PERFORMANCE INDICATORS THAT ALLOW

TO TRACK OVERPRODUCTIVITY AND DIGITAL POLLUTION.

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INTRODUCTION

"Dangerous abuse for the planet". Could such a warning apply to digital technology? While this question may seem provocative, it reflects the reality of the environmental impacts generated by the digital sector. Digital pollution includes the various harmful effects generated by information technologies: greenhouse gas (GHG) emissions, massive production of electronic waste, excessive energy consumption, and degradation of ecosystems. In a world where big data and technological innovations dominate our daily activities, these issues require increased attention.

Context and challenges of digital pollution

Digital technology is a fast-growing sector, driving innovation and economic transformation. It is perceived as a lever for optimizing and dematerializing processes, improving productivity and facilitating access to information. However, this expansion comes with significant environmental consequences. Far from being immaterial, digital technology is based on a massive physical infrastructure requiring significant energy consumption and exploiting scarce natural resources.

Digital pollution encompasses various environmental impacts, such as the carbon footprint of equipment, the energy consumption of IT infrastructure, and the accumulation of electronic waste. According to The Shift Project, digital technology now accounts for about 4% of global greenhouse gas (GHG) emissions[1], a figure that is constantly increasing due to the exponential growth in the volume of data and digital services.

Among the main contributors to this pollution are data centers, communication networks and user terminals (computers, smartphones, tablets). These infrastructures require not only a continuous supply of electricity, but also significant resources for cooling and maintenance. The proliferation of digital uses, including streaming, cloud applications and artificial intelligence, is further intensifying this consumption.

[1] The Shift Project – Report: Deploying Digital Sobriety, October 2020

Rationale for study

Faced with this observation, it becomes imperative to understand how digital technology can be managed more responsibly. The main objective of this study is to identify ways to optimize the management of digital assets to limit their environmental impact. More specifically, this research focuses on the management and processing of data through performance indicators, which are one of the key factors of digital pollution.

The rise of Big Data and related technologies has led to a massive increase in data production and storage. However, this data is not always used efficiently. Many obsolete or redundant files continue to take up space on servers, increasing energy demand without added value. Optimizing the data life cycle, including its collection, storage and deletion, is therefore a major challenge to reduce digital pollution. Dangerous abuse for the planet". An analysis of the strategies put in place by certain companies and institutions to improve the efficiency of their data management will make it possible to identify concrete levers for action. This study takes a theoretical approach, based on an in-depth analysis of best practices for optimizing storage infrastructures, streamlining data flows, and reducing unnecessary data. It will focus on existing conceptual frameworks and recommendations from scientific literature in order to assess digital over productivity and monitor its evolution through relevant performance indicators adapted to current environmental issues.

Problematic

In view of the issues raised, several questions arise:

- What are the key parameters for identifying and measuring over productivity and digital pollution?
- How can companies and institutions optimize the management of their digital infrastructures to reduce their carbon footprint?
- What tools and performance indicators can be put in place to measure the effectiveness of data management strategies?

To answer these questions, analysis of different theories on the interactions between digital infrastructures, user uses, and environmental impacts is necessary. By examining existing theories and conflicting perspectives, this study will help raise awareness among digital players of the challenges of more responsible data management.

Objectives of the study

The general objective of this study is to identify and implement relevant performance indicators to assess digital pollution, while proposing concrete solutions for sustainable data management.

Specific objectives

a. **Identify the main drivers of digital over productivity**: Analyze how excessive data production impacts the energy consumption and carbon footprint of digital infrastructures.

b. **Optimize data management**: Provide methods for streamlining data flows, intelligent archiving, and deleting junk files to reduce unnecessary storage.

By exploring these axes, this study aims to make a significant contribution to the reflection on the ecological impact of digital technology and the means to minimize it. Better data management represents an opportunity to reconcile innovation and environmental responsibility, by adopting more sober and sustainable practices.

State of the art

Key definitions

- Digital pollution :

Digital pollution is a generic concept, still vague and difficult to measure (ARCEP, 2020). It can be defined as the set of environmental impacts resulting from digital activity. Three main sources of pollution can be identified and covered by this concept. The first source of pollution is generated by the multiplication of

digital equipment and devices (e.g. smartphones, computers, screens, tablets) used by the population to connect (special use case), a second source of pollution comes from communication networks (mobile networks are much more energy-intensive than fixed networks) and the data flows (constantly increasing) they carry, and the third comes from computer centers, also known as data centers, which require considerable volumes of energy and water to operate[2] .

- Over productivity :

According to the Larousse dictionary, over productivity is the *excessive production* of a product or a series of products in relation to needs.

- Performance Indicator :

A Key Performance Indicator (KPI) is a measure or set of measures that address a critical aspect of an organization's overall performance. Its purpose is to give a quick and clear idea of a situation in order to help decision-makers. Generally speaking, KPIs are visual indicators whose purpose is to determine whether a goal has been achieved.[3]

- Data:

"By data, we mean known facts that can be recorded and have an implicit meaning. For example, consider the names, phone numbers, and addresses of people you know. (Elmasri & Navathe, 2016, p. 4).

For Borgnan (2015), "Data are representations of observations, objects, or other entities used as evidence for phenomena for research or scholarship purposes."

Data is a recorded and meaningful fact, essential for various strategic analyses and decisions. It comes in several categories, such as demographic data, which describes the characteristics of the population (age, gender, income), behavioral data, which details consumers' actions (purchases, online visits), and geographic data, which provides information about their location (addresses, regions). This data can come from internal sources, such as sales histories or CRM systems, or external, such as social media or public data. Maxime Alliume, lead author of *The Criteria for Quality Marketing Data Storage*, draws on the contributions of experts interviewed in a qualitative study to highlight the importance of data. Structured, semi-structured or

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[2] Caroline D, Jean-Philippe N. Towards a duty of digital vigilance, in Revue Interdisciplinaire Droit et RIDO Organizations n°4, p4

[3] Boris NORO, December 2022, Business Intelligence with Excel From Raw Data to Strategic Analysis (2nd Edition), ENI Ref: HSSOB2EXCBI | ISBN: 9782409038488.

unstructured, they bring value according to their usefulness and the meaning that the company can attribute to them.

