Rebound Effects Make Digital Audio Unsustainable

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***Abstract*—The development of fast and lightweight systems for consumer electronics has the potential to improve the energy efficiency of digital audio. Hence, end-user applications become more affordable and thus in higher demand. Ultimately, the expected gains which were made possible by technological advancement are hampered by changes in modes of consumption. This is known in environmental economics as rebound effects. In this context, our article presents two case studies: plastic use in discs and cassettes during the late twentieth century and energy use in online streaming platforms since the 2010's. For the former, we find that resource consumption has grown even so per-unit audio coding efficiency has improved, because of a rise in demand and of the use of plastic in packaging. For the latter, the risk of rebound effect is real but the digital music industry is enacting a strategy of opaqueness which prevents precise estimations. Scientists of the "Internet of Sounds" must take action to involve sociopolitical factors in their impact assessment of digital audio.**

***Index Terms*—Extractivism, rebound effects, sustainability.**

I. Introduction

A. Sustainable computing meets ecomusicology

A growing number of researchers in electrical engineering and computer science (EECS) recognize sustainability as a primary goal in system design. For example, in France, a CNRS special interest group known as "Ecoinfo" has been promoting ecological responsibility in EECS since 2006 and currently gathers 60 members[1]. Relatedly, the International Conference on Information and Communications Technology for Sustainability (ICT4S) is held yearly since 2013 and has published 20 articles in 2023 [2]. Another example is the yearly distributed workshop on "Computing within Limits", which is "grounded by an awareness that contemporary computing research is intertwined with ecological limits in general, and climate- and climate justice-related limits in particular"[3].

Yet, the ecological unsustainability of audio technologies had not received a dedicated examination until recently. The situation has changed in 2019 with *Decomposed: A Political Ecology of Music*, by musicologist Kyle Devine [1]. In his book, Devine retraces the material and political conditions which have made possible the globalization of music listening practices in the twentieth century. According to him, the recording industry depends on the petroleum industry since 1945 and the gradual replacement of shellac by vinyl. Furthermore, against the myth of "dematerialized" consumption, Devine shows that accessing digital music via the Internet involves heavy industrial processes, from the deployment of submarine communication cables to the assembly of smartphones and other playback terminals.

B. Problem statement

The publication of *Decomposed* has spurred a generation of historians and social scientists to address the scientific question of "making infrastructures audible"; that is, to reveal "the hidden dimensions of how music is made, delivered, and disposed of" [2]. Meanwhile, the EECS community is also starting to examine its own ecological responsibility in the development of software and hardware for digital audio processing [3], [4]. In a 2022 article, Gabrielli and Turchet have called for a the emergence of a "sustainable Internet of Sounds" (IoS) [5]; i.e., one in which technological innovation is put at the service of ecological safety and social justice [6]. A more recent paper by Masu *et al.* envisions strategies to account for environmental and social sustainability in network-based interactive music systems [7].

Yet, one question remains insufficiently discussed, both in ecomusicology and IoS: could technological innovation lead to a "rebound" in demand? In other words, is there a risk of hurting sustainability when trying to improve efficiency?

C. Contributions and outline

To understand the concept of rebound effect, we shall return to its original formulation by British economist William Stanley Jevons [8]. In Section II, we recall that the modern reception distinguishes direct rebound effects, arising from lower price for the same use; versus indirect effects, arising from new uses. In Section III, we provide quantitative evidence that, between 1973 and 2003, the market of recorded music in the US has undergone rebound effects for plastic use, both direct and indirect. In Section IV, we show qualitatively that the digital music industry entertains a myth of weightlessness, despite looming risks of shortages for multiple materials. In Section V, we discuss four challenges deserving further inquiry: the influence of caching, the role of record companies, the multimateriality of hardware, and the difficulty for scientists to find reliable sources.

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[1]Ecoinfo: https://ecoinfo.cnrs.fr

[2]ICT4S: https://conf.researchr.org/series/ict4s

[3]Computing within Limits: https://computingwithinlimits.org/2024

II. Direct versus indirect rebound effects

A. Historical context

In *The Coal Question* (1865), Jevons predicted "the probable exhaustion of our coal-mines" in the age of the steam engine [8]. Here, let us remind our reader that James Watt did not invent the steam engine: in fact, a steam-powered turbine known as aeolipile was known in early Roman Egypt, and some fully operational steam pumps date back to British inventors Thomas Savery (1698) and Thomas Newcomen (1712). However, Watt's 1769 patent describes "a method of lessening the consumption of steam engines—the separate condenser". The main advantage of the condenser was that, compared to Newcomen's, Watt's engine used half as much coal to produce the same power. Said otherwise, the so-called "steam engine revolution" is not primarily attributable to a new product but, rather, to gains in fuel efficiency—and, to a lesser extent, a greater flexibility and regularity in yield.

