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Towards Improved Datacenter Assessment: Review and Framework Proposition

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ABSTRACT

Our growing needs for social networks, cloud storage and more recently machine learning have fueled the increasing demand for datacenters (DC). It is estimated that by 2030, in the US alone, datacenter power consumption could more than double from 2022. In Europe, the energy consumption is expected to rise by 28%, from 77TWh to 99TWh. This surge, coupled with the increasing scrutiny imposed on Information and Communication Technology (ICT) from stakeholders, regulators and competition, regarding environmental impacts, and to stay on the path of net-zero, has spotlighted datacenters as key contributors to these environmental concerns. Consequently, companies have set major milestones for the next decades in terms of renewables, energy consumption and water use. This paper aims to shed light on the imperative necessity of revisiting and evaluating various metrics and methodologies used to gauge the impact of datacenters, extending beyond merely assessing sustainability factors. More in detail, we focus on four paramount criteria which encompass the whole datacenter lifecycle and its direct and indirect impacts: environmental impact, economic performance, ecosystem integration and external influence. These are usually evaluated through three types of analysis: single indicators, lifecycle analysis and multi-criteria assessment, all of which are analyzed here.

Keywords: Datacenter, Life Cycle Analysis, Multi-Criteria Decision Analysis, Intelligent Energy Systems

1. INTRODUCTION

While our society has become more and more interconnected, datacenters have become a critical element to generate, manage, process and store all information. As digitalization is recognized an enabler of smarter energy systems, this increasing role of data collection, storage and processing is further reinforced in low carbon scenario and the emergence of smart energy systems. Datacenters are thus expected to be increasingly used everywhere, from e-commerce to cloud computing, transport optimization, climate data collection and processing and the generalization of artificial intelligence and machine learning in scientific and industrial processes.

The datacenter industry has witnessed exponential growth and evolution over the past few decades [1]. The rise of the Internet of Things (IoT), big data, and the increasing demand for cloud-based services have driven the need for more data storage and computing power [2]. The shift to hyperscale and colocation infrastructure, as well as the increasing performance of electronic equipment have led to the development of larger, more powerful, and more efficient datacenters [3–5].

This growth comes with significant environmental implications from CO_2 emissions to water consumption in scarce regions. Datacenters are high consumers of electricity – between 200-320 TWh according to the IEA [1]. This electricity is used to power the servers that store and process data, to cool pieces of equipment and to maintain optimal operating conditions. As a result, datacenters contribute significantly to global greenhouse gas emissions, with some estimates suggesting that they account for nearly 2% of global CO_2 emissions – comparable to that of the aviation industry [6]. By 2030, this consumption could rise by more than 30% [7].

This has led to growing concerns about the environmental impact of the datacenter industry, with cloud companies leading the way on sustainability targets. Balancing the operational needs of datacenters with the imperative for environmental responsibility and sustainability is mandatory, especially considering engagements towards carbon neutrality, and as the demand for digital services continues to grow [2].

In this context, understanding the environmental impact of datacenters and exploring ways to reduce their footprint – not just carbon – is not just an academic

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exercise but a pressing necessity. The objective of our work is to highlight the differences between the methodologies, the approaches, and the indicators assessed in the literature to demonstrate the need for a comprehensive framework, which is proposed in the discussion section.

2. *ENERGY CONSUMPTION IN DATACENTERS*

2.1. Datacenter choices and architecture

A datacenter is an architecture that stores, processes and disseminates data and applications. They play a critical role in our society, from cloud computing to e-commerce and data storage. There are four different typologies of datacenters:

- Enterprise datacenter are private facilities supporting an organization or a company. Hardware and software are usually stored onsite.
- Multi-tenant or colocation, which offer spaces in their facilities. Clients can host their hardware and software offsite.
- Hyperscale datacenters, which are very large infrastructures, usually operated by internet giants.
- Edge datacenters, which are small infrastructures, nearby demand sites to enable low latency and handle quick actions.

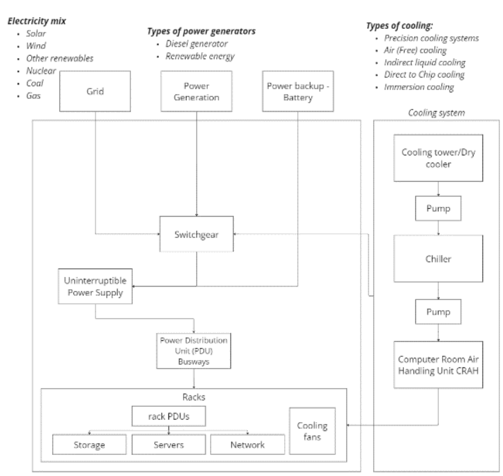

Figure 1. Diagram model of a datacenter.