Existing academic work and reports

Research on digital pollution and over productivity is based on studies conducted by organizations such as GreenIT, The Shift Project, and many others.

Data pollution

The energy and environmental challenges of digital technology have been studied since the late 1990s (Dedrick and Green, 2010). Interest in the environmental issues of information and communication technologies (ICTs) has continued to grow over the past twenty years, particularly around the notion of "Green It".

According to the aforementioned GreenIT study, the carbon footprint in the world is distributed as follows:

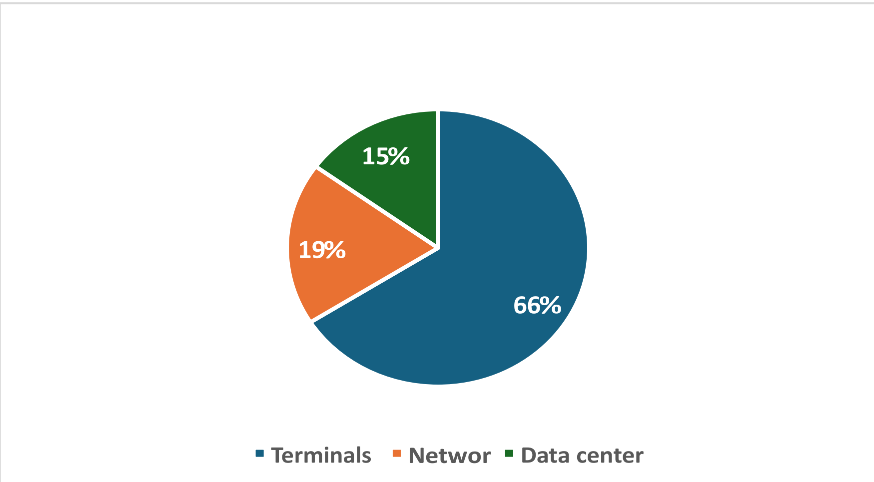
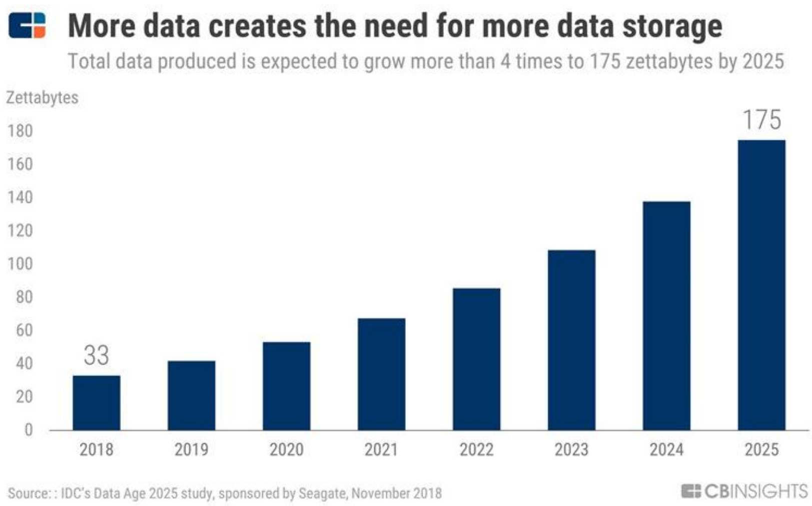


Figure 1: Distribution of the carbon footprint in 2019

Terminals (smartphones, tablets, PCs, etc.) in 2019 accounted for 66% of the total consumption of typology. Conversely, for networks (19%) and data centers (15%), the impact of the manufacturing phase is less than the impact of their use. This means that organizations' efforts can focus on responsible purchasing policies to limit the impact of manufacturing, and on the use of infrastructure (data centers and networks).[4]

Data centers, which are essential for storing and processing data, are energy-intensive infrastructures that contribute significantly to global electricity consumption. If the internet were a country, it would rank as the third-largest consumer of electricity, just behind the United States and China, accounting for between 10 and 15 percent of global energy consumption, with 4 percent attributed specifically to data centers. Among the intensive uses, cryptocurrencies, and in particular Bitcoin, illustrate the scale of this consumption, requiring as much electricity as a country like Austria, thus highlighting the importance of the energy issues related to the digital transition.

Between 2018 and 2025, the amount of data produced globally is expected to more than quadruple, from 33 zettabytes to 175 zettabytes, showing exponential growth. This rapid and steady increase, visible through annual trends, reflects a significant acceleration in data production each year. This is directly linked to the increasing digitalization and mass adoption of technologies such as the Internet of Things (IoT), artificial intelligence, video streaming, and e-commerce, which generate immense volumes of data. However, this boom is putting increased pressure on storage infrastructure, including data centers, posing major challenges in terms of energy consumption, operational costs, and environmental sustainability. The possible data center development forecasts, as reported in the IDC data 2025, are very telling: Data accumulates data.



