# CURRENT PERSPECTIVES ON SUSTAINABILITY IN CLOUD COMPUTING: A COMPREHENSIVE REVIEW

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**Abstract:** Information technology already contains one of the main elements of life, as described by people and enterprises. With the emergence of the Internet and its subsequent availability, there is a digital revolution, the source of which is a reality without mobile devices, web browsers, and instant messengers. In this group, cloud computing plays an increasingly important role, enabling the sharing of more data available via the Internet.

At the same time, the increasingly growing awareness of sustainable development and its current role means that this issue has been explored in the context of cloud computing for several years. Therefore, this paper aims to perform a systematic literature review on sustainability issues in cloud computing. The study included scientific publications from two databases - Scopus and Web of Science, and the review itself was based on the PRISMA procedure. After conducting an initial quantitative analysis, a detailed review of the publications was carried out to determine the role and impact of cloud computing sustainability on the areas in which it is used, which constitutes the article's novelty. The obtained results show that, firstly, cloud computing sustainability is an issue that is currently gaining popularity, which is reflected in the growing number of scientific publications. Moreover, it is characterized by various impacts on social and environmental issues, depending on the area in which cloud computing is used. Furthermore, the results show that cloud computing is perceived as one of the main elements of digital transformation.

## Introduction

Nowadays, running a business without modern information and communication technologies (ICT) is impossible. Modern enterprises operating on the market extensively use a wide range of IT tools that improve management processes in the company and communication processes both inside and outside the organization. The widespread use of ICT tools has undoubtedly contributed to the popularization of the Internet, which has improved and accelerated many processes in the enterprise, whether related to management, communication, or customer and supplier service. Apart from the Internet itself, ICT tools available on the market also enable the collection and analysis of data, e.g., regarding changes taking place on the market, forecasting future trends, making strategic or operational decisions, efficient and

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effective modeling of business processes, improving customer service processes, both during sales and after-sales service, or enable employees to switch to remote mode - a form of work that has become widespread as a result of the almost two-year COVID-19 pandemic. It is also worth mentioning that ICT tools also accelerate an enterprise's digital transformation, positively impacting its competitiveness and strengthening its market position and further development (Chidozie et al., 2024).

Among these tools, the most noteworthy is Cloud Computing (CC). This solution enables enterprises to use many IT solutions without purchasing and installing systems or computer software. CC is a solution (or service) that companies have used for many years. The introduction of this solution had a significant impact on the functioning of the enterprise itself - by accelerating many operations related to enterprise management, reducing costs resulting from the possibility of leasing rather than having to purchase, improving the work of employees by enabling them to have constant access to data and information collected on electronic media. Cloud Computing is not an entirely new solution allowing the processing of data and information; its primary goal is to provide IT services in a mass manner, from any place and at any time, eliminating the need for users to familiarize themselves with and understand issues related to the collection, processing, and sharing of data and information. (Dziembek, 2019). In Poland, the use of Cloud Computing is still not very common. This solution is used by almost half (44.4%) of public administration units that use the CC and ¼ of business entities. However, the significant impact of Cloud Computing on the functioning of enterprises and public administration units allows us to assume that over the years, the percentage of both groups of these entities will systematically increase, and Cloud Computing will become a widely used solution.

Cloud Computing, like any ICT solution, is characterized by a specific impact on the natural or social environment. Servers collecting and storing data require large amounts of energy and water.

The growing awareness of the impact of Cloud Computing on the natural environment has resulted in many studies on the relationship between Cloud Computing and sustainable development (sustainability) in recent years. Several reasons have been identified as to why sustainable development and cloud computing can create a relationship that benefits both the company and the social and natural environment. The emergence and subsequent implementation of cloud computing into the enterprise's operations enable the acceleration of specific processes, e.g., those related to the collection, transmission, or processing of information. It also influences the business model and enterprise management processes, considering sustainable development. The sustainability dimension in Cloud Computing is manifested, among others, by using renewable energy sources to reduce energy consumption, which results in a significantly reduced carbon footprint generated by the use of Cloud Computing.