Figure 1 describes the interactions between the different components of a datacenter. This is a high-level view, not considering the redundancy between components.

2.2. Cases of energy related integration challenges

Concrete real-world cases have demonstrated that the impact of integrating a datacenter in a broader system, e.g., a city or a country, should also be considered. For instance, for smaller countries relying on datacenter industries, energy consumption is already a key challenge. In Ireland, the total electricity consumption rose to 18% in 2022 up from 5% in 2015. This is as much as the total electricity consumed by urban dwellings, and almost twice as much as that of rural dwellings [8]. Moreover, according to a recent Eirgrid (Ireland's national public grid operator) report, up to 28% of Ireland's electricity demand could come from datacenters and other tech users [9] by 2031. With the increasing pressure on the Irish grid, The Comission for Regulation of Utilities (CRU) issued a directive to enable EirGrid and other operators to assess datacenter connections and assess "whether a connection offer can be made within the system stability and reliability needs of the electricity network" [10]. Different criteria are looked, such as location, onsite power generation or DC energy consumption. Criteria can be ranked freely by the operators. Furthermore, with the concentration of computing infrastructures in cities like Amsterdam, politicians have taken actions. In 2019, a year-long ban on building new datacenters was implemented as they were taking up a lot of space and pressurizing the electricity grid [11]. In 2022, Dutch government imposed a 9-month moratorium on the development of new hyperscale datacenters.

3. *INDICATORS AND THEIR VARIETY*

3.1. Static indicators

Static indicators are indicators that are usually considered during the design phase of a project. A datacenter component can have a component with a static part and dynamic part. For example, the redundancy of an equipment or its lifetime are static indicators.

3.2. Operational Indicators

Operational indicators focus on the operational phase of the lifecycle, from direct energy use to water consumption as well as the efficiency of a datacenter. The most commonly used and assessed operational indicator is Power Usage Effectiveness (PUE) [4], which measures the ratio of total energy used by a datacenter to the energy used by its IT equipment (the equipment that creates value for the datacenter). Introduced by The Green Grid in 2007 [12], PUE has become a standard metric in the datacenter industry for assessing energy efficiency. However, while PUE provides valuable information about how effectively a datacenter uses its power, it has several limitations among which type of energy used and other aspects of a datacenter's operations such as water usage or waste generation [13]. More examples of datacenter metrics can be explored within the resources provided by the Uptime Institute (2012) and the Green Grid (2012) organizations. These metrics predominantly revolve around ratio-based assessments of datacenter efficiency. Nonetheless, it appears that there have been no efforts to develop a unified composite indicator or a distinctive label for this purpose.

3.3. Lifecycle Indicators

Lifecycle indicators, on the other hand, encompass the whole lifecycle of a product, i.e., from mineral extraction to end of life. These indicators provide a holistic view, ensuring that every phase of a product is covered, but are limited to environmental impacts. Examples of indicators are Climate change, Land Use, Eutrophication and more [14].

4. ***METHODOLOGIES OF ANALYSIS***

4.1. Life cycle analysis

Lifecycle Assessment (LCA) methodologies, such as those outlined in the ILCD Handbook [14], provide a comprehensive view of a datacenter's environmental footprint, and usually follow guidelines or methods that are standardized like the ISO 14000 series [15]. They consider a wide range of factors, from energy use, material consumption, waste generation, and greenhouse gas emissions, to water consumption and acidification, and provide an unbiased view of a product's lifecycle, if a detailed life cycle inventory is conducted.

However, one the main limitations is that conducting an LCA can be a complex and time-consuming process. It requires detailed data on every aspect of a datacenter's lifecycle, which can be difficult to obtain, especially considering the customization demanded from customers. Furthermore, the results of an LCA can vary depending on the specific methodologies and assumptions used [16]. For example, different LCA methodologies may use different functional units, which are the basis for comparing the environmental impacts of different systems. This can make it difficult to compare the results of LCAs conducted by different researchers or organizations [17].

The reviewed papers [18–22] help identifying methodological choices that influence the impact assessment of DCs. Factors such as local climate conditions, the availability of renewable energy sources, and local regulations can all affect a datacenter's environmental footprint[22], [23]. Most of the studies have highlighted that the biggest contributor to the DC emissions is during the consumption phase [20], [22]. A study of a datacenter in Trondheim has shown that embodied emissions were the most important. However, this study describes a small-scale pilot [18] thus incorporating sources like EPDs, published literature, ecoinvent data, and not the actual values of the pilot. The accuracy of the results can thus be compromised by the lack of quality data and the use of proxies. Yet with the personalization of the DC projects to customers, this could also pose a problem to industry specific cases when assessing the environmental impact.