[4] CIGREF report, Digital sobriety: Managing the environmental footprint of digital technology through measurement – December 2021, page 15

The engine of consumption is data, its processing, transmission and storage. The reasons are various in terms of the increase in video resolution (4K, 8K), the intensification of viewing (in the train, the subway and perhaps the autonomous car), the rise of video games and all kinds of immersive uses ("digital twins" in terms of design, for example, *building information modeling*, etc.), the training of artificial intelligence and work on big data, virtual currencies, various digital communication networks (corporate social networks), electronic currencies (Bitcoin consumes as much electricity as Switzerland), etc. The growing use of digital data for information and control is leading to the renewal of terminals, the widening and acceleration of traffic lanes (4G, 5G, etc.) and a rapid growth in computing and storage, which is materialized in the construction and renewal of data centers. A "lock-in", i.e. a socio-technical situation that is "blocked" or difficult to change[5] , has already taken hold quite widely, without any real anticipation of its implications, while the natural sciences and in particular the climate sciences are reinforcing their warnings a little more each year – such as the latest IPCC report (2021).

Data is a recorded and meaningful fact, essential for various strategic analyses and decisions. It comes in several categories, such as demographic data, which describes the characteristics of the population (age, gender, income), behavioral data, which details consumers' actions (purchases, online visits), and geographic data, which provides information about their location (addresses, regions). This data can come from internal sources, such as sales histories or CRM systems, or external, such as social media or public data. Maxime Alliaume, lead author of *The Criteria for Quality Marketing Data Storage*, draws on the contributions of experts interviewed in a qualitative study to highlight the importance of data. Structured, semi-structured or unstructured, they bring value according to their usefulness and the meaning that the company can attribute to them.

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5 W. BRIAN ARTHUR, "Competing Technologies, Increasing Returns, and Lock-In by Historical Events", in Cahiers, Droit, Sciences & Technologies, Fabrice Flipo (2021), *The Imperative of Digital Sobriety,* https://doi.org/10.4000/cdst.4182

Digital overproduction and pollution

Taking into account the growing impact of global digital technology on greenhouse gas emissions, according to GreenIT.fr (GreenIT.fr, 2019), the global digital world consists of about 34 billion pieces of equipment (excluding accessories such as chargers, keyboards, mice, USB keys, etc.): "Digital equipment is generally classified into three categories: users, data centers, and networks that connect users to each other and to data centers. Worldwide, the most widespread equipment is smartphones (3.5 billion). The share of digital technology in global GHG emissions amounted to 3.5% in 2019 with a worrying growth in its impacts, more than 6% per year, incompatible with the 2°C trajectory of temperature increase.

Technological overconsumption, fueled by the democratization of technologies, is leading to a continuous increase in the number of connected devices, posing major environmental challenges. Every stage of the life cycle of these devices contributes to pollution: the extraction of the rare metals needed to manufacture them depletes natural resources and causes ecological damage, while their production, transport and use generates a significant carbon footprint. For example, charging these devices accounts for about 10% of a household's electricity consumption. In addition, their end-of-life is problematic, as 80% of e-waste is not properly recycled, compounding waste management and global pollution problems. This dynamic underscore the urgency of rethinking technology consumption and encouraging more sustainable practices by considering the diagrams below:

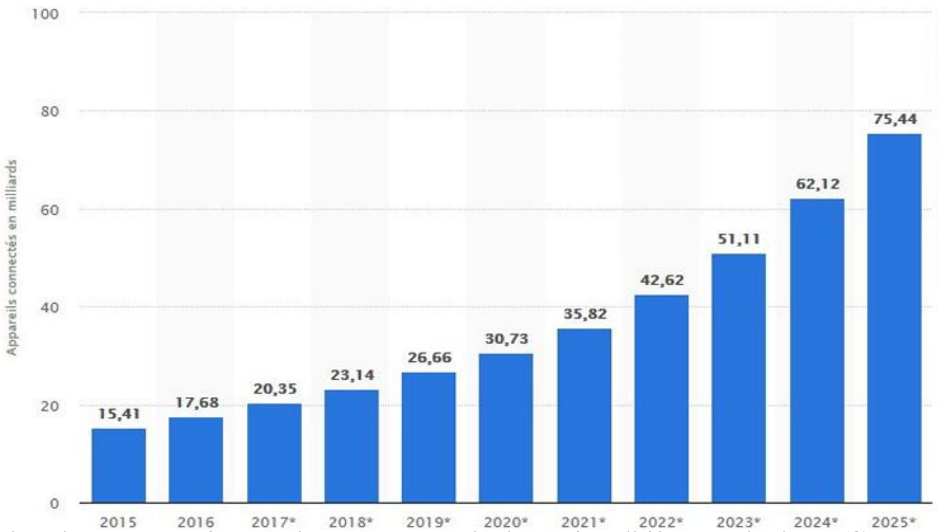

Figure 4: Histogram of greenhouse gas emissions for different devices (Source: © Carbone 4)

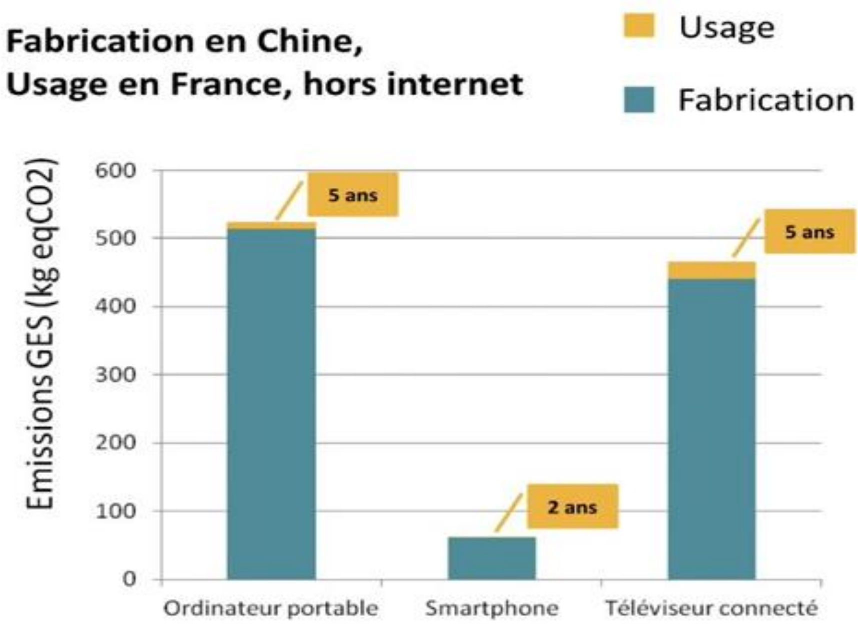

Figure 5: Evolution of the number of connected devices worldwide (Source: © Statista 2019)

