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# When Good Enough is the Best Option: Use of Digital Sufficiency to Fight Climate Change

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**Abstract.** The ICT sector has seen many improvements in productivity and efficiency in the past decades. However, its total energy consumed, as well as its carbon emissions, has never decreased. This is mostly due to a systemic phenomenon called the rebound effect: although each process consumes less energy, the global increase in process usage results in an unexpected growth in carbon emissions. In this paper, we present energy-efficient techniques and we argue why it is necessary to combine efficiency with a new approach. This novel approach is digital sufficiency, involving users and developers to reduce the demand in addition to efficiency improvements.

**Keywords:** Climate change · Digital sufficiency · Sustainable computing

## 1 Introduction

Anthropogenic climate change fueled by the emissions of greenhouse gases such as carbon dioxide is a threat to human well-being and planetary health [5]. A recent report shared that there is a 50% likelihood to reach a 1.5°C increase above the 1850–1900 average if we emit at least 200 Gigatonnes of CO<sub>2</sub> (Gt CO<sub>2</sub>) after 2024 [2]. It will be achieved by 2029 at the current emission level.

The Information and Communication Technology (ICT) sector plays a major role in carbon emission, as we burn fossil fuels and emit carbon dioxide throughout the whole lifecycle of digital equipment and services, in addition to being a driving force behind human activities. New digital services (Artificial Intelligence, blockchain, IoT, etc.) are likely to boost the demand and increase carbon emissions in the next few years. In this paper, we argue in favor of sufficiency techniques, which aim to reduce this demand. An example of a digital sufficiency approach is approximate computing, where energy consumption can be reduced with a ‘good enough’ solution [9]. Our purpose is to provide an overview of the following points:

- Limitations of energy efficiency techniques to reduce carbon emissions.
- Challenges to apply digital sufficiency.
- Opportunities of digital sufficiency.

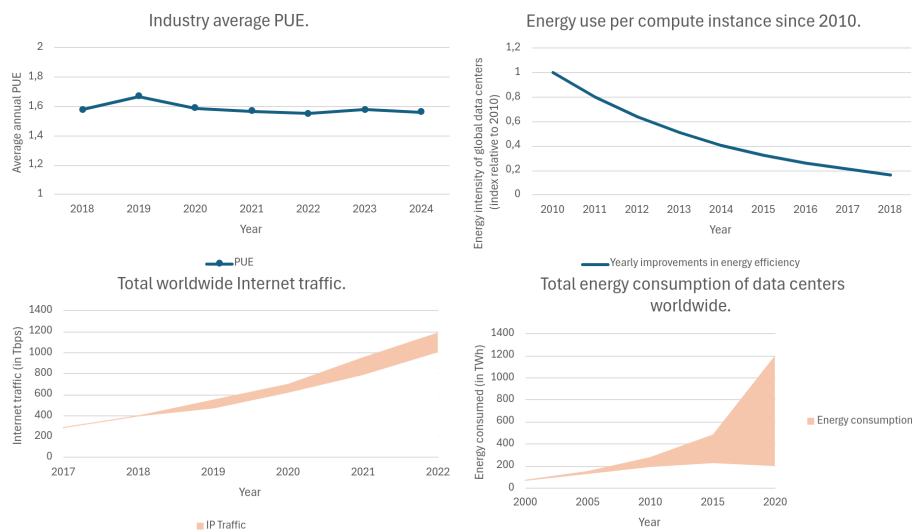
## 2 Limitations in energy efficiency improvements

Many improvements in energy efficiency have been achieved in the past decades. At the software level, we can mention the use of virtualization, workload balancing through consolidation and placement of virtual machines, data management strategies to optimize data placement, etc. At the hardware level, we can consider the use of low-power processors, dedicated energy-saving architectures such as Field-programmable Gate Arrays, accelerators such as Graphic Process Units, Dynamic Voltage and Frequency Scaling (that adjusts power and speed settings of resources to maximize power savings), the adoption of eco-labels to promote efficient energy use, etc. At the data center level, we can consider the adoption of cooling methods to reduce the heat generated by devices with air-conditioning, free cooling, liquid cooling, overhead, and underfloor air delivery technologies [1].

These combined techniques have certainly helped to limit the increase in electricity consumption, but there is no evidence that this trend will continue or accelerate to reduce carbon emissions. According to Freitag et al. [3], carbon emissions from the ICT sector have always increased to reach 1.8%-3.9% of global carbon emissions in 2021. This can be explained by the explosion of demand, faster than improvements per-device, which is called a rebound effect [8]. Rebound effects explain the increase in global energy consumed by the global increase in users and use. For instance, data centers are more efficient, and the energy used to compute a workload is lower, but as the Internet traffic and workloads to compute have grown faster, the overall energy consumption has increased.

In Figure 1, we illustrate both efficiency improvements and the consequences of increasing demand using four key measures. We depicted the evolution of the average Power Usage Effectiveness (PUE) of industries over the last few years, which represents the energy consumption of their IT equipment on the global infrastructure, the decrease in energy consumption per computing instance between 2010 and 2018, the increase in total internet traffic worldwide over the last few years, and finally the evolution of the energy consumed to power data centers worldwide. We elaborated these graphs considering data provided by [3] and other related reports.

We believe that it is necessary to apply new techniques to reduce the overall demand for current and future digital services. These new techniques are called sobriety or sufficiency techniques. This global concept was presented in the latest Intergovernmental Panel on Climate Change (IPCC) reports [5], and then adapted by Santarius et al. in the ICT sector as digital sufficiency [11]. Santarius et al. defined digital sufficiency as ‘any strategy aimed at directly or indirectly decreasing the absolute level of resource and energy demand from the production



**Fig. 1.** Trends in energy efficiency of ICT and Internet traffic worldwide.

or application of ICT'. Digital sufficiency is also used by the French community, such as the association 'The Shift Project' with their work on lean ICT, and by the French Environment and Energy Management Agency to present policy recommendations to businesses, local governments, and the general public.