4.2. Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) are methods used to find the best possible balance and facilitate decision making by weighting and analyzing multiple criteria. This is particularly useful when dealing with a set of criteria in complex systems, such that of datacenters. The main drawbacks associated is that criteria are usually arbitrated based on user input or historical trends and data, potentially skewing the outcome of the results. The reviewed papers [23–26] also highlight a diversity of purpose and criteria considered.

The work done by Covas et al [23] showed an effort in this sense. A new indicator was introduced, the Temperature of the Region Usage Effectiveness (TRUE), derived from the well-known PUE. The objective of this parameter to consider the free cooling possibilities in the PUE calculation to encourage the use of free cooling. This indicator is a first attempt to incorporate location, through temperature conditions into performance criteria and can be considered as a multi-criteria indicator. Moreover, an MCDA approach was also incorporated, using the ELECTRE optimization methodology, defining five criteria levels through interviews with experts to assess the DC performance and environmental impacts: Carbon emission factor, TRUE, server utilization, ER and Local Environment Impact. As early as in 2011, the urge of having a Datacenter Sustainability framework consensus between companies was highlighted. An example of such initiatives is that of Infrastructure Masons, a global nonprofit association connecting infrastructure stakeholders [27].

Additionally, Yuna et al. [24] use multi criteria analysis to determine the best location of a datacenter in Turkey along five criteria: natural disaster, climate index, energy index, accessibility index, and human capital and life quality index.

In a similar manner, Kheybari et al [25] have focused on three criteria to evaluate a datacenter to select the right location while Zhang & Yang [26] designed a comprehensive evaluation model for big datacenter sustainability that evaluates both qualitative and quantitative criteria. However, they only address the sustainability topic, mainly focusing on energy consumption and equipment layout.

5. *DISCUSSION*

Based on the literature review, we propose a framework to synthesize the contributions made and offer a holistic view of a datacenter project assessment (Figure 2).

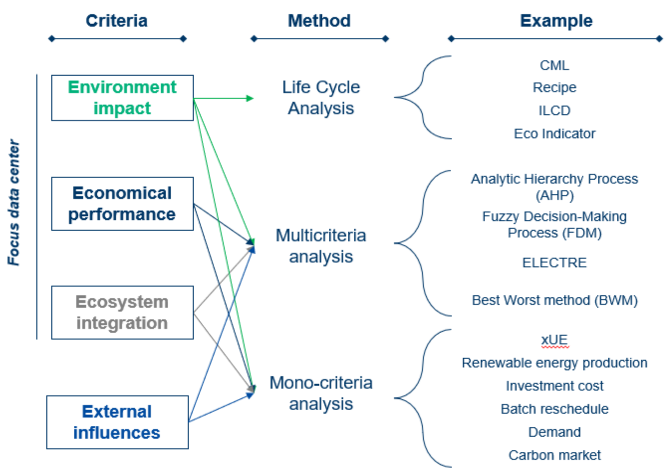

Figure 2. Framework proposition for datacenter analysis.

To enable arbitrations during the design and operational phases of a datacenter project, we propose to extend the literature with a fourth criterion: dynamics of external influences. The criteria's objective is to consider how dynamic change over time of external factors such as demand, renewable energy mix or others could affect the datacenter. Its aim is to show how corrective measures can be applied, or new constraints emerge over the lifetime of a project. The primary aim of the proposed framework is to offer a comprehensive methodology for assessing datacenters by considering four critical dimensions: environmental impact, economic performance, ecosystem integration, and external influences. While existing methodologies often focus predominantly on environmental factors, the multifaceted nature of datacenters necessitates a broader perspective. Our framework fills this gap, ensuring that assessments capture the full scope of implications tied to datacenter operations.

6. *CONCLUSIONS*

Developing systemic assessment frameworks to optimize the design, select the location and reduce the impacts of datacenters is essential to make better decisions. Datacenters (DCs) operate in a complex environment and this preliminary literature review highlights contributions made by various authors and their methodological choices. The classification of existing contributions has brought to light the necessity of incorporating novel challenges stemming from the growing influence of dynamic constraints and opportunities that emanate from factors beyond the conventional scope of a datacenter project. These factors should be encompassed within a fresh framework tailored for comprehensive datacenter assessments.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript

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