To refer to digital sobriety, the report 'Decarbonizing industry without scuttling it[6] ' explores solutions to reduce 80% of greenhouse gas (GHG) emissions from French industry by 2050 while preserving its economic competitiveness. Industry, responsible for around 20% of national emissions, plays a crucial role in the energy transition. Three main levers are identified: continuous progress (energy efficiency and recycling), disruptive technologies (decarbonized hydrogen and carbon capture), and sobriety (reduction of non-essential production). Priority sectors, such as steel, cement and chemicals, will have to adopt innovative and decarbonized practices. These transformations aim to strengthen the resilience of value chains, while creating new economic opportunities and aligning industry with national climate goals.

The environmental footprint of digital technology is responsible for nearly 4% of global GHG emissions in 2019, with unsustainable annual growth. The report 'Deploying digital sobriety[7]' produced by the Shift Project proposes a transition to a more sober digital world, based on a rigorous assessment of the energy relevance of technologies, a sustainable transformation of information systems, and a collective mastery of digital uses. By advocating for appropriate public policies and tools, it aims to minimize negative impacts while preserving essential societal benefits.

Among the main factors identified, the energy consumption of data centers is a major issue, especially with the rise of generative AI, whose rapid adoption increases the pressure on

6 The Shift Project – Report: Decarbonizing Industry Without Scuttling It – January 2021

7 The Shift Project – Report: Deploying Digital Sobriety, October 2020

infrastructures. Projections estimate a significant increase in energy demand, reaching 2100 TWh in 2030. Faced with these challenges, several levers of digital sobriety are recommended, such as the optimization of infrastructures, the reduction of superfluous uses and a systemic approach integrating these issues into company policies. Transparency and monitoring of energy consumption also appear to be imperatives to better understand and control these impacts, thus promoting a transition to a more responsible digital world[8].

The exponential growth of digital technology poses major environmental challenges, particularly due to the energy consumption of data centers and the carbon footprint of digital equipment. The rise of new technologies, such as generative AI and connected objects, accentuates these pressures, making the adoption of digital sobriety strategies urgent. To limit these impacts, it is essential to optimize infrastructure, reduce unnecessary use and strengthen energy transparency. A transition to a more sustainable digital world is based on a systemic approach that integrates these issues into public and industrial policies, in order to reconcile technological innovation and compliance with climate objectives.

Faced with the growing environmental and energy challenges of digital technology, it is becoming essential to rethink performance monitoring and evaluation tools. Until now, traditional approaches have mainly relied on financial and energy consumption indicators to measure the impact of digital. However, these methods, while necessary, remain limited in their ability to integrate broader dimensions, such as innovation, sustainability, and the overall strategy of organizations.

Traditional vs. innovative approach with the Balanced Scorecard

According to the study by Châari Zouhour and Didier Leclère (2008), the management dashboard plays a key role in the decision-making of managers by structuring the information essential to the management of companies (Châari & Leclère, 2008). This research was conducted among 39 managers from 15 large Tunisian companies, mainly in the sectors of industry (43.6%), agri-food (41.1%), construction and public works (10.2%), and IT and office automation (5.1%). A large part of the companies studied belong to the Poulina and Groupe Chimique Tunisien groups, two of the largest industrial groups in the country. The traditional

[8] The Shift Project. (2023). The levers of digital sobriety. Revue de la Transition Énergétique, 12(3), 45-60. https://www.theshiftproject.org

approach is mainly based on financial and operational performance indicators, making it possible to analyse past results, anticipate problems and situate responsibilities. However, this approach shows limits in considering the environmental and societal impacts related to the digital transformation (Châari & Leclère, 2008).

In the context of the assessment of over productivity and digital pollution, the current indicators of traditional dashboards focus on economic efficiency, without always integrating negative externalities, such as the carbon footprint of digital infrastructures or the energy consumption of data centers (Châari & Leclère, 2008). The study highlights that internal management control systems are more effective in identifying levers for action, but that they remain focused on economic and operational objectives, neglecting indicators related to sustainability and digital sobriety (Châari & Leclère, 2008).[9]

According to Caroline Devaux and Jean-Philippe Nicolaï (2022), published in the *Interdisciplinary Journal of Law and Organizations (RIDO),* analyzes digital pollution as a growing environmental externality, representing 2.5% of greenhouse gas emissions in France. Based on institutional reports (ADEME, ARCEP, GreenIT, The Shift Project), it highlights the inadequacy of current regulations and proposes to integrate digital pollution into corporate governance through the duty of vigilance (Devaux & Nicolaï, 2022).

In a classic scorecard approach, performance evaluation is based on financial and energy consumption indicators, mainly used to measure the profitability and operational efficiency of companies. However, this approach omits the environmental impacts of digital technology, including:

- ✓ The carbon footprint of infrastructures (data centers, networks)
- ✓ Energy consumption of data storage and processing
- ✓ The management of the life cycle of digital equipment (obsolescence, recycling, reuse)

The study highlights those existing laws, such as the 2021 REEN law, remain limited in regulating these impacts. Currently, digital companies, network operators and large organizations using digital services are not required to integrate digital sobriety into their

[9] Châari, Z., & Leclère, D. (2008). *The impact of using the management dashboard on executive satisfaction.* Paper presented at the conference *Accounting, Control and Auditing between Change and Stability*, France. Available on HAL Open archives: https://shs.hal.science/halshs-00522446v1

strategic management tools, thus slowing down the adoption of sustainable practices (Devaux & Nicolaï, 2022).