Currently, in the literature, the relationship between Cloud Computing and sustainable development is manifested by the use of terms such as "Sustainable

Cloud Computing", "Cloud Sustainability", "Green Cloud Sustainability", or "Green Cloud Computing", meaning the use of cloud services to achieve sustainability benefits within economic, environmental and social systems.

Therefore, to introduce and deeply explore the relationship between the concepts mentioned above, a systematic literature review (SLR) was conducted. It will enable us not only to identify the differences between these concepts but also to identify the relationships and dependencies between Cloud Computing and sustainable development, the implications of this relationship for business entities, its possibilities, and its impact on the functioning of the enterprise, or establishing theoretical foundations for future research in the literature on Cloud Computing.

**Literature Review**

The idea of cloud computing dates back to the 1960s when, in 1961, Professor J. McCarthy stated that "computing may someday be organized as a public utility just as the telephone system is a public utility" (Garfinkel, 2011). However, the concept of "cloud computing" was first used by R. Chellappa during his lecture at the INFORMS in 1997. He stated that cloud computing would be a "computing paradigm where the boundaries of computing will be determined by economic rationale rather than technical limits alone" (Chellappa, 1997). Over the years, many definitions of cloud computing in the literature have been more business-oriented or technology-oriented (Madhavaiah et al., 2012; Vaquero et al., 2008).

The essence of Cloud Computing is the transfer of IT services from traditional desktop computers to remote data centers. Cloud service deployments cover everything from using business applications to the latest apps on the latest smartphones. It enables users to seamlessly access infrastructure on demand, eliminating the need for on-premises installation and maintenance. Cloud computing (CC) is an IT (Information Technology) performance model that combines existing technologies and concepts such as virtualization, autonomous computing, mesh computing, and usage-based pricing (Foster et al., 2022; Zhang et al., 2010). However, cloud computing refers to delivering scalable IT resources over the Internet instead of hosting and servicing them locally (Armbrust, 2019). Cloud computing is a subscription-based service that allows you to access your computer's network storage and resources (Huth, Cebula, 2011). According to NIST: "Cloud Computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Liu et al., 2011). Cloud Computing is also defined as:

- a processing style in which scalable IT solutions are massively delivered as services over a network to many external recipients (Plummer et al., 2008);
- a new way of processing in which dynamically scalable and often virtualized resources are delivered as services via the Internet (Furth, Escalante, 2010);

- an IT service model in which computing services are delivered to customers on demand over the network in a self-service manner, regardless of device and location (Marston et al., 2011);
- storage devices to store and maintain the data and applications (Rajeswari, 2019).
- various types of services and applications provided in the Internet cloud and the fact that, in many cases, the devices used to access these services and applications do not require any special applications (Introduction…, 2024).
The most important properties of Cloud Computing include (Introduction..., 2024):
- shared infrastructure that uses a virtual software model, enabling the sharing of physical services, storage, and networking capabilities. This solution seeks to maximize the use of available infrastructure among many users;
- dynamic provisioning enables the provision of services based on the current demand reported by users. This is done automatically using appropriate software, allowing you to expand and shrink service capabilities as needed;
- network access is necessary, which requires access via the Internet from a wide range of devices, such as computers, laptops or mobile devices;
- managed metering uses measurements to manage and optimize services and provide reporting and billing information. As a result, users pay for services based on how much they use in a given billing period.
Cloud Computing can be classified according to the adopted models and types (table 1).