### 3 Challenges

To reduce demand, we identified three main challenges. We need systematic assessments of the coming demand if we want to be able to act at this level. In addition, we need to be able to share with end-users, and/or developers, carbon emissions assessments to propose an alternative to encourage action. Finally, we must try to involve as many actors as possible, as this is a global problem, it is necessary to deploy it at the largest scale as possible.

#### 3.1 Challenge 1: Reducing the demand

Nowadays, most people are not necessarily aware of carbon emissions linked to the use of their IT devices, nor of the world's remaining carbon budget or the climate targets we are committed to achieving. This information is however necessary to act on the right scale. Santarius et al. identified in [11] that many of the current studies on sustainability do not include a proposal to reduce direct or indirect rebound effects.

In addition, improving the efficiency of the services solutions share a narrative that technology will be sufficient to reduce carbon emissions, without the need to reduce the demand [3]. Including the rebound effects assessment is a complex

task, and often involves many actors, but we argue that it is a necessity to reduce effectively carbon emissions.

### 3.2 Challenge 2: Assess carbon emissions

To assess carbon emissions of the ICT sector, the current usual solution is to use life cycle assessments (LCA), protocols (e.g., the Greenhouse Gas protocol), and measurement tools (with event counters or sensors like Intel RAPL, or with power meters). The challenges associated with assessing carbon emissions are the choice of method, the access to data from companies and users, and the heterogeneity of collected data. The margin of error is significant, depending on the scope of the assessment. Freitag et al. described this difficulty in their review with the example of ‘truncation error’: the partial exclusion of supply chain pathways leads to underestimation of the carbon footprint of ICT [3].

Monitoring and collecting accurate energy data in real time is also difficult with today’s devices and their various hardware architectures. Not all equipment includes sensors for collecting energy data or models for estimating usage. Kanso et al. show the possibilities of generating power models for appliances and equipment and the advantages of having an accurate power model for smart and non-smart appliances [6]. Due to this high variability and complexity, current assessments vary considerably [3]. The lack of reporting by researchers or companies increases the difficulty of providing accurate results and limits the reproducibility of experiments [7].

### 3.3 Challenge 3: Involve the user to apply user sufficiency

The current limitation to raising awareness of good behavior is to share good information with the user and suggest alternatives. When we give the user an estimate of carbon emissions, one has to bear in mind that this is only an estimate of CO<sub>2</sub> emissions, as we can only provide a forecast of the cost of a specific digital service [4]. This is a concern because users will never know the real impact of their use, and this might push them to act when it is not necessary. The feedback to users must also be accompanied by solutions which are not always available. End-users can be discouraged if they cannot change their behavior because of that, and might also resist change with high workload or when energy consumption is perceived as low, as analyzed in the study of Nouredine et al. [10].

## 4 Opportunities

Implementing sufficiency techniques offers many opportunities. These techniques are already available and they do not require revolutionary technology. Furthermore, ICT is currently not sustainable if we consider the limits of extracting non-renewable resources such as coal, fuel, rare metals, etc., to build devices, networks, and data centers. The application of sufficiency techniques is also a solution for increasing ICT sustainability beyond carbon emissions.

To implement sufficiency techniques, it is possible to set constraints on carbon emissions when developing efficiency techniques [12]. With this approach, the sector is more likely to reduce its emissions year after year, which will encourage demand reduction when energy efficiency improvements are insufficient. An example of sufficiency techniques is workload shifting in space and time. This concept includes a set of solutions to deploy digital services where and when there is available renewable energy, with a negligible impact on the quality of service provided to the users. For example, Wiesner et al. have estimated a 20% saving in carbon emissions in most regions of the world by shifting part of the workload to weekends [13]. Another example is the approximate computing paradigm, which accepts a good enough solution to save resources and energy [9].

To involve users in changing their behavior, Nouredine et al. [10] proposed three techniques inspired by the building sector: social interactions (comparing users' energy consumption), gamification (involving people emotionally with interactive games), and eco-feedback (providing energy consumption indicators to users). Labels such as energy scores are also good examples of feedback to influence users' choices towards energy-efficient products. Guyon et al. proposed their own ecolabel 'GLENDa' (Green Label towards Energy proPortioNality for IaaS DAta centers), combining Power Usage Effectiveness (PUE) and Green Energy Coefficient (GEC) to push cloud providers to do more for greener data centers and helping energy-conscious users to choose among cloud providers [4].

## 5 Conclusion

We argue the urgent need to adopt a 'sufficiency' attitude with actions and policies to reduce carbon emissions. We reviewed some of the energy efficiency solutions implemented over the last few decades and their limitations in terms of reducing carbon emissions. In particular, we have identified the need to implement sufficiency techniques aimed at reducing demand to limit rebound effects. Implementing digital sufficiency techniques faces several challenges: the complexity of assessing the carbon footprint of digital services, the lack of consideration for rebound effects in current literature, and an absence of coordinated action in favor of reducing demand in ICT. To enable the use of sufficiency techniques, we support the need to develop and use monitoring tools with understandable metrics to raise awareness of end-users and developers, and to involve users with positive feedback. Suitable data management techniques are needed to help people to take decisions. As this decade is crucial for tackling climate change, sufficiency techniques represent a good opportunity, as they are already available and will contribute to increasing the sustainability of ICT.

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