Faced with these shortcomings, the study proposes to strengthen regulatory frameworks by mobilizing the duty of vigilance. This concept, introduced in France in 2017, imposes greater responsibility on large companies for the environmental and social externalities of their activities. Its extension to digital technology would make it possible to impose on companies:

- ✓ Monitoring of digital emissions and energy consumption
- ✓ Increased transparency on the environmental footprint of their digital infrastructures
- ✓ Concrete commitments in terms of eco-design, energy efficiency and responsible management of equipment[10]

The study conducted by Travail, D., & Marsal, C. (2006), examines the relationship between the automation of dashboards and the coherence of management control in two distinct sectors: a clothing company and a regional bank. The results show that automating dashboards improves the perception and monitoring of objectives, reduces opportunistic behavior, and decreases conflicts of interest. However, it has limitations, especially in terms of information overload, which can affect the quality of decision-making. This information overload is a key aspect of digital pollution, where an overabundance of data can lead to inefficiency in the management of digital infrastructures. To optimize the management of digital infrastructures and reduce their carbon footprint, companies and institutions must prioritize data and avoid too fine and complex analysis. Automating dashboards, while improving the consistency of representations and behaviors, must be accompanied by strategies to minimize digital pollution. This includes implementing information management systems that filter relevant data and reduce information overload. By adopting these practices, organizations can not only improve their operational efficiency but also contribute to the reduction of their carbon footprint[11].

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10 Devaux, C., & Nicolaï, J.-P. (2022). *Towards a duty of digital vigilance (or how to integrate the problem of digital pollution into corporate governance).* Revue Interdisciplinaire Droit et Organisations (RIDO), (4), 13-30.
11 Travail, D., & Marsal, C. (2006). Automation of dashboards and consistency of management control: about two cases. *Revue Française de Gestion*, 32(162), 123-138. https://doi.org/10.3166/rfg.162.123-138

The Balanced Scorecard offers an integrated vision by taking into account several strategic dimensions.

Information systems in commercial industries provide access to metric information formalized by algorithms and mathematical calculations to guide managers' actions and maximize profit. An *information* is a complex network of structured relationships involving people, machines and procedures, which aims to generate orderly flows of relevant information, from sources inside and outside the company, to serve as a basis for decisions [12]. It is an organized set of resources (hardware, software, personnel, data, procedure) that make it possible to control different processes within an organization and to produce information on the state of the managed structure and on the company's environment.

The function of an Information System is to regulate a set of information flows classified into three main categories:

- ✓ The basic flow that includes sales, purchasing, production, and personnel.
- ✓ The recording and measurement flow that are the accounting and financial flows.
- ✓ The flow of forecasting and control.

For most companies, these information flows represent the bulk of the information that can promote the economic growth of their turnover. It is important for them to follow up on their information to analyze the achievement of the objectives set. However, Kaplan and Norton (1996) argue that this type of indicator is no longer sufficient to capture all facets of firm performance. Companies themselves recognize that current performance measurement systems need to be adapted[13].

The design of performance indicators must be able to establish a strategic relationship of differentiation. It is in this exercise that Abernathy and Lilis (1995) have tried. Their results

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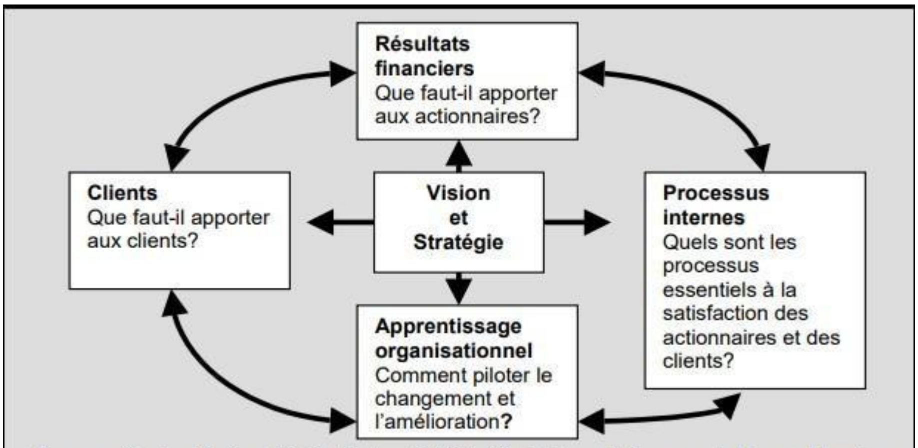
[12] Lambin Jean-Jacques, *La recherche Marketing*, Paris, Mc Graw Hill, 1990, p. 26. In Angot, H. (2006). Chapter 1. The information system seen from the perspective of information flows. In:, H. Angot, *Système d'information de l'entreprise: Des flux d'information au système d'information automatique* (pp. 11-104). Louvain-la-Neuve: De Boeck Supérieur.

[13] Kaplan, Robert S. and David P. Norton (1992), "The balanced scorecard: measures that drive performance", Harvard Business Review, Jan-Feb, pp. 71-79

show that a company that adopts a differentiation strategy that allows it to comply with customer demand as quickly and as well as possible, and therefore moves closer to a differentiation strategy, will use less traditional financial indicators in favor of performance indicators of a more qualitative or non-financial [14]nature. In the same vein, Perera and Poole (1997) were able to demonstrate that there are general links between a differentiation strategy and the use of an information system for broader performance monitoring. However, they concluded that there is no link between the use of an expanded information system and performance. Some researchers such as Mia and Chenhall (1994) have succeeded in proving that the more an extended control system is used, the more performance increases in the case of the marketing function. For Chong (1996), it is rather managerial performance that is elevated when an expanded performance system is used.

