ON THE SUSTAINABILITY OF DIGITAL MEDIA

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Abstract:

In the need to keep up with rapid innovations individuals and enterprises are urged to connect to the largest global computer network comprised of billions of interconnected devices, servers, and the underlying infrastructure. Most people are aware of the fact that the digital world has a significant environmental impact. This awareness drive the efforts of companies and organisations to make a good impression in this aspect as well. The World Wide Web Consortium recently introduced Web Sustainability Guidelines to make web products and services more sustainable. Efficiency indices were created and standardised to quantify data centre's total power effectiveness. It has a high marketing value wether the infrastructure runs on clean energy. Stakeholders of the internet seem to be willing to take efforts towards the usual goals of environmental awareness. The the concept of sustainability is multifaceted and so is digital media's sphere of influence. The UN sustainable development goals may provide a comprehensive framework for evaluation, the supportin institutions generally look positively on the impact of digitization and digital media regarding society and economy. Although sustainability has a wider scope than just the environment, putting prosperity and people before the planet would be a backward step. This study aims to highlight crucial aspects and trends that may direct ICT developments, including digital media, towards a more sustainable future.

Keywords: *sustainability, digital media, word wide web, energy efficiency*

1. INTRODUCTION

In the 1999 movie The Matrix humans live a passive life lying in their pods with their minds interfaced to a virtual reality world. A quater of century later we may interpret this as a sinister allegory for new generations to come. In the movie the ecosystem of artificially intelligent machines lives on the energy harvested from human bodies. Today in modern societies people do not have to have their bodies exploited as batteries, yet they contribute with a considerable amount of resources to the digital infrastructure which becomes fundamental for entertainment, work and everyday life. The development of the digital framework is quantitative and qualitative simultainously, more and more people access the improving services of the digital platforms.

Indeed, technological progress has the greatest impact on our lives. Within this, technological development over the past decade or two has been understood almost exclusively in terms of the expansion of the capacity of information and communication tools and networks and the deepening of their integration. This dramatic change has had a fundamental impact on our economic structure, social relationships and cultural relations. The ICT development is one-sided, seemingly unstoppable, and planetary, global networks shape our view on our personal future. We have become passive and reluctant recipients of technology, rarely questioning its expansion, with critical interpretations hardly ever appearing in public discourse. One exception is the perspective of sustainability, which is a fashionable ideological trend of our time.

Sustainability is often interpreted as the balanced mixture of the three primaries: environment, society and economy. The concept also involves meeting the needs of the present without compromising the future. The impact of the ICT development on society and economy is impressive but difficult to characterize in terms of quality due to its fast sweeping nature. For example we have very little control over social media companies, or people using their products. The impact on environment has direct and indirect, positive and negative components. A direct negative factor is the increasing energy

consumption and carbon footprint of the evolving infrastructure. An indirect positive impact are efforts and investments toward digital innovation that accelerate environmental and social sustainability.
The latter is included in the Action Plan of the UN Coalition for Digital Environmental Sustainability (CODES) [1]. It supports the 9th UN Sustainable Development Goal (SDG): Industry, Innovation and Infrastructure. The SDG framework has 17 goals detailed in 169 targets providing a roadmap for governments, businesses, and individuals to foster sustainable development [2]. Novel technologies can support certain sustainability goals, but they can also threaten others. Similarly, digital media can contribute to achieving a number of SDGs. Hunger and malnutrition can be reduced (SDG 2) by making agricultural practices more data-driven and efficient, to increase crop yields and reduce the use of energy. Direct patient care, health informatics contribute to good health and well-being (SDG 3). Improved connectivity promotes quality education and skilled workforce (SDG 4) also the closing of the gender gap (SDG 5) by digital access to jobs and education from home while reducing inequalities (SDG 10) by extending access to technologies and knowledge to disadvantaged groups of society [3]. While the big picture looks promising it is worth to look what is hiding in the details.

2. DISCUSSION

In the following section I would like to highlight a few diverse topics that are closely related to the sustainability of digital media. Processing units of the underlying infrastructure translate complex tasks into a sequence of fundamental binary operations which makes energy efficient computing a key factor. Modern tasks, e.g., big data, cloud computing, often require IT equipment to be concentrated in so-called data centers, where data is not only stored but also processed. These facilities have special energy requirements worth addressing because their number and significance are growing. The World Wide Web is fundamental to our digital activities, its development is diverse and offers a wealth of opportunities, thus it is important to know that guidelines were worked out for those who want to make it sustainable as well. And last but not least: artificial intelligence, which will definitely have a substantial impact and is already affecting all three dimensions of sustainability.