**Table 1. Cloud Computing models and types**

| Models: | | Types: | |
|---|---|---|---|
| Public | Solutions are available to everyone interested recipients | IaaS – Infrastructure as a Service | The supplier offers access to hardware infrastructure components by generating images of virtual machines that have the computing power defined and required by the recipient, along with the operating system and the required disk space |
| Private | Solutions are created and available exclusively to the individual enterprise, organization, or individual entity | PaaS – Platform as a Service | It involves the supplier, in addition to the necessary infrastructure, also providing a programming environment for creating, launching, |

| | | | and developing applications based on Internet technologies of varying degrees of complexity |
|---|---|---|---|
| Partner | Solutions are available to a selected group of enterprises or organizations pursuing common goals and having common areas of interest | SaaS – Software as a Service | Solutions are available to a selected group of enterprises or organizations pursuing common goals and having common areas of interest |
| Hybrid | The solutions are a combination of different types of clouds, e.g., public and private | CaaS - Communications as a Service | The service provider provides recipients with a telecommunications platform (e.g. e-mail, instant messaging, voice calls, voicemail, video calls) |
| Dedicated | A solution in the form of a separate part of the provided cloud for a given enterprise, organization, or entity that does not have sufficient resources to create its private cloud or does not want to use a typical public cloud | BPaaS - Business Process as a Service | The recipient transfers the implementation of an established business process (e.g., accounting, advertising, helpdesk) to the supplier in the form of a service, and the recipient supervises the correctness of the process |

**Source:** Dziembek, (2019)

There are also services available on the market, such as BaaS (Backup as a Service), EaaS (E-mail as a Service), AaaS (Archive as a Service), and others.

Sustainability and sustainable development are two concepts often treated as synonyms despite their significant differences. Sustainability means prioritizing environmental practices, emphasizing the preservation of the good condition of the natural environment in the face of constant technological progress, industrialization, and globalization (Ruggerio, 2021). In turn, sustainable development means

activities related to economic development and includes activities related to economic growth increasing social well-being, among others. By improving the condition of the natural environment (Duran et al., 2015). It can, therefore, be assumed that the concept of "sustainable development" is broader, covering the economic and social dimensions to some extent. At the same time, sustainability puts the main emphasis on issues related to the natural environment. However, despite these differences, both concepts adhere to the doctrine of conserving resources and meeting our needs without limiting the ability of future generations to meet their own needs. (Moore et al., 2017).

Sustainable development is derived directly from the idea of development that has accompanied societies since the dawn of time - the constant pursuit of discovering, learning, improving, or giving a physical character to ideas and ideas (Ashby et al., 2012; Szczepańska-Woszczyna and Kurowska-Pysz, 2016; Rydecki and Chłąd, 2023). Thus, sustainability, the emerging concept of sustainable development, was used as a suggestion regarding a more responsible use of forest resources.

Sustainable development organizes previously known values and seeks to combine them into a coherent system, the advantages of which include, among others, reconciling conflicting economic, social, and ecological interests. Referring sustainable development to one of the many definitions of systems, it is possible to treat it as a system operating for a specific purpose, consisting of elements interconnected through certain relationships and jointly implementing the assumed functions. One of the elements of this system is cloud computing, as one of the tools of information and communication technologies, which affects the functioning of entities not only in the economic dimension but also in the social and environmental dimensions. Awareness of this impact has created many concepts emphasizing sustainability in cloud computing.

Cloud Computing plays a key role in helping organizations become more sustainable. It facilitates the business case for a sustainable approach by reducing carbon footprint and associated costs while supporting the research and innovation necessary to build a viable future with sustainability in mind.

According to MJ Khan et al. (2022), sustainable cloud computing is the most popular technology in the modern era. The ecological aspect of the cloud is one of the most significant advantages of cloud computing. The environmental benefits of cloud services include reducing the company's carbon footprint, better data center performance, dematerialization, environmental savings, and lower electricity consumption. (Devi and Ganesan, 2019).

Green cloud computing technology has become an essential aspect of designing and using cloud computing in organizations (Kumar et al., 2022). Green cloud computing is the science and practice of properly designing, manufacturing, using, and disposing of computers, servers, and related subsystems, such as displays, printers, storage devices, and networking and communication systems, while minimizing or eliminating environmental impacts (Samyukthaa and Vinothraja, 2022).

