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Towards digital sobriety: why improving the energy efficiency of video streaming is not enough

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Abstract—IPCC conclusions are unequivocal: we must divide our greenhouse gas emissions by two before 2030 if we want to maintain the global warming below 1.5°C in 2100. Hence, it becomes urgent to aim sobriety. Contrary to what is often claimed, digital technologies must also target global emission reduction, as their impact on the climate is huge and exploding every year. Among the digital world’s emissions, those related to video processing and streaming are significant. At the same time, a lot of research efforts are currently done to reduce the energy consumed by video transmission algorithms or infrastructures. In this paper, we demonstrate that, even though such research works are crucial, they are not sufficient to enable global video streaming emissions reductions. The conclusion is that we must collectively think of other complementary solutions.

Index Terms—video streaming, global warming, energy reduction, rebound effect

I. INTRODUCTION

Contrary to popular belief, the digital world *is not* intangible nor dematerialized. According to [1], its emission of greenhouse gas (GHG) corresponded to 4% of the global world emissions in 2019 (equivalent to the world air traffic), and this percentage could be doubled in 2025. Concretely, this GHG emission is due to (i) the energy consumed by the data centers (19%), the network (16%) and the terminals (20%) but also due to (ii) the production of computers, TVs, smartphones (45%). Online video streaming takes a significant part among these emissions. In 2018, online video streaming constituted 60% of the global data flow, and, by itself, generated 1% of the global emissions [2] (as much as a country like Spain emits). And this quantity explodes: video traffic is estimated to grow by 79% between 2021 and 2027 [3].

At the same time, the sixth report of the Intergovernmental Panel on Climate Change (IPCC) [4] states that if we want to keep the global warming under 1.5°C (Paris agreement), one should target a global emissions decrease of 50% when compared to those of 2019. This corresponds to a decrease of 7.6% per year [5]. They also state that *this is not the path that is currently taken*. Hence, every part of our society must urgently aim sobriety. This is for example the case of online video streaming. So the question is simple: what are the solutions that should be envisaged to halve by 2030 the GHG emissions due to video streaming ?

As these emissions are correlated (not necessarily proportional) to the video data flow, one could rely on the progress of video compression algorithms to decrease the size of every

individual video. For example, the last H.266/VVC standard reaches 50% of gain when compared with the previous codec H.265/HEVC [6] published 7 years before. Even though similar gains can be expected for the future codec, this cannot, by itself, enables a drastic emissions reduction, because of at least three reasons. First, the size reduction is achieved on individual videos and not on the global flow. In other words, video compression does not fight against the number of videos that is created or consumed. Yet, this amount of video streamed will explode in the coming years [6]. Second, compression gains are usually not exploited to decrease the required bandwidth but rather to increase the video resolution or to create new video usages (IoT, Virtual Reality, etc.) [6]. Last, compression gains are achieved only at the expense of huge algorithm complexity. Encoding a video becomes more and more complex and thus requires, for each codec, more energy [7], [8].

Another cause of video streaming gas emissions is precisely the complexity of the operations all along the transmission chain (including the video coding algorithms as mentioned just above). Intensive research efforts have been made to decrease this complexity and thus the consumed energy. Without sake of completeness, works have been conducted to improve energy efficiency of 5G/6G [9]–[12], routing protocols [13], [14], video encoding/decoding [15]–[19], display [20].

Even though these research results are crucial and make the energy expenditure more optimized, we demonstrate in this paper that this is insufficient to achieve the goal set by the IPCC. We build a simple model inspired by [21] and derived from the Kaya identity. This model enables to compare the order of magnitude of the energy reduction on one side and the digital affluence on the other side. Results show that even drastic energy reduction cannot cope with the forecasted video data flow explosion.