The analysis shows that companies looking to differentiate themselves need to adapt their performance measurement tools to include indicators that better reflect their strategies. However, it is crucial to understand that the effectiveness of an expanded information or control system depends on the organizational context and specific areas of application. Strategic differentiation therefore requires a nuanced and tailor-made approach in the design of indicators.

The Balanced Scorecard presented by Kaplan and Norton has inspired several writings on this subject. This table seeks to understand the realities of companies and allows us to assess performance in four (4) areas (see figure below). It should be remembered that performance indicators are a function of the business environment and its visions. They should inform managers in a timely manner of events that may adversely affect the achievement of objectives.



Source : Kaplan R. S. et D. P. Norton (1996), *The balanced Scorecard*, Harvard business School Press, p.21

Figure 6: Balanced Scorecard

[14] Kaplan, Robert S. and David P. Norton (1992) bis.

The financial, customer aspects, internal processes and organizational learning are areas considered in this table. All this information will not be usable without influencing the behavior of individuals in the company.

Management control allows managers to determine whether the company is achieving the desired performance and motivates, thus influencing people to work to maintain, improve, correct or anticipate performance[15]. Social control is one of the components and one of the extensions of management control. It is a system of support for the social management of the organization with the objective of contributing to the management of human resources in their performance and costs. A distinction is made between strategic social management control and operational social management control.

The first helps management identify the fundamental assumptions to guide the company's activities and structures towards its long-term goals. The second allows each manager to track success factors, compare results to short-term goals, and correct deviations by taking the necessary actions.

Sustainable development approaches environmental management from two complementary functions. When we consume a resource excessively at its renewal rate, we irreversibly deteriorate its regenerative function. Conversely, when we pollute the river at a rate greater than its self-purification capacity, we irreversibly deteriorate its drinking quality. All this is easy to quantify and put into perspective.

Assuming that the choice of livelihood acquisition strategies by societies influences sustainable development policies; Mancebo, F. (2010) shows that these choices are determined by the combination of financial gains that are grouped into five (5) categories or capital. They are:

- ✓ Physical capital, including
- ✓ Financial capital or financial resources
- ✓ Human capital,

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[15] Hélène Bergeron. Performance Indicators in the SME Context, Which Model to Apply, 21ST AFC CONGRESS, May 2000, France. Pp 9.CD-ROM. ffhalshs-00587425.

- ✓ Social capital
- ✓ Natural capital.

All these categories will have to be taken together to improve living conditions in a substantial and sustainable way[16].

In this sense, two schools of thought are opposed: the proponents of "strong sustainability" and the proponents of "weak sustainability".

Proponents of weak sustainability consider that natural capital and built capital (i.e. capital manufactured and accumulated by human activities) can be substituted for each other in an almost perfect way. Low sustainability is defined as the rule that the sum of natural and built capital must be kept constant.

Proponents of strong sustainability believe that natural and built capital cannot be perfectly substituted for each other. "Any energy transformation is accompanied by an irremediable degradation of energy in the form of heat". According to proponents of strong sustainability, there is therefore a threshold, known as critical natural capital, beyond which natural capital must be preserved, as it provides goods and services that are not replaceable by built capital (Daly H., 1998).

These two thoughts agree, among other things, on the fact that growth and development models cannot continue to produce goods and services that maintain inequitable situations between developed and non-developed areas, regardless of the scale considered [17].

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[16] Encore

[17] Mancebo, F. (2013). Sustainable development. (2nd ed.). Armand Colin. https://doi-org.univ-smb.idm.oclc.org/10.3917/arco.ncebo.2013.01.

TABLEAU 4 DURABILITÉ FORTE ET DURABILITÉ FAIBLE

	Idée-Clé	Conséquence	Terme-clé	Enjeu du développement durable
Durabilité forte	Capital naturel et capital construit ne peuvent être substitués de manière parfaite.	Certaines actions humaines conduisent à des irréversibilités.	Capital naturel critique.	Préserver les stocks de capital naturel irremplaçable.
Durabilité faible	Capital naturel et capital construit sont parfaitement substituables.	La somme du capital naturel et du capital construit doit être maintenue constante.	Allocation optimale des ressources.	Trouver des solutions techniques dites « propres » pour remplacer produits et procédés, ou restaurer l'environnement.

Source: Mancebo, F. (2013). Sustainable development. (2nd ed.). Armand Colin

Laura, F., Coelho, F. & Delmond, M.-H. (2009) deal with the challenges of sustainable data governance, highlighting its ecological and economic impacts. Faced with the exponential growth in data volumes, the energy consumption of data centers is becoming a major challenge. The authors emphasize that optimizing storage infrastructures is not enough and that a more holistic approach to data management is needed. Their study is based on 70 analyzed calls for tenders and 12 interviews with experts in Green IT and data management, highlighting the lack of maturity of companies in this field.

To structure this governance, the authors identify five key principles: (1) legal and regulatory compliance, which ensures compliance with standards (GDPR, ISO 14001) and archiving or deletion obligations; (2) the protection of personal data, which imposes strict confidentiality and access management measures; (3) data security, through backup and redundancy policies to prevent cyberattacks and information loss; (4) data lifecycle management, which aims to classify, store and archive data according to its importance and frequency of use; and (5) the optimization of storage infrastructures, by promoting the use of eco-responsible technologies (virtualization, cold storage, compression).