The popularity of sustainability in cloud computing results from the fact that more and more enterprises consider the level of CO2 emissions and the overall carbon footprint generated by modern information and communication technologies, including cloud computing. Sustainability in cloud computing refers to a sustainable method that reduces energy demand while caring for the natural environment. Moving traditional IT infrastructure to the cloud benefits the environment for several reasons. First, it reduces the number of physical servers and increases the average utilization of available computing units (Li et al., 2017). If cloud service providers get it right, a measurable impact on a company's CO2 footprint can be achieved. Sustainability in cloud computing also applies practices that, among others, reduce energy consumption and greenhouse gas emissions, assume the use of renewable energy from various sources, maximize energy efficiency, promote recycling, and strive to minimize the use of hazardous materials. Sustainable Cloud Computing includes the use of renewable energy instead of grid energy generated from fossil fuels, the use of waste heat generated by heat dissipation servers, the use of free cooling mechanisms, and the use of energy-saving mechanisms. All these factors contribute to reducing carbon footprint, operating costs, and energy consumption.

Based on the above consideration, the following RQ can be formulated:

RQ: What is the current state of knowledge regarding sustainability in cloud computing?

The analyses presented below will ultimately make it possible to answer this question.

## Research Methodology and Materials

There are several approaches in the literature review methodology: systematic literature review, semi-systematic literature review, and integrative literature review (Snyder, 2019). This article conducts a systematic literature review (SLR) with an organized, transparent, and replicable methodology and presentation. These include a comprehensive and systematic search to locate all relevant published works that address the topic being analyzed, along with a systematic presentation and integration of the characteristics and conclusions drawn from the research conducted (Agazu and Kero, 2024). The aim of SLR was not only to identify a core set of bibliometric performance indicators but also to find the main research areas regarding the sustainability of cloud computing. The conducted SLR not only made it possible to identify the process of evolution of publications on sustainability in cloud computing but also guided the possibilities and directions of future research on the analyzed issue.

The PRISMA procedure was used to conduct the SLR, which involves a four-phase process of minimal "evidence-based" analysis and reporting of existing literature through "systematic reviews and meta-analyses" (David et al., 2023).

The article aims to systematically review the literature to determine the current state of knowledge on sustainability in cloud computing. Moreover, the aim is also to identify the practical dimension of sustainability in cloud computing in various areas

and fields. This will ultimately enable an understanding of the essence of sustainability in cloud computing.

Bearing in mind that the aspect of sustainability in cloud computing takes the form of concepts such as "sustainable cloud computing", "green cloud computing", "green cloud", cloud computing sustainability", "cloud sustainability", the paper search process has been delimited by the following research strings:

- For Scopus database: (TITLE-ABS-KEY("cloud computing") AND TITLE-ABS-KEY((sustainability OR sustainable OR "sustainable development" OR "green" OR "green cloud" OR "cloud computing sustainability" OR "green cloud sustainability"))) AND PUBYEAR > 2008 AND PUBYEAR < 2024 AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO(PUBSTAGE,"final")) AND (LIMIT-TO(SUBJAREA,"BUSI")) AND ( LIMIT-TO ( DOCTYPE,"ar")).