II. METHODOLOGY

In [22], Kaya *et al.* proposed a model stating that the global carbon footprint can be expressed as the product of four factors: population, affluence, expressed in Gross Domestic Product (GDP), energy intensity (per unit of GDP), and carbon intensity (GHG emissions per unit of energy consumed). Even though the limitations of such simple model have been largely discussed, this formulation enables to express the carbon footprint with readily available data, highlighting at the same

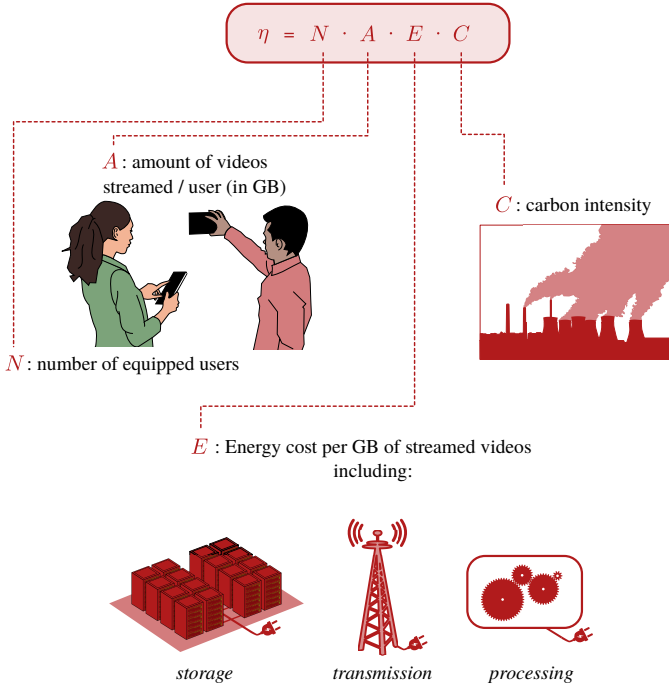


Fig. 1. Rough video streaming carbon footprint modeling inspired by the Kaya identity.

time the elements on which one could act to reduce emissions. This model as been employed by the IPCC for its report in 2000 [23].

Recently, Bol *et al.* has adapted this model to evaluate the Information and Communication Technology (ICT) carbon footprint evolution [21]. In their model, the economic factors have been avoided, and the four above factors have been reformulated such that they focus on the ICT sector. In our paper, we go one step further by restricting the model to the video streaming emissions evaluation. The proposed formula is illustrated in Fig. 1. In this formula, the GHG emissions of video streaming η is expressed as:

$$\eta = N \cdot A \cdot E \cdot C \quad (1)$$

◊ *The population* is denoted by N and corresponds to the amount of people who are equipped with a device able to create or watch a video online (e.g., mobile, computer, tablet).

◊ *The “video affluence” per user* is denoted by A . It corresponds to the amount of video data streamed by user, expressed in GB.

◊ *The video streaming energy intensity* E corresponds to the energy needed to stream 1 GB of video data, expressed in kWh. This is the factor on which video streaming energy optimization can operate.

◊ *The carbon intensity* C indicates the amount of GHG emitted for one kWh of consumed energy.

This simple model is not intended to be used to estimate the magnitude of the global emissions, but rather their evolution over time. Concretely, we define α_N , α_A , α_E and α_C the

evolution coefficients for each of the factors between time t and $t - 1$, i.e., the Compound Annual Growth Rate (CAGR). The global evolution can be now expressed recursively as:

$$\eta(t) = N(t) \cdot A(t) \cdot E(t) \cdot C(t), \quad (2)$$

where

$$N(t) = \alpha_N N(t - 1) \quad (3)$$

$$A(t) = \alpha_A A(t - 1) \quad (4)$$

$$E(t) = \alpha_E E(t - 1) \quad (5)$$

$$C(t) = \alpha_C C(t - 1). \quad (6)$$

III. SCENARIOS AND RESULTS

We now simulate the emissions based on the model in (2). For the number of equipped users N , we take the evolution of the number of internet users. In [24], the CAGR of internet users is estimated at 6% between 2018 and 2023. For the video affluence A , we take the forecasted CAGR of the Mobile data traffic per smartphone between 2021 and 2027 estimated at 24% [3]. For the carbon intensity factor C , we take an optimistic CAGR of -1% [25].