These gains in fuel efficiency have played a decisive role in the adoption of the steam engine for manufacturing and transportation, eventually raising the cumulated demand for coal: "the greater number of furnaces", Jevons writes, "will more than make up for the diminished consumption of each". Hence a rebound effect, also known as take-back effect or Jevons paradox, as a systemic consequence of innovation:

> It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth. [8]

Jevons goes as far as to argue that no amount of technological development is able to meet the demand it creates. Indeed:

> Whatever [...] conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam-engine, and to enlarge the field of its operations. [8]

B. Modern reception

Admittedly, part of *The Coal Question* did not age well: even so the British production peaked in 1913, the global production of fossil fuels (coal, oil, gas) kept increasing until today. Moreover, the neo-Malthusianism of Jevons has been disproved by history: the British population has doubled between 1865 and 1965 while considerably improving its standard of living. Despite such caveats, *The Coal Question* is regarded today as a founding text of environmental economics, and its conclusions were integrated into the neoclassical doctrine under the name of Khazzoom–Brookes postulate.

Yet, the scope of validity of the Jevons paradox remains debated until today. In a 2013 position paper for Nature, economist Kenneth Gillingham *et al.* claim that "the rebound effect is overplayed" [9]. Crucially, the authors point out that there are at least four kind of rebound effects. Rebound effects of the first kind, also known as "direct" effects, are those described in *The Coal Question*: they describe a direct association between a greater efficiency in resource use, a lower price of the same primary resource, a greater demand of the finished product or service, and ultimately a greater demand in the primary resource. Meanwhile, other rebound effects are known as "indirect": they do not necessarily stimulate the demand for the finished product but create new uses.

Given these definition, we proceed to show, in the next section that the advent of compact discs (CD's) has considerably improved the efficiency of plastic use for audio coding, but that these improvements were hampered by a greater demand for playing time (direct rebound) and, more significantly, by the resort to plastic packaging (indirect rebound).

III. The age of plastic (1950–2000)

The Second World War coincides with a shift in materiality in the record industry, from 78 rpm (revolutions per minute) discs to 45 and 33 rpm discs. While the former were made out of shellac, a resin which is secreted by the lac beetle, the latter were made out of polyvinyl chloride (PVC), a synthetic polymer which is derived from ethylene. As such, it is dependent on the supply by the petrochemical industry. Thus, vinyl records inaugurate what Devine has described as the "plastic age" of recorded music: it extends until 2000 and includes compact cassettes as well as compact discs (CD's).

Our hypothesis is that searching for rebound effects in plastic use has the potential to reveal more about the environmental history of recorded music in the US than what Decomposed gives to see. We begin by considering rebound effects of the direct kind, i.e., as theorized by Jevons, by charting the growth of playing time in units sold per year. Then, we present an indirect rebound effect: the switch from cardboard sleeves for vinyl packaging to polystyrene cases for cassette and CD.

A. Coding efficiency

Chapter 3 of *Decomposed* estimates the total mass of plastics used by the recording industry at different moments in its history. Devine breaks down units sold per format given publicly available data from the Recording Industry Association of America (RIAA) and proportionality rules:

> Looking at the years 1977, 1988, and 2000—the US sales peaks of the LP, cassette, and CD—we can see that despite various formats rising and falling in terms of total sales (and record sales generally increasing), when totaling the amounts of its main formats the amount of plastics used by the US record industry remains relatively constant over this period: 58 million kilograms at height of the LP, 56 million kilograms at the height of the cassette, 61 million kilograms at the height of the CD. [1, p. 156]

To put these figures into context, we evaluate and compare the coding efficiency of different formats, defined as the ratio of playing time to mass of plastic substrate. Simply put, a format is considered more efficient than another if it requires fewer grams of plastic to store as much recorded music.