- for Web of Science database: (Title-Abstract-Author Keywords("cloud computing") AND Title-Abstract-Author Keywords(sustainability OR sustainable OR "sustainable development" OR "green" OR "green cloud" OR "cloud computing sustainability" OR "green cloud sustainability")
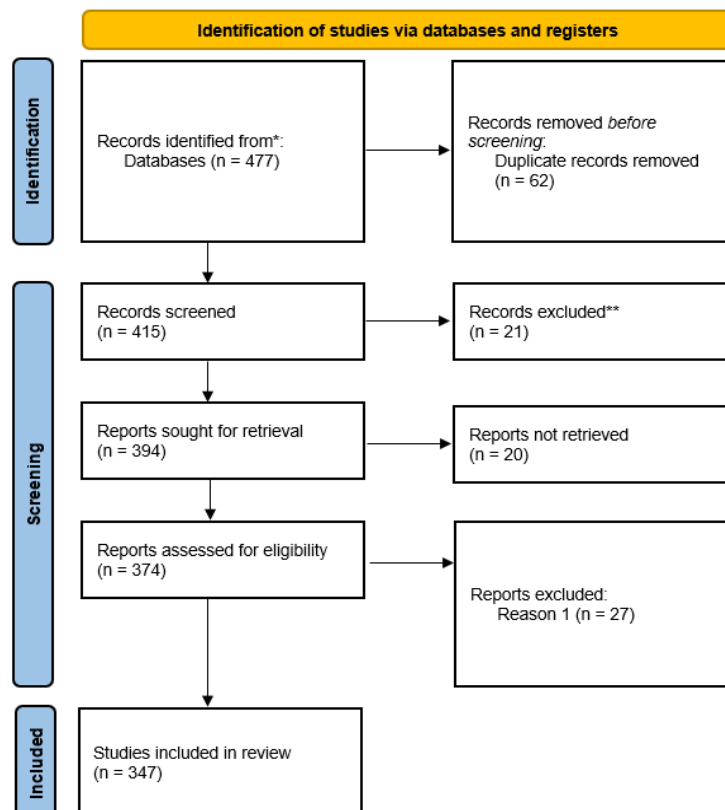


**Figure 1: PRISMA procedure**

The studies also included specific inclusion and exclusion criteria. Inclusion criteria included time of publication, publication status, publication type, scientific area, and publication language. However, the exclusion criteria included relevance, quality, and duplication. The process of identifying articles for exclusion was carried out manually. First of all, all duplicate publications were removed, then the abstracts of all articles were read, and the article's content was checked to see whether it matched the mentioned keywords. The research method adopted was bibliometric analysis, often used to examine trends and results of scientific research in many scientific disciplines. A bibliometric analysis was carried out to meet the adopted goals based on data obtained from the Scopus and Web of Science databases. The reason for using these two databases is that these databases index the most significant number of journals among the other databases.

**Table 2. Summary of data source and selection criteria**

| Category | Specific standard requirements |
|---|---|
| Research databases | Scopus and Web of Science |
| Searching period | From 2000 to 2023 |
| Language | English |
| Type of the publication | Article |
| Search within: | Article title, Abstract, Keywords |
| Publication status | Final |
| Research area | Social Sciences, Environmental Science, Business, Management and Accounting |
| Keywords: | Cloud computing, sustainability, sustainable development, green cloud computing, green computing, green cloud sustainability, cloud sustainability, cloud computing sustainability |
| Data extraction: | Export with records to the CSV file |

**Source:** Own elaboration

**Research Results**

To understand the sustainability research field in Cloud computing, it is worth presenting basic quantitative information that will illustrate the development trend

of the analyzed issue. Figure 2 presents the distribution of articles analyzed from 2010 to 2023.
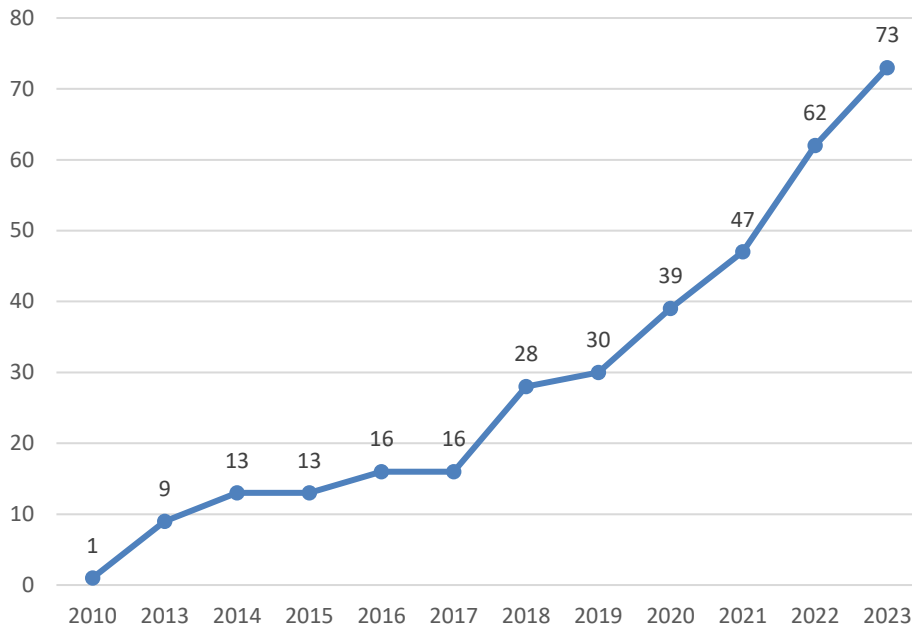