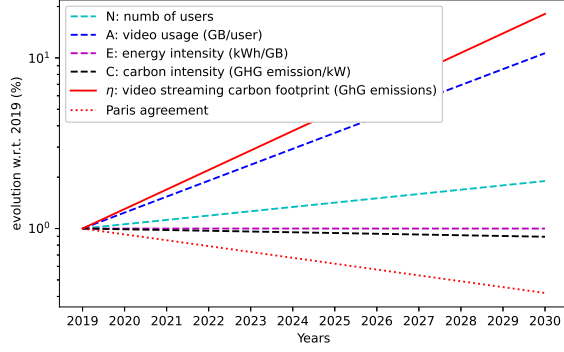
For the energy intensity E , we consider different scenarios, from the most pessimistic to the most optimistic, as seen in Fig. 2.

◊ **S1 (no energy saving):** $\alpha_E = 1$. This scenario is pessimistic in the sense that it does not consider the huge research effort dedicated to energy efficiency optimization in video streaming. Another way to see it, is that each gain of energy is annihilated by another increase in energy. This is for example what may happen if video compression gains are achieved with extremely high encoding complexity. We can see in Fig. 2(a) that this worst case scenario leads to an explosion of the GHG emissions (multiplied by ten between 2019 and 2030).

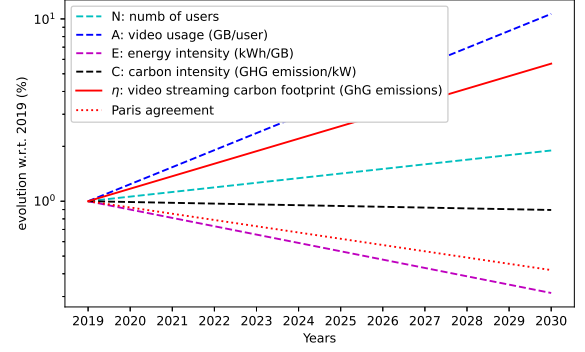
◊ **S2 (realistic energy saving):** $\alpha_E = 0.9$. This take into account the energy optimization initiatives, by considering a realistic energy decrease. Even though it is hard to consider what is realistic or not, this CAGR enables in 10 years to decrease the energy by more than 50%. This is typically the kind of gains that are achieved for video compression in a same period of time [26]. Unfortunately, this scenario depicted in Fig. 2(b) also leads to a GHG emissions explosion.

◊ **S3 (optimistic energy saving):** $\alpha_E = 0.8$. In order to go further, we now consider a scenario that bet on (super) optimistic energy savings: every year the video streaming energy decreases by 20%. This means that in 2023, the energy necessary to stream one GB corresponds to only 10% of the one in 2019. We can see in Fig. 2(c) that even with such gigantic gain, the GHG emissions is not stabilized and still slightly grows.

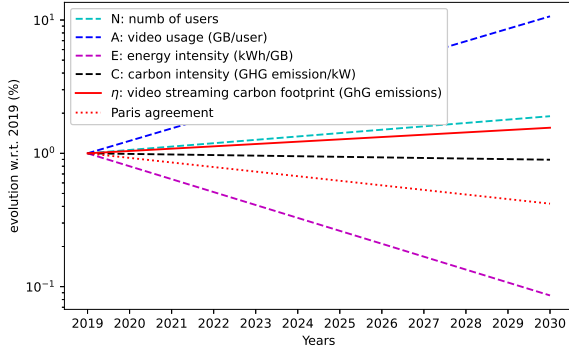
◊ **S3 (unrealistic energy saving):** $\alpha_E = 0.7$. We have finally considered a scenario with an energy intensity sufficiently decreasing to fulfill the Paris agreement (see Fig. 2(d)). It corresponds to the unrealistic decrease of 30% per year, which means that in 2023, the level of energy necessary to stream one GB corresponds to only 1% of the one in 2019.



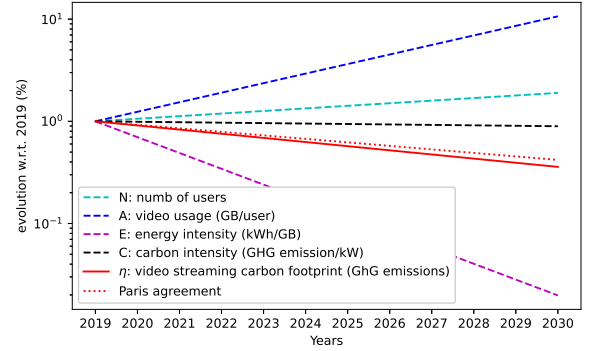
(a) $\alpha_E = 1$



(b) $\alpha_E = 0.9$



(c) $\alpha_E = 0.8$



(d) $\alpha_E = 0.7$

Fig. 2. Evolution of GHG emissions due to video streaming for different scenario of yearly energy saving α_E .

