer society," as sociologist Jean Baudrillard theorised in the 1970s, too focused on desire, nor a mere "creation of false needs," as the sociologist Razmig Keucheyan evoked, from which it would be easy to free ourselves once the power was in our hands. The challenge is rather to oppose a lock-in of choice architectures, a concrete lock-in, that's both material ("large technical systems") and ideal ("attention economy"). [...] So how do we get away from this? By forming alternative networks where information is more open, decision-making is better controlled and the ecological footprint is lighter. [58]

As for the future, little can be said with certainty, except that music streaming subscription prices will increase: as Deezer delicately put it during its recent investor day presentation, there's headroom for price increase. [59] The "lock-in of choice architectures" which Flipo mentioned is therefore proven. Note that the author concludes his book with a specific policy recommendation: "Require any company putting a new product on the market to produce a document certified by a trusted third party (such as a consumer organisation) assessing the environmental and social effects of the product rollout and its widespread use, on the market in question, so as to ensure uses have a social dimension [...]." [60]

As for research, setting up new interdisciplinarity activity between digital sciences, "Earth system science" and social sciences is necessary. This is why the CNRS EcoInfo service group is working to highlight the socio-environmental impacts of digital technology through publications and awareness-raising actions. At the same time, the Internet, AI and Society research group organises a monthly seminar entitled "Digital Environmental Policies." It is likely that these two initiatives, amongst many others, will have a lot to do in the coming years, because the tension between the digital transition and energy transition will persist.

Compared to other digital data, is music simply one case amongst many others? Can we really reduce our study to that of a communication technology? Not quite. According to Kyle Devine, it may be that the social representation of streaming as a source of environmental and social damage affects musical content, and ultimately musical practices themselves. Hence a form of sociological reflexivity that is reminiscent of Bourdieu's "theory effect":

The digitalization of music does not remove all traces of previous musical practices or media systems. It absorbs them, reconfigures them, magnifies them, and is dependent upon them. […] Then perhaps part of the promise of our contemporary situation is that these developments will signal the emergence of another new form of self-conscious attachment to music – a form of attachment in which an awareness of material intensity, energy consumption, human labor, and political ecology may become an integral part of what it means to be a music fan. [61]