**Figure 2: Publications' time trend based on Scopus and Web of Science**

First of all, it can be said that the issue of sustainability in cloud computing is relatively new. Until 2010, no article meeting the adopted criteria was indexed in the Scopus and WoS databases. This may be because, at that time, scientists focused more on the issue of cloud computing and its impact on the functioning of entities or the perceived benefits resulting from its use, ignoring social and environmental aspects. However, since 2010, there has been a generally clear upward trend in the number of articles published yearly. This period shows great interest in this topic. It can be assumed that the number of scientific articles will continue to increase in the coming years. Research on the issue of sustainability in cloud computing will attract the attention of an increasingly more comprehensive group of researchers.

*Journals' analysis*

Journals are the best place to publish scientific articles. Very often, the decision to publish an article in a given journal is made based on two criteria: the number of articles published and the number of citations. A more significant number of scientific articles and a high number of citations translates into the journal's IF, proving its high impact on a given scientific field. Table 3 below presents the first seven journals with the largest number of published articles in the area of sustainability in cloud computing.

**Table 3. The list of the most productive journals indexed
in Scopus and Web of Science**

| Journal title | Number of articles | Number of citations | Avg cit per article | IF |
|---|---|---|---|---|
| Sustainability | 60 | 3592 | 59,86 | 3,9 |
| Remote Sensing | 21 | 1423 | 67,76 | 5 |
| Journal of Cleaner Production | 17 | 1305 | 76,76 | 11,1 |
| International Journal of Grid and Utility Computing | 12 | 79 | 6,58 | 0,5 |
| International Journal of Scientific and Technology Research | 7 | 89 | 12,71 | 0 |
| Journal of Network and Systems Management | 6 | 192 | 32,00 | 3,6 |
| International Journal of Networking and Virtual Organisations | 5 | 13 | 2,60 | 0 |

**Source:** Own elaboration

While the table above presents the first seven journals with the largest number of published articles in the area of sustainability in cloud computing, it is worth mentioning that the total number of journals in which you can find scientific articles on this issue is 163. On the one hand, this indicates a large dispersion of the published articles; on the other hand, it may indicate that the topics discussed correspond to the scientific profiles of many journals. Regarding the number of published articles, the undisputed leader is the Sustainability journal, which published almost 20% of all analyzed articles. Sustainability is also the leader in the total number of citations - articles on the issue of sustainability in cloud computing have been cited over 3.5 thousand times. The Remote Sensing journal is behind this journal, which published 21 articles and was cited over 1.4 thousand times. In third place is the Journal of Cleaner Production, which has published over 21 articles on the issue of sustainability in cloud computing. In total, they were cited over 1,300 times. The next place is the International Journal of Grid and Utility Computing, which published 12 articles with 79 citations. Right after this journal, there is the International Journal of Scientific and Technology Research, which published seven articles and cited 89 times. However, it is worth noting that there is a particular relationship between the IF value of a given journal and the average number of citations per article. Among the journals listed, the Journal of Cleaner Production

has the highest IF and average citation per article. The same applies to other journals, and it is visible that the greater the IF of a given journal, the greater the average citation of a single article. Although sustainability is characterized by the largest number of published articles and the highest number of citations, on average, one article was cited 59 times, translating into an IF of 3.9. The opposite happens only in the case of the International Journal of Scientific and Technology Research. Although its IF value is 0, each published article was cited on average 12 times. However, it can be assumed that the Journal of Cleaner Production and the Journal of Network and Systems Management publishes the most valuable articles on the analyzed issue.