Computation costs energy

Advances in semiconductor fabrication brought forward dramatic increases in transistor density per chip. It resulted in exponentially enhancing processing power as well as energy efficiency. The former is often characterised by Moore's law: the number of transistors on a microchip doubles in every 18 to 24 months. Efficiency is addressed by Koomey's law which observes that the number of computations per joule (J) doubles also in about roughly 18 months [4]. Both laws slowed down in the past decade [5] as transistor sizes approaching a few nanometers thus physical limits, material constraints and other factors challenge development. From a sustainability perspective, it is desirable for operations to consume as little energy as possible, but is there an ideal value and how far are we from it at present?
It would be an overstatement to say that modern computing architecture technically consist only of NAND gates, but these logical gates (a combination of an AND gate and a NOT gate) are theoretically important for understanding the minimum energy requirement of computation. Any Boolean function can be implemented by using a combination of NAND gates allowing for the construction of any complex digital processing unit using type of logical gate only. Table 1 shows shows the outputs for the possible input combinations the 2-input NAND gate.

Table 1: Truth table of a NAND gate

Input		Output
A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0

Since the NAND gate has only one output, one of its inputs has effectively been erased in the process, whose information has been lost forever. The change in entropy that is associated with the lost of one bit of information is $ln(2)$, which, thermodynamically, corresponds to an energy increase of $k_B T\ ln(2)$, where k_B is Boltzman's constant and T is the temperature. Thus the operation of NAND gates will in theory and practice dissipate heat as a sign of physical irreversibility.
The above principle was named after Rolf Landauer, who proposed it first in 1961 as the minimum energy needed to erase one bit of information. The Landauer limit can be demonstrated under laboratory conditions, but modern transistors in a computing environment where performance matters consume energy several orders of magnitude higher than that. The Landauer limit sets the ceiling to how efficient classical computers may become, which may be approached as technology continues to advance, but it will not happen in the near future. [6]

Data centers

There are more than 12,000 data centers worldwide, about 10% of them are hyperscale data centers (often >1,000m2 and 5,000+ servers) with extreme scalability capabilities, often owned and operated by a single provider. In these facilities the vast amounts of GPU and CPU servers, storage systems, cooling, networking and UPS (to survive power outages or fluctuations) devices generate a power demand that is quite a challenge.
Deloitte forecasts that global data center electricity usage could nearly double from 536 terawatt-hours (TWh) - about 2% of global electricity - in 2025 to approximately 1,065 TWh by 2030 (3.7%). AI data centers' annual power consumption is roughly one-seventh of the predicted consumption of all data centers globally [7].
The concept of Power Usage Effectiveness (PUE) was introduced in 2007 in response to the demand for a consistent method to compare the energy performance of data center facilities. It compares the total energy used by the entire data center (IT equipment and support systems like cooling, UPS and lighting) to the energy used strictly by the computing equipment using a simple formula:

$$\text{PUE} = \text{Total Facility Energy} / \text{IT Equipment Energy}$$

The ideal PUE value is 1.0, in this 100% power is utilized by the IT equipment [8]. A facility that uses evaporative water for cooling will have a further impact on the environment by using water resources. Evaporative cooling consumes less energy, but significantly more water. The trade-off between water and energy use is addressed by introducing Water Usage Effectiveness (WUE) as a data center key performance indicator [9]. WUE is measured in cubic meters of water per megawatt hour of energy (m^3/MWh).
While DCs consume enormous amounts of power it is rewarding to invest into innovative cooling and renewable energy to reduce cost and environmental impact. Many big tech and cloud providers are investing in carbon-free energy sources demonstrating their commitment to sustainability and benefiting on the marketing side as well.
Nevertheless, two important observations must be added to the above. First, the global average PUE has been stagnating at around 1.5 for the past five years. In addition, note that PUE is a dimensionless quantity, a ratio of two energy values that does not indicate the specific quantity involved.

Efficiency of the World Wide Web

The Web infrastructure is the underlying framework of hardware, software, network systems or simply servers plus internet. There are a number of environmental consiserations regarding the architecture and operation of the indidvidual components of the framework.