1. Shellac, or E904, is a coating agent derived from the secretion of an Asian cochineal species. Shellac was the foundation of the 78 rpm record industry; it was gradually replaced by synthetic plastics (bakelite, then vinyl in 1938).
2. In networking, a packet is a small segment of a larger message. Data sent over computer networks, such as the internet, is divided into packets. These packets are then recombined by the receiving computer or device.
3. Kyle Devine, Decomposed. The Political Ecology of Music (Cambridge: MIT Press, 2019),133.
4. Fabrice Flipe, L'impératif de la sobriété numérique. L'enjeu des modes de vie (Paris: Éditions matériologiques, 2020).
5. "Que faire de mes déchets ? CD-ROM," Ademe: quefairedemesdechets.ademe.fr/dechet/cd-rom. Translation by Kate Maidens.
6. Court of Justice of the European Union, "Appeal – Establishment of a list of substances subject to authorisation – List of substances identified with a view to their eventual inclusion in Annex XIV to Regulation (EC) No 1907/2006 – Updating of the entry of the substance bisphenol A as a substance of very high concern," ECLI:EU:C:2021:1047, 21 December 2021.
7. Matthew S. Brown et al., "Upcycling Compact Discs for Flexible and Stretchable Bioelectronic Applications," Nature Communications 13, article no. 3727, 2022: www.nature.com/articles/s41467-022-31338-9.
8. "Compact disc hits 25th birthday," BBC News, 2007-08-17: news.bbc.co.uk/2/hi/technology/6950845.stm.
9. "U.S. Sales Database," Recording Industry Association of America (RIAA): www.riaa.com/u-s-sales-database.
10. 140 g in an "LP" vinyl record (12 inches; disregarding the case of 180 g vinyl), 42 g in a "single" vinyl (7 inches), 32 g in an audio cassette, 22 g in a "Stereo 8", 16 g in a compact disc (12 cm; disregarding the case of 8 cm-"single" CDs).
11. The mass of plastic in these boxes may vary. We estimate it at 30 g for a Compact Cassette and 60 g for a CD. Cardboard CD sleeves and so-called longbox packaging were disregarded.
12. Concerning music, one could observe that this process of repeat purchases was already at the core of phonogram producers' strategies throughout the 20th century; the same works being marketed in 78 rpm format, then 45 rpm, then 33 rpm, then CD. On this subject, read: Ludovic Tournès, Du phonographe au MP3. Une histoire de la musique enregistrée, xix-xxie siècle (Paris: Autrement, 2008).
13. Hughes Ferrebœuf et al., "Lean ICT: Towards Digital Sobriety," The Shift Project report, March 2019: https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf.
14. Deezer, "Déclaration de performance extrafinancière 2021" e-cdn-files.dzcdn.net/pdfs/legal/DPEF2021.pdf.
15. Jeanne Guien, Le consumérisme à travers ses objets (Paris: Divergences, 2021).
16. Arcep, "Renouvellement des terminaux mobiles et pratiques commerciales de distribution. Éléments de réflexion," French government recommended report, 2021-06-03: 27.
17. Jeanne Guien, Le consumérisme à travers ses objets, 157.
18. Ibid.,148.
19. Vance Packard, The Waste Makers (New York: David McKay Company, 1960).
20. "Why Do I Need To Update My Deezer App?" Deezer Support, 2022: https://support.deezer.com/hc/en-gb/articles/360013577457-Why-Do-I-Need-To-Update-My-Deezer-App-.
21. Julia Meyer et al., "Environmental Impact Assessment of the Digitilization of Cultural Services," report conducted by I Care for the Ademe, November 2022.
22. Fabrice Flipo et al., Peut-on croire aux TIC vertes? Technologies numériques et crise environnementale (Paris: Presses des Mines, 2012).
23. Axel Müller, "The Chemistry of the Mobile Phones Nokia Nuron 5230, Nokia 5130 and Sony Ericsson W595," Geological Survey of Norway, NGU report 2013.026, 2013-07-01.
24. [24]
25. Fabrice Flipo, La numérisation du monde. Un désastre écologique (Paris: L'Échappée, 2021).
26. Guillaume Pitron, La guerre des métaux rares. La face cachée de la transition énergétique et numérique (Paris: Les Liens qui libèrent, 2018).
27. Ferrebœuf et al., "Lean ICT: Towards Digital Sobriety."
28. Guien, Le consumérisme à travers ses objets, 179.
29. Observatoire Gouvernance et Paix: observatoire-securite-privee.org/fr/content/observatoire-gouvernance-et-paix-ogp.
30. Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas
31. Jenny Chan and Ngai Pun, "Suicide as Protest for the New Generation of Chinese Migrant Workers. Foxconn, Global Capital, and the State," The Asia-Pacific Journal. Japan Focus 8, no. 2, 2010.
32. Jenny Chan et al., La machine est ton seigneur et ton maître (Paris: Agone, 2022).
33. Günther Anders, Die Antiquiertheit des Menschen (Munich : Beck, 1956).
34. Guien, Le consumérisme à travers ses objets,177.
35. Vicky Xiuzhong Xu et al., "Uyghurs for Sale. 'Re-Education', Forced Labour and Surveillance Beyond Xinjiang," Australian Strategic Policy Institute, 2020-03-01: www.aspi.org.au/report/uyghurs-sale.
36. Guien, Le consumérisme à travers ses objets, 181-82.
37. Devine, Decomposed, 142.
38. Ibid.
39. Ibid, 142.
40. Ibid., 142-43.
41. Deezer, "Déclaration de performance extrafinancière 2021."
42. Deezer, "Conditions générales d'utilisation," December 2022: www.deezer.com/legal/cgu.
43. Ibid

44. Spotify, “Equity and Impact Report 2021,” December 2021: https://www.lifeatspotify.com/reports/Spotify-Equity-Impact-Report-2021.pdf.
45. George Pogorel, “A European Audio-Visual Area for the Age of Global Entertainment,” European Liberal Forum 3, 2021-04-21.
46. Stéphane Bortzmeyer, L’Internet, un espace politique (Caen: C&F Éditions, 2018), 119-21.
47. A synecdoche is a figure of speech in which a part is used for the whole.
48. Fanny Lopez, À bout de flux (Paris: Divergences, 2022), 15-19.
49. Spotify, “Equity and Impact Report 2021.”
50. Aryn Baker, “Taylor Swift’s New Album Is Finally Out. But Do You Really Need Four?” Time, 2022-10-21: time.com/6223774/vinyl-records-cimate-impact-taylor-swift-midnights.
51. Ellen Peirson-Hagger and Katherine Swindells, “Is Spotify Bad For The Environment?” The New Statesman, 2021-11-05: www.newstatesman.com/environment/2021/11/how-environmentally-damaging-is-music-streaming.
52. Deezer, “Déclaration de performance extrafinancière 2021.”
53. Devine, Decomposed, 147-48.
54. Lopez, À bout de flux, 19.
55. Antoine Bordeleau, “Comment le streaming a transformé l’écoute de la musique,” 2020-01-15: voir.ca/musique/2020/01/15/comment-le-streaming-a-transforme-lecoute-de-la-musique.
56. Flipo, La numérisation du monde, 41.
57. Ibid., 102.
58. Ibid., 15.
59. Deezer, “Deezer Investor Day,” 2022-10-04: www.deezer-investors.com/wp-content/uploads/2022/10/Deezer-2022-Investor-Day-Oct-4.pdf.
60. Flipo, L’impératif de la sobriété numérique, 141.
61. Devine, Decomposed, 135.