Table I summarizes the coding efficiencies of some well-known formats, from a shellac record (1897) to a MiniDisc equipped with ATRAC3+ low-bitrate perceptual coding (2006). We have relies on web sources for analog media and on geometrical volume formulas for digital media[4]. We observe a growth by four orders of magnitude over the twentieth century, from two seconds per gram of shellac in 1897 to ten hours per gram of bisphenol A polycarbonate (BPA-PC) in 2006.

B. Direct rebound effect: growth in playing time

We use the coding efficiencies of each format in Table I as proportionality factors for the RIAA data. This operation produces a bulk estimate of coding efficiency, all formats combined. We observe a roughly nine-fold gain between 1973 and 2003, primarily due to compact cassette and CD's: see Figure 1. Thus, we confirm that the premise of the Jevons effect applies: technological advancements have improved the efficiency of use for the resource of interest, i.e., plastic.

Then, we compute a bulk estimate of playing time for the market as a whole by multiplying units sold by the playing time of each format and summing across formats. The resulting chart provides evidence of a direct rebound effect. Simply put: comparing 1999 to 1973, US consumers have bought musical formats which were 8.7 times more efficient on average; but they bought 3.5 times more hours of recorded music; so the reduction factor of plastic use is only 2.5. Note that the growth in demand is not purely a consequence of growth in population, which is of the order of 1.4 over that period.

C. Indirect rebound effect: conversion to plastic packaging

In addition, we inquire about a rebound effect of the indirect kind that is due to record packaging. On one hand, vinyl records are typically packaged in a cardboard sleeve. On the other hand, the tape of the compact cassette is in a plastic shell, which is itself inserted into a polystyrene case. Similarly, most CD's are sold in a polystyrene case. We postulate that the packaging of the compact cassette adds 30 grams of plastic use, and 60 grams for the CD. After including them to the proportionality factors for units sold in the RIAA data, we observe a stasis between 1973 and 1985 followed by a slow growth between 1985 and 1999, peaking above 80 kilotonnes per year in 1999. Such is the paradox of the plastic age for recorded music: its greatest dependency on the fossil industry coincides with the mass production of "compact" formats, i.e., cassette and CD.

IV. THE AGE OF DATA (2000–PRESENT)

In the previous section, we have quantified rebound effects in plastic use during Devine's "age of plastic" (1950–2000) in the history of recorded music. We now turn to ask whether our "age of data" (2000–) is susceptible to a similar kind of rebound effect for other resources besides plastic.

[4]The mass of BoPET in a C60 was deduced from density (1.39 g/cm³), length (90 meters), width (3.81 mm), and thickness (13 µm). The mass of BPA-PC in a CD was deduced from density (1.20 g/cm³), diameter (120 mm), thickness (1.2 mm), and hole diameter (15 mm). The mass of BPA-PC in a MiniDisc was deduced from density (1.20 g/cm³), diameter (64 mm), thickness (1.2 mm), and hole diameter (11 mm). Web sources : www.soundfountain.eu, www.nfsa.gov.au, www.retrostylemedia.co.uk.

A. The celestial jukebox: a rhetorical trap

The age of data may roughly be decomposed into two shorter periods: a decade of file sharing and legal downloads from 2000 to 2010 followed by music streaming since 2010. Admittedly, digital audio was already available for general consumption in the age of plastic, under the form of CD's. Yet, the use of CD's requires a dedicated object, the CD player, which in turn determines a certain mode of use, thought, and lived experience. In comparison, the functionality of MP3 decoding does not have an immediately visible or tangible manifestation.

Paul Goldstein, a professor at Stanford Law School, is widely recognized for his 1994 textbook *Copyright Highway: From Gutenberg to the Celestial Jukebox*. Goldstein's celestial jukebox is far more graceful and self-effacing than the datacenters of today: it consists of a single "technology-packed satellite, orbiting thousands of miles above the Earth, awaiting a subscriber's order" [10, p. 199]. The music industry has retained this Utopian discourse of weightlessness, one in which streaming is presented as an act so innocent and unintrusive as to be akin to stargazing.