*The main aspects of sustainability in cloud computing*

To determine or identify the main aspects of sustainability in cloud computing that are the subject of scientific considerations, scientific articles that met the search criteria and were published in 2019-2023 were thoroughly reviewed. The review shows that CC affects sustainable development in various areas.

First, CC influences enterprises' sustainable development, manifested in better environmental, financial, and social results (Al-Sharafi et al., 2023). Thanks to the opportunities offered by CC, enterprises can adapt their activities to demanding business environments, ensuring long-term sustainable development and strategic flexibility (Pilipczuk, 2021). CC enables creating and maintaining a sustainable work environment where employees can devote more time to innovative and creative activities (Gupta and Jauhar, 2023). CC enhances the effect of using green methods in personnel management, stimulates the implementation of the corporate sustainable development strategy, and opens new career opportunities for employees (Shayegan et al., 2023). CC, as one of the main elements of digital transformation, provides enterprises with new ways to strengthen ecological (green) innovations (Fan et al., 2022; Feng et al., 2022) and achieve sustainable development (Bai et al., 2022). The main benefits of CC regarding environmental sustainability include improved energy efficiency, reduced carbon footprint, reduced operating costs, and reduced e-waste (Dura et al., 2022). Sustainability in cloud computing also means striving to increase the use of renewable energy at the expense of reducing energy consumption from non-renewable sources (Patchell and Hayter, 2021).

In the industrial sector, sustainability in cloud computing is manifested, among others, in the impact of CC on sustainable production by decentralizing supply chains and optimizing sustainable production by reducing over- or under-production by anticipating customer requirements (Hector et al., 2021). It has a significant impact on the transformation of conventional production plants into smart factories, contributing to the development of a circular economy bringing significant economic, environmental, and social benefits (Pandey et al., 2023; Mesjasz-Lech et al., 2024) and driving innovation in the field of green technologies (Sun et al., 2023). SaaS provides operational benefits by facilitating energy-efficient manufacturing, while IaaS reduces the energy consumption of internal hardware and IT infrastructure (Park et al., 2023).

CC has a significant impact on the sustainable development of cities (Gupta et al., 2023), e.g., thanks to the use of financial CC, which, by influencing the city's financial system, contributes to the optimization of its financial structure, increasing the efficiency of its development, and promotes close integration of science and technology and finance (Abbasi et al., 2023) and promotes a green economy and sustainable management (Song et al., 2023). Sustainability in cloud computing manifests itself in improving the quality of life, increasing the efficiency of the economy and infrastructure, ensuring the safety of communities, and promoting the sustainable development of a smart city (Kalenyuk et al., 2023).

In logistics, sustainability in cloud computing enables the selection of the most promising scenario for developing an intelligent reverse logistics system, which will serve as a guide when making decisions in building sustainable circular economy systems and closed supply chains (Krstic et al., 2022). It also influences the transformation of supply chains into more economical, agile, and ecological chains. Using CC in the last mile supply system is a good way to increase operational efficiency, save time and energy, and improve sustainability in SCM (Akkad et al., 2022). In port logistics, sustainability in cloud computing influences the promotion of intelligent and sustainable development of logistics (D'Amico et al., 2021). Sustainability in cloud computing also contributes to the development of sustainable supply chain finance (SSCF) (Soni et al., 2022).

To sum up, the impact of sustainability in cloud computing is highly diverse and occurs in many areas.