In order to integrate these principles into business strategy, the authors propose a thematic Balanced Scorecard, articulated around four axes: a financial perspective aimed at reducing energy costs and improving the use of infrastructure, a customer perspective taking into account internal expectations in terms of data quality, a process perspective defining sustainable management practices that comply with regulations, and a learning perspective, focused on the training of actors and the dissemination of good practices.

The article concludes on the urgency of proactive data governance to limit its proliferation, optimize storage resources and reduce the environmental impact of IT infrastructures. By integrating these issues into the corporate strategy, organizations can reconcile performance, compliance and environmental responsibility[18].

The study by Figge, F., Hahn, T., Schaltegger, S., & Wagner, M. (2002) proposes an adaptation of the Balanced Scorecard (BSC) in order to integrate environmental and social objectives into the strategic management of companies. The authors point out that traditional approaches to performance measurement are mainly focused on financial and operational indicators, thus neglecting ecological and societal impacts. They emphasize the need for a strategic framework that allows companies to align their sustainability initiatives with their economic objectives, while ensuring effective monitoring of results.

To achieve this, the authors develop three possible approaches: (1) the addition of environmental and social indicators to the existing BSC outlook, (2) the creation of a fifth perspective dedicated to sustainability, and (3) the development of a thematic Balanced Scorecard specifically focused on sustainable performance. These models make it possible to structure companies' actions by integrating ecological issues into their decision-making processes, by valuing the economic benefits of responsible management and by facilitating the communication of results to stakeholders.

The authors conclude that the adoption of the Sustainability Balanced Scorecard (SBSC) is a key strategic lever for organizations seeking to reduce their environmental impact without compromising their competitiveness. By integrating environmental and social reporting tools, companies can better meet regulatory and societal expectations, while strengthening their transparency and commitment to sustainability[19].

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18 Laura, F., Coelho, F. & Delmond, M.-H. (2009). *Sustainable data management: an update on the issues at stake and a proposal for a performance management approach based on a thematic balanced scorecard.*
19 Figge, F., Hahn, T., Schaltegger, S., & Wagner, M. (2002). *The Sustainability Balanced Scorecard: Linking Sustainability Management to Business Strategy. Business Strategy and the Environment, 11(5), 269-284.*

Study Methodology

In the context of this study, the methodology adopted is based on an analysis of secondary data, allowing for an in-depth exploration of theoretical frameworks and best practices in the responsible management of digital resources. The magnitude of the environmental impacts of digital technology justifies an approach based on a critical review of existing literature, including academic research, institutional reports and case studies of companies committed to reducing their ecological footprint. This methodological choice guarantees a global understanding of the phenomenon of digital over productivity, by identifying the strategic levers to optimize the use of infrastructure and data.

In addition to this literature review, a systemic approach was adopted to understand digital pollution in all its complexity. This approach makes it possible to study the interactions between the different components of digital technology (infrastructures, uses, regulatory framework, technological innovations) and their environmental impacts. Rather than looking at these elements in isolation, the systems approach offers a holistic view by identifying the cascading effects and interdependencies between data management, energy consumption, and strategies for optimizing digital infrastructure. By cross-referencing scientific work on data management and eco-design strategies for infrastructure, this study will highlight the points of convergence and divergence in terms of best practices.

Critical analysis of existing theories and discussion of results

Identification and measurement of over productivity and digital pollution.

Existing theories about over productivity and digital pollution revolve around several key parameters: excessive use of computing resources, data redundancy, and overconsumption of energy. Studies often consider cognitive overload and digital waste (duplication of files, execution of unnecessary processes) as indirect indicators of over productivity.

Critical analysis: While these approaches provide an overview of the imbalances caused by excessive digital activity, they often lack standardization. Measurement methods are not unified, making comparisons between different industries complexes. In addition, the notion of "digital pollution" is still being debated, with some linking it only to energy aspects, while others integrate social and cognitive dimensions.

Optimization of digital infrastructure management to reduce carbon footprint.

The theories discussed in the literature review present several optimization strategies:

- ✓ Virtualization and the use of cloud computing to limit the use of physical servers.
- ✓ Energy efficiency in data centers with solutions such as free cooling or renewable energies.
- ✓ Green IT, which advocates sustainable practices at every stage of the IT infrastructure lifecycle.

Critical analysis: While these solutions are relevant, they are often based on technological assumptions that are not always suitable for all companies. For example, outsourcing to cloud can reduce a company's carbon footprint but increase that of large cloud providers. In addition, the transition to greener digital management requires organizational transformation, which is often held back by high upfront costs.

Measuring the effectiveness of data management strategies

Data management is an essential lever in reducing digital pollution and optimizing the performance of IT infrastructures. The Tools and performance Indicator covered include:

- ✓ PUE (Power Usage Effectiveness) to assess the energy efficiency of infrastructure.
- ✓ Environmental KPIs like digital carbon footprint per user.
- ✓ Data lifecycle analysis to optimize data storage and processing.
- ✓ Implementing data governance policies to reduce redundancy and improve the quality of stored information.

Critical analysis: These tools can quantify certain aspects of digital impact, but they do not always incorporate qualitative dimensions such as optimizing the use of data. In addition, the overabundance of data (Big Data) is rarely taken into account in sustainability strategies. Establishing effective data governance would require more robust methodologies to classify, prioritize, and archive data according to its actual usefulness, limiting unnecessary retention.

Recommendations

The analysis of existing theories partly answers the questions asked. The parameters for identifying over productivity and digital pollution are defined but lack standardization. The optimization of digital infrastructures is a solid avenue, but its technological and economic limits remain underestimated. Finally, performance indicators allow a partial measure of the effectiveness of strategies, but they would benefit from being complemented by more qualitative and cross-cutting approaches. A more in-depth reflection on the interconnection between these different axes, by integrating advanced data management and governance strategies, could strengthen the analysis and lead to more operational recommendations adapted to contemporary issues.