At this stage, we must emphasize the simplicity of the considered model. With the aforementioned curve, we do not intend to propose an accurate GHG emissions evaluation, as the complexity of the chain requires more evolved models [27]. Another very important limitation is that this model neglects the rebound effect (the fact that energy saving may accelerate the video data consumption explosion). However, this model still enables to put the energy efficiency optimization efforts in perspective with the growth of video usage per user. And the conclusion is clear: the video affluence (the amount of video data streamed per user) grows much too fast. This is the reason why, we explore in the next section, the case where video affluence is limited or decreases.

IV. LIMIT THE VIDEO AFFLUENCE

As seen in the previous section, optimizing the energy intensity E is not enough to achieve the GHG emissions decrease of Paris agreement, mostly because a too big increase of video affluence A . Let us now study scenarios in which the video affluence is limited, or even decreased. This cannot be achieved with technology improvement, and is only possible thanks to laws or regulations (as it is claimed by some actors [2]).

In Fig. 3(a), we simulate the case where a decision have been taken to limit the video affluence at its nowadays level. In parallel, the realistic energy saving of scenario S2 are pursued.

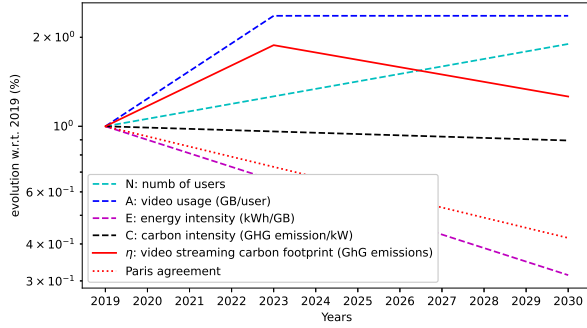
In that case, the GHG emissions decreases, but not enough. In 2030, we don't even achieve the level of 2019's GHG emissions.

In Fig. 3(b), we go further, and we consider a regulation rule making the video affluence decrease by 10% every year. We can see that, with again the energy saving of scenario S2, the Paris agreement objectives is achieved in 2030. In this scenario, the amount of allowed video data streamed per user is decreased when compared to the one in 2019.

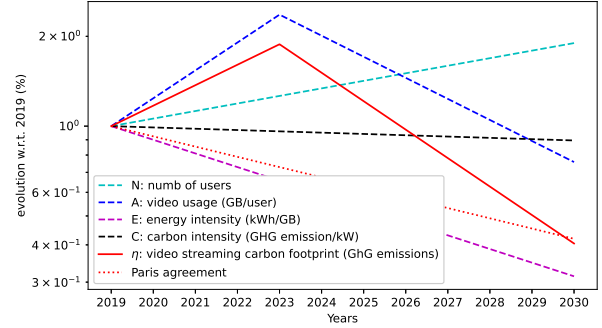
Once again, the simplicity of the model prevents us to use it as an accurate forecast. However, it shows that, if energy optimization is not sufficient by itself to decrease GHG emissions, it becomes interesting and crucial when completed by, for example, laws and regulations restraining the allowed amount of data per user.

V. CONCLUSION

In this paper, we have studied the effect of the numerous methods performing energy optimization over the video transmission pipeline. We have shown that the forecasted explosion of the amount of data per user annihilate such efforts. To achieve Paris agreement objectives (half emissions in 2030 when compared to 2019), the academic, industrial and politic actors must also consider laws and regulation to limit the video data consumption.



(a) $\alpha_A = 1$ after 2023



(b) $\alpha_A = 0.9$ after 2023

Fig. 3. GHG emissions for the case when video affluence A is limited or is decreased. This simulation is run for the realistic scenario S2 of energy saving.

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