For Devine, the confusion between invisible and immaterial is a "rhetorical trap" which has been fallaciously entertained by the music industry and the tech industry alike. In *Decomposed*, he insists upon the materiality of digital music consumption, from submarine cables to datacenters and playback terminals:

> The so-called cloud is a definitely material and mainly hardwired network of fiber-optic cables, servers, routers, and the like. Even the aspects of digital streaming that seem most immaterial - including digital files themselves as well as the electromagnetic waves that travel to personal listening devices from local wireless routers, cell phone towers, or satellite dishes- are in fact only invisible. Digital music streaming in undeniably material, and it requires both a lot of energy and a lot of labor. To think otherwise is to be fooled by the commercial rhetoric of streaming and cloud computing, to underestimate the material infrastructure and energy usage of data processing, and to misunderstand their consequences. [1, p. 131]

B. Weightlessness of digital music in marketing slogans

Initially, digital music arose to mass consumption via a promise of weightlessness, allowed by ever denser information storage and by miniaturization of computing hardware. The slogan of Apple for its first iPod promotional campaign is "1000 songs. In your pocket", which we could interpret as "more CD playing time than your pocket can hold". And indeed, returning to Table I, one thousand songs translates to more than one kilogram of plastic in CD format, packaging not included.

Relatedly, in 2007, the slogan for the iPod shuffle 2G was "put some music on". Anonymous torsos are seen unzipping a jacket, folding a scarf, slipping a T-shirt above their necks. For each character and each outfit, the digital device is gently pinned to the garment in a split second. The video offers a sensation of fluidity between gender expression, skin color,

TABLE I

CODING EFFICIENCY OF AUDIO RECORDING FORMATS. SEE SECTION III-A FOR DETAILS.

Medium of substrate	Year	Recording substrate substrate	Mass of substrate	Playing time	Coding efficiency per gram
Phonograph record (12", $\sim$78 rpm)	1897 (Deutsche Grammophon)	Shellac	$\sim$300 g	$\sim$8 minutes	$\sim$2 seconds
LP (12", 33 rpm)	1948 (Columbia)	PVC	$\sim$120 g	$\sim$46 minutes	$\sim$23 seconds
EP (7", 45 rpm)	1952 (RCA Victor)	PVC	$\sim$60 g	$\sim$15 minutes	$\sim$15 seconds
Compact Cassette tape (C60)	1963 (Philips)	BoPET	$\sim$6 g	$\sim$60 minutes	$\sim$10 minutes
CD	1982 (Sony, Philips)	BPA-PC	$\sim$16 g	$\sim$74 minutes	$\sim$4.5 minutes
Hi-MD (ATRAC3+ 48 kbps)	2006 (Sony)	BPA-PC	$\sim$4.5 g	$\sim$45 hours	$\sim$10 hours