Since big tech companies own and manage the lions' share of this infrastructure, it may seem, that there is little room for maneuver for web developers. But web power consumption is divided between the front-end (user device) and the back-end (servers and internet), and optimization on the front-end can reduce client-side energy consumption significantly. Also, a lot depends on how the web application uses back-end resources. Therefore the World Wide Web Consortium (W3C) colleted best practices to design and implement digital products, services and content to meet sustainability requirements.

The Web Sustainability Guidelines

The W3C adopted the PPP (Planet, People, Prosperity) principles of sustainability that includes protecting environmental ecosystems, individuals, communities, and society, and ensuring a good quality of life without crossing the boundaries of our planet.

The initiative is very similar to their previous achievement, the Web Content Accessibility Guidelines which explain how to make web content more accessible to people with disabilities. The implementation of the sustainability guidelines can have several benefits regarding economy, performance, security, privacy, environment, social equitiy, etc. Economic and performance benefits are direct motivation to carry out development in compliance with the guidelines.

The guidelines are organized into four groups: user experience design, web development, hosting, infrastructure and ecosystems, business strategy and product management [10]. The qoal of user experience design is to create efficient, relevant, functional and pleasant experiences for users. The Web Development section mainly addresses client and server-side software development. The goal is to obtain a code that runs faster, more efficiently and uses the least hardware resources. Guidelines about infrastructure and ecosystems help content, code, and data to be stored and processed in a sustainable way. A well-designed system will be resource efficient, save energy and reduce operational and investment costs. Business strategy and product management can be as important as technical considerations. High level strategic decisions can align company actions with the sustainability goals, if they are made by well-informed, aware and committed people.

The W3C recommends a "progress-over-perfection" approach when utilizing the Web Sustainability Guidelines. Indeed, the specification is long and comprehensive, but specialists can easily find and focus on their fields where they can introduce sustainability concepts step by step. The rest is just a question of commitment and persistence - provided that the energy saved here is significant compared to the demand of the underlying infrastructure.

The AI challenge

Most of us do not want a much bigger house or car than what we already have. But is there a limit to how intelligent one would like to be - especially when we consider the benefits that come with it? The rapid evolution of AI can be measured in months rather than years. Generative AI (Gen AI) produces media such as text, images, audio, video and animation by learning patterns from large datasets to create novel content. Gen AI investments demand so much electricity that global net additional power for AI data centers increased 25% the previous year [11]. While generally the electricity demand is growing at a relatively stable rate due to industrialization, electric transportation, the energy for AI is rising much more steeply. Its widespread application could unleash such a demand for electricity in the world that within years it could challenge electricity grids, which are already struggling due to the fluctuations of green energy.

At this stage of its development, it is transforming and restructuring the social and economic environment so swiftly and in such a complex way that it would be too early to perform an in-depth analysis [12]. There are plenty of well-founded optimistic and pessimistic ideas about this. However, its direct impact on the environment - the crucial factor of sustainability - is clearly negative due to its extraordinary energy requirements. The question is whether the knowledge and services created by AI can sufficiently reduce its overall environmental impact.

3. SUMMARY

The aim of this study was to draw attention to the side effects and downsides of the developments contributing to digital media, as well as to energy efficiency considerations that are often overlooked in a technological context. The minimum energy cost of computation can be theoretically defined by the Landauer principle. The Landauer limit represents a very small amount of energy, however modern computers consume several orders of magnitude more energy for single logical operation. The Web Sustainability Guidelines establish a framework to reduce the emissions of digital media by optimizing code, data, infrastructure and services. Followers of the Guidelines contribute to the creation of a faster, more efficient, user-centered and sustainable Web. Data centers concentrate energy guzzler hardware in facilities, which has a higher potential to become energy efficient than the IT equipment inside. Then AI infrastructure will far surpass the present scenario of environmental impact within a very short time. It is still spreading its wings, while the ambitious vision of tech companies, the intensive publicity and novel investment opportunities result in a driving force that foreshadows an enormously growing footprint.

In terms of sustainability, the environmental impact of digital media is perhaps the most significant, but its influence on the economy and society should not be underestimated either. Unfortunately, society's reaction time for innovative, game-changer technologies can be measured in years, remember the time it took to make laws that allow regulation of the use of cell phones in schools. It is reasonable to assume that with such an unprecedented growth rate of development, investment, and energy demand the interaction of the various trends can lead to unpredictable extremes even in a relatively short term.

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