Proposal: Performance indicators to monitor digital pollution and over productivity, focus on data management.

Prospects	Performance indicators	Description / Objective
Financier	Storage cost per TB	Track expenses related to storing and archiving unused data.
	Cost/benefit ratio of retained data	Evaluate the cost of storage versus the true value of the data.
	Rate of reduction in energy expenses related to IT infrastructures	Evaluate the cost savings generated by better data and server management.
Customer	Level of transparency on data management	Measurement of the degree of customer information on the ecological impact of digital services.
	Stakeholder satisfaction Indicator	Assessment of the perception of the company's efforts to reduce its digital carbon footprint.

Internal	Data redundancy rate	Percentage of duplicate data, identified, and deleted to optimize storage space.
	Compliance with file/data naming standards by business sector	Followed the application of naming conventions to avoid orphaned files and improve accessibility.
	Average data retention period	Comparison of internal conservation policies with regulatory recommendations.
	Percentage of data not used for more than one year	A key indicator for setting up a deletion or archive strategy.
	Adoption of data management best practices	Percentage of employees trained in optimal data management practices.
Innovation & Learning	Share of investments in Green IT solutions	Tracking efforts to reduce the digital environmental footprint.
	Adoption rate of optimized data governance	Measurement of the implementation of data management and classification policies.
	Effectiveness of data lifecycle assessment tools	Evaluation of tools to sort and eliminate unnecessary data.

Limitations of the study and research perspectives

Although the study provides a relevant analysis of the issues related to over productivity and digital pollution, several limitations can be identified.

First, the diversity of theoretical approaches poses a challenge for the standardization of evaluation methods. The different definitions and analytical frameworks on digital pollution and over productivity do not always allow for a coherent and comparative view across industries. The lack of a scientific consensus on these concepts complicates their practical application in companies.

Secondly, the solutions proposed, particularly in terms of optimizing digital infrastructures, often remain dependent on economic and technological constraints. Adopting sustainable practices requires significant upfront investments, which can hinder their implementation, especially for SMEs. In addition, the shift to greener infrastructure, such as cloud computing, raises the question of whether emissions will shift rather than actually reduce them.

Another point of limitation lies in the focus on quantitative indicators. While tools like PUE or digital carbon footprint per user are essential, they don't take into account some more subjective aspects, such as organizational impact or behavioral changes needed for better digital asset management.

Finally, the study focuses mainly on a theoretical analysis and does not take into account in-depth case studies or field experiments. A more empirical approach, with feedback from companies that have implemented sustainable digital infrastructure management strategies, could have enriched the analysis and offered more pragmatic perspectives.

Thus, although the study partially answers the research questions, these limitations underline the importance of a more methodological deepening and a more integrated vision of the issues to obtain more effective operational recommendations.

To deepen the study and overcome some of its limitations, several perspectives can be considered.

An empirical approach based on case studies of companies that have implemented effective strategies to reduce the digital footprint could enrich the results. These observations would make it possible to identify good practices and possible obstacles encountered when implementing sustainable solutions.

In addition, the integration of a behavioral dimension into the assessment tools could complement the analysis. Indeed, training and raising employee awareness of the impact of digital technology on the environment are major levers to support the transformation of infrastructures and optimize the use of IT resources.

Finally, a reflection on the evolution of regulatory and normative frameworks in terms of digital pollution could be carried out. The development of public policies that encourage companies to adopt responsible digital practices, through financial incentives or green certifications, could accelerate the transition to more sustainable infrastructure.

Thus, by combining a theoretical approach, field experimentation and an adapted regulatory framework, it would be possible to refine digital management strategies and improve their effectiveness in the long term.

CONCLUSION

The objective of our study was to propose a methodological approach to measure and monitor digital pollution and over productivity, with a particular focus on data management and the lifecycle of digital infrastructures. The challenge was to identify relevant indicators to assess the environmental impact of digital uses and to optimize the management of IT resources to reduce the carbon footprint of companies and institutions.

To this end, we have structured our thinking through the framework of the Balanced Scorecard, defining indicators from four key perspectives: financial, customer, internal and innovation & learning. Our proposals highlight the need for more rigorous data governance through optimized data collection, processing and retention practices, while integrating standards adapted to the specificities of the business sectors. In addition, we have broadened our analysis to include the management of the life cycle of digital equipment, which is a major lever for limiting obsolescence, promoting refurbishment and encouraging a responsible purchasing policy.

The results of our analysis highlight that digital over productivity and associated pollution result from excessive and uncontrolled data accumulation, inefficient use of IT infrastructures and too rapid renewal of equipment. Indeed, the proliferation of useless, often redundant or obsolete data burdens systems and generates significant energy and financial costs. Similarly, the lack of consideration of environmental impacts in the management of IT equipment contributes to a high carbon footprint.

In terms of consequences, the lack of a comprehensive strategy to address these issues can lead to excessive storage costs, increased energy consumption and an increase in e-waste, thus compromising organizations' sustainability commitments.

Thus, to address these challenges, we considered it essential to formulate concrete proposals aimed at establishing a more efficient and sustainable management of digital resources. Among these proposals, we insist on:

- Optimization of data storage through appropriate sorting and archiving policies.
- Applying strict data management standards to avoid redundancies and ensure more structured access to information.

- Extending the lifecycle of digital equipment through maintenance, refurbishment and recycling practices.
- Monitoring of precise indicators to assess the environmental and economic performance of digital infrastructures.

These recommendations are part of a responsible digital transformation process, combining economic efficiency, respect for the environment and continuous improvement of data management practices. They aim to enable companies and institutions to reconcile their performance imperatives with a significant reduction in their ecological footprint.

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