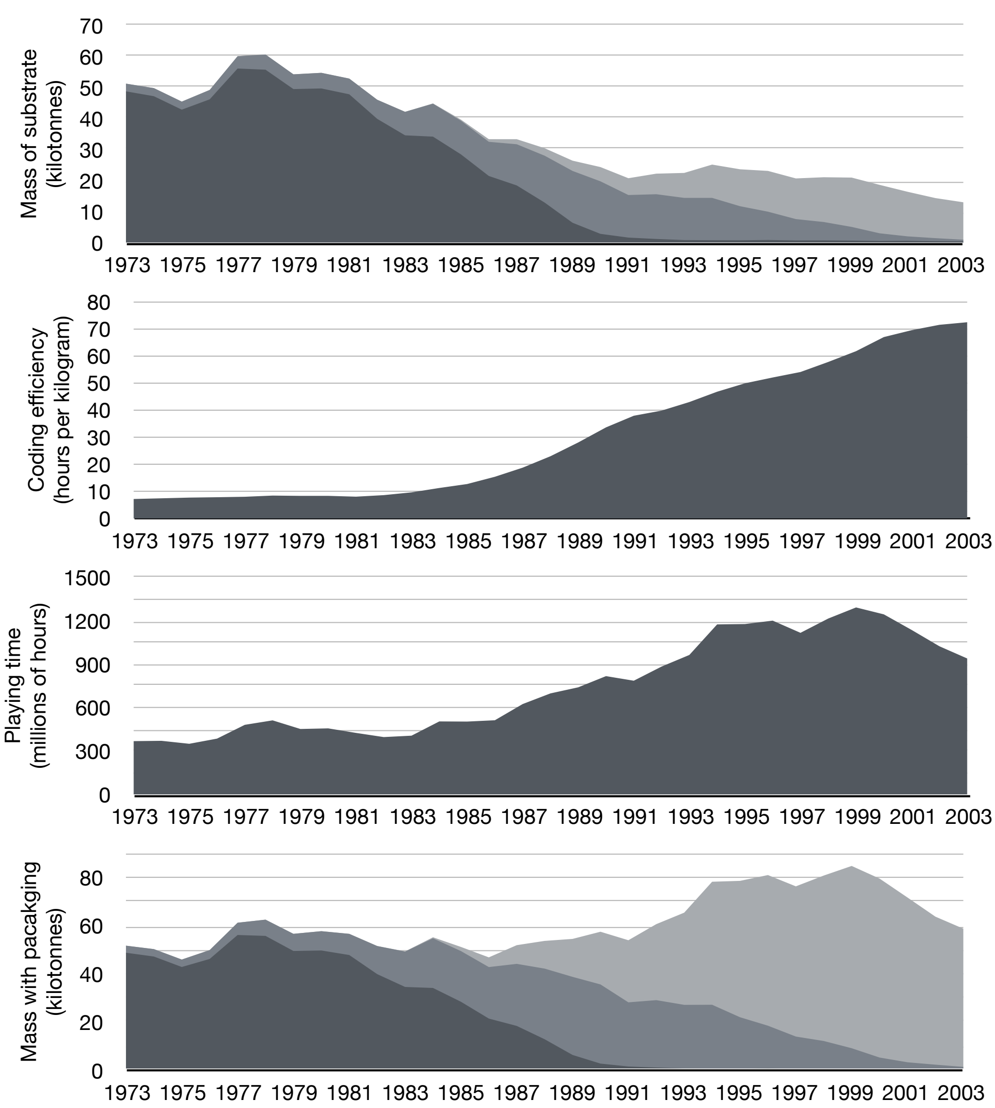

Fig. 1. Evidence of rebound effects on the US market of recorded music between 1973 and 2003. Direct effect: the decrease of mass of substrate (a) is not as drastic as the improvement in coding efficiency (b) due to a growth in playing time (c). Indirect effect: the presence of plastic packaging in cassettes and CD's adds to the mass of substrate, thus causing a rebound in plastic use in the 1990's. Dark gray: vinyl (LP and EP). Medium gray: compact cassettes: Light gray: compact discs. Original research from RIAA sources.

and attire—from leather to sportswear and from crop top to raincoat. In this ever-changing flux of human bodies, the only stable element is the pair of earplugs, always on display.

The promotional campaign for the Apple Watch (2020) is an in-joke for early adopters of the iPod. It follows the linguistic pattern of the 2001 slogan, "1000 songs in your pocket", and updates it to "60 million songs on your wrist". From download (2001) to streaming (2020), the technology has changed but the marketing argument of weightlessness remains intact, and even emboldened. The Apple Music streaming service is presented as a kind of superpower, one that grants watch-wearers with colossal arm strength: 60 million songs, or 3 million hours of playing time, would roughly translate to 18 kilotonnes of cassette tape, 40 kilotonnes of CD, or 470 kilotonnes of vinyl.

C. Multimateriality and risks of shortages

The symbolic connotation of digital music devices as weightless is starkly at odds with the massive amounts of material resources which are necessary for their manufacturing. According to the Fraunhofer Institute, out of 34 different elements which are needed to make a smartphone, 11 are not produced in sufficient quantity to meet the demand of emerging technologies by 2040— see [11] (in German). For example, lithium is in great demand to make batteries for smartphones, but also for electric vehicles. Another example is ruthenium, which is involved in giant magnetoresistances (GMR). The aforementioned study predicts an annual demand for ruthenium of 630 tonnes in 2040, compared to an annual production in 2018 of 12 tonnes.

From the above, it appears that the gains in coding efficiency and form factor which have been achieved by smartphone manufacturers are predicated on the availability of numerous materials, some of which are exposed to chronic shortages. If these shortages are poorly anticipated, they will cause compatibility breaks and therefore accelerate the obsolescence process. The social and geopolitical aspects of the market of rare metals are inseparable from its ecological aspects, and understanding them as a whole is crucial for the sustainability of digital music as a technological infrastructure [12].

We find suggestive evidence for a rebound effect in energy use. On one hand, decoding audio from flash memory, as opposed to from a CD, improves energy efficiency, since there is no need to spin the storage medium anymore. On the other hand, "as the Jevons effect predicts, the miniaturization of music formats and their increased energy efficiency are offset by massifications of devices and listening" [1, p. 134].

Unfortunately, current rebound effects of digital miniaturization in the age of data are far more difficult to analyze than past rebound effects of compact formats in the age of plastic, as we did in the previous section. This is, in no small part, because the age of data is an age of *multimateriality*: plastic, metal, glass, and more. Multimateriality in a single object is concurrent with a diversification of playback terminals, and with the coexistence of digital objects with media from the age of plastic. Just like oil has not entirely replaced coal, streaming and downloading have not entirely replaced vinyls, CDs and cassettes [13]. Under these factors, there is not one but multiple potential rebound effects, both of direct and indirect kinds.

D. From resource network to discourse network

Yet, the complexity of the age of data should not mislead us into thinking that its rebound effects are without remedy. As the name implies, rebound effects are not *ex nihilo*: they have causes. Furthermore, these causes are political through and through. "Every resource network is a discourse network", writes Devine [1, p. 24]. Hence, in addition to describing the conditions of a political ecology of music, we shall critique "a particular conception of music that encourages us to take those conditions for granted in the first place" [1, p. 21].

With this goal in mind, we point out that streaming platforms tend to download the same music repeatedly on behalf of the user and unbeknownst to them. Meanwhile, the number of streams per song per user is automatically logged as metadata, allegedly for reasons of content recommendation and artist compensation only. Yet, in recent years, we have observed that this networked practice of music accounting has become a key element in the marketing campaigns of streaming platforms. In doing so, they radicalize the user interface of Apple's iTunes (2001), which keeps a count of the number of times a song is played on device. In December 2018, as part of its yearly Wrapped campaign, Spotify has summarized the individual listening history of over 7,000 users and displayed it on giant screens in the UK, USA, Canada, France, and Australia. The precision of the number ("Minutes listened: 43,726") contrasts with the evasiveness of the text ("Top genre: Pop").

This precision is sometimes formulated as a kind of athletics ("you have reached a peak on October 8th at 492 minutes"), going as far as to praise the user as member of a social elite ("you are in the top 1% of fans"). In return, the user is incentivized to share their high achievements on social media, under the form of a "story" of time-limited clips. A personalized button suggests to thank one's favorite artist for having streamed the same song on repeat all year long.

Another campaign by Spotify, known as *Thanks, It's Been Weird*, reports the streaming habits of a fictional user with disturbing precision and ends with a sarcastic question: "dear person who played 'Sorry' 42 times on Valentine's Day, what did you do?". The premise is that repeated playback over a short time span is a fundamental trait of human nature, something mildly embarrassing but ultimately worth celebrating.

The precision of these numbers becomes even more uncanny once aggregated them across multiple users. "More than 165,337,002 streams for Chris since 2018": the possibility to track an artist's career down its least significant digits entertains a discourse which aims for the greatest possible magnitude of mechanical reproduction. And indeed, algorithms in business analytics offer a central role to aggregated streaming usage data in investment strategies of recording labels.

V. Looking forward

Even so there is tentative evidence in favor of the existence of rebound effects in the age of data, both direct and indirect, their magnitude remains to be determined. Unlike for the age of plastic, for which we have been able to quantify resource use with sufficient precision, we lack the confidence to make a precise statement about the sustainability of the age of data as a whole. In this last section, we present four open questions explaining why this is the case.

A. When is it worthwhile to store in cache?

According to the International Federation of the Phonographic Industry (IFPI), the global average listening time was 20.7 hours per week in 2023, compared to 20.1 hours per week in 2022. Nevertheless, even so it is technically feasible to store liked songs in cache, streaming applications remain opaque regarding its effects. Downloading a playlist is an opt-in, and the cache is presented as "temporary files that Spotify stores for a faster experience in slow networks"; i.e., as an improvement in the quality of service and not as a reduction of ecological impact. With Deezer, the inclusion of local files is limited to premium subscribers, with a cap of 2,000 songs. In other words, the monetary incentive is *against* sustainability, because streaming the same song repeatedly is free of charge whereas using the local version is for a fee.

In 2019, environmental scientists Sharon George and Deirdre Mackay have estimated that "streaming an album over the internet more than 27 times will likely use more energy than it takes to produce and manufacture a CD" [14]. Yet, digital music platforms do not incentivize their users to replace on-demand streaming by legal download, let alone by pre-MP3 formats. At the very least, they could integrate carbon tracking features inside their interfaces, i.e., the possibility for users to estimate their CO_2 emissions of a given song, at a given time, on a given device, with a given IP address.

B. What is the impact of record companies?

In addition to streaming platforms, record companies are also complicit in a global systemic risk of rebound effects for digital music. This complicity is apparent in the marketing strategy of "deluxe" box sets which typically combine multiple plastic formats. For example, in 2024, Warp Records have released an expanded edition of Aphex Twin's Selected Ambient Works 85–92. While the original edition (1994) was released as either double CD, double cassette, or triple LP, the anniversary edition has all of triple CD, double cassette, quadruple LP, and digital download. In this case, one may argue that the multiplication of formats is not *in spite of* streaming, but *because of* streaming—see [15] (in French). Even so record companies have a role to play towards making digital music more sustainable in the age of data, their coordination with IoS scientists remains unclear.

C. Are rebound effects still a useful concept?

First, the multimateriality of digital music is at odds with the classical theory of rebound effects, as theorized by Jevons. Indeed, the reasoning of Jevons was based on the consumption of one single resource: namely, coal. On the contrary, the infrastructure of digital audio depends on a myriad of material and energetic resources of unequal spatial availability and supply. Thus, the situation is far more complex than it was for the steam engine in the age of Jevons, or even on plastic in the age of discs and cassettes: the risk of shortage is not concentrated on a single resource but spread out over multiple ones. In a sense, the very notion of rebound effect finds its explanatory limits in the Internet of Sounds, a sector in which innovation aims toward multiple definitions of efficiency at once, some coming at the detriment of others. Over 150 years after *The Coal Question*, another framework is needed to understand the benefits and damages of energy-efficient algorithms and devices for digital audio processing [16].

D. Where to find reliable sources?

Another hurdle resides in the reluctance of platforms to communicate to the public about their dependency on energetic and material resources. In *Decomposed*, Kyle Devine points out that "database providers and streaming services are not forthcoming about their actual energy consumption, making it difficult to compare streaming with earlier formats" [1, p. 147]. Likewise, when the French national Center for music (CNM) launched an investigation on stream manipulation, only three platforms agreed to share their stream counts for 10,000 tracks: Qobuz, Deezer, and Spotify. YouTube, Apple Music, and Amazon did not comply [17]. This example illustrates that the sustainability of digital music is not purely, or even primarily, a scientific issue. It is a political issue calling for sustained and coordinated action from the IoS community.

VI. Conclusion

In this paper, we have contributed to the environmental history of recorded music in the wake of Kyle Devine's 2019 textbook, *Decomposed*. For this purpose, we have recalled the main takeaways from a founding text in environmental economics: *The Coal Question* by William Stanley Jevons (1865). Even so Jevons makes no mention of the greenhouse effect caused by carbon dioxide, nor of the health hazards of coal fumes, its political underpinnings foreshadow the notion of sustainability:

> Our duties wholly consist in the earnest and wise application of [material wealth]. We may spend it on the one hand in increased luxury and ostentation and corruption, and we shall be blamed. We may spend it on the other hand in raising the social and moral condition of the people, and in reducing the burdens of future generations. Even if our successors be less happily placed than ourselves they will not then blame us. [8]

In light of *The Coal Question*, we have adopted a modernized definition of rebound effects, encompassing "direct" and "indirect" kinds. Having replicated the methodology of Devine in search of rebound effects, we have charted two important and lesser-known consequences of the compact disc: the growth in total playing time sold per year and the growth in plastic use due to packaging. Then, we have compiled suggestive evidence of rebound effects in the "age of data" for music, i.e., via Internet download and streaming. We have also shown that the digital music industry is enacting a discourse of innocence and weightlessness which is dangerous to the sustainability of the sector as a whole. However, the paradigm of the Jevons effect cannot be straightforwardly applied in an era where playback devices do not consume *one* but *multiple* resources, hence widening the risk of shortage and accelerating obsolescence.

In this context, future research is needed to dispel the uncertainties which are cast on music technologists, artists, and listeners alike. Only through a new kind of interdisciplinarity between computer sciences, social sciences, and Earth sciences can such timely challenges be duly addressed.

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