**Table 4. An impact of sustainability in cloud computing in different areas**

| Sustainability in cloud computing | Enterprises | - improves the economical, social and ecological outcomes,<br>- promotes strategic flexibility,<br>- creates the sustainable work environment,<br>- promotes green management,<br>- enhances sustainable corporation strategy,<br>- introduces ecological (green) innovations,<br>- allows for better energy efficiency,<br>- decreases in carbon footprint<br>- decreases operational cost,<br>- decreases e-waste level,<br>- increases in renewable energy use |
|---|---|---|

| | | |
|---|---|---|
| | Industry | - decentralizes supply chains,<br>- optimizes sustainable production by reducing over- or under-production by anticipating customer requirements,<br>- it has a significant impact on the transformation of conventional production plants into smart factories,<br>- contributes to the development of a circular economy bringing significant economic, environmental, and social benefits<br>- drives innovation in the field of green technologies,<br>- provides operational benefits by facilitating energy-efficient manufacturing,<br>- optimizes the resource allocation,<br>- reduces the energy consumption of internal hardware and IT infrastructure |
| | Cities' development | -contributes to the optimization of its financial structure, increasing the efficiency of its development<br>- promotes close integration of science and technology and finance<br>- promotes a green economy and sustainable management<br>- increases the efficiency of the economy and infrastructure,<br>- ensures the safety of communities, - promotes the sustainable development of a smart city |
| | Education | - contributes to creating a sustainable environment that strives for the coherence of the population with its surroundings in such a way as to guarantee economic growth in balance with the social and natural environment,<br>- enables the implementation of mobile learning, which in the educational dimension plays a very significant role in sustainable development |
| | Logistics | - enables the selection of the most promising scenario for developing an intelligent reverse logistics system,<br>- influences the transformation of supply chains into more economical, agile, and ecological chain,<br>- increase operational efficiency, save time and energy, and improve sustainability in SCM,<br>- influences the promotion of intelligent and sustainable development of logistics,<br>- contributes to the development of sustainable supply chain finance (SSCF) development<br>- sustainable supply chain finance development |

| | | |
|---|---|---|
| | Other areas: | - has impact on the creation of a digital economy perceived as a clean, efficient and ecological economy, <br> - makes clinical data repositories more sustainable, <br> - promotes standardized and computerized medical waste management <br> - contributes to the creation of an ecological e-procurement system <br> - contributes to introducing sustainable innovations (social and environmental, only social and only environmental). <br> - contributes to the development and protection of marine resources and promotes sustainable development. |

**Source:** Own elaboration

Moreover, research conducted by many scientists has confirmed that sustainability in cloud computing is also manifested in improved production efficiency and optimization of resource allocation (Saah et al., 2019), impact on the creation of a digital economy perceived as a clean, efficient and ecological economy (Su et al., 2022). The impact of sustainability in cloud computing on issues related to healthcare is equally noticeable, e.g., the use of CC in creating, storing, and collecting medical records makes clinical data repositories more sustainable (Augustyn et al., 2021); promotes standardized and computerized medical waste management (Cheng and Ma, 2022) or contributes to the creation of an ecological e-procurement system (Fu et al., 2019). Sustainability in cloud computing also generates benefits for the aviation sector, especially concerning their sustainable development (Nunes and Barbosa, 2020). Sustainability in cloud computing contributes to introducing sustainable innovations (social and environmental, only social and only environmental) (Ardito, 2023). In the maritime economy, sustainability in cloud computing not only contributes to the development and protection of marine resources and promotes sustainable development (Yuo et al., 2020). In education, sustainability in cloud computing contributes to creating a sustainable environment that strives for the coherence of the population with its surroundings in such a way as to guarantee economic growth in balance with the social and natural environment. CC enables the implementation of mobile learning, which in the educational dimension plays a very significant role in sustainable development (Ahmad et al., 2020). Also, in the construction sector, the impact of CC on the development of sustainable construction is noticeable, and the adoption of CC methods and tools in construction projects has a positive impact on the implementation of sustainable construction projects (Oke et al., 2023).

**Conclusion**

Enterprises operating on the market have been using IT solutions for many years, of which cloud computing is one of the main elements. While initially, the benefits of its use were perceived only in economic terms, e.g., reducing operational costs of IT infrastructure, attention is now drawn to the impact of cloud computing on social and ecological aspects.

The systematic review of the literature on the issue of sustainability in cloud computing conducted in this article clearly shows that the impact of cloud computing on social and environmental issues is comprehensive. This dimension is identified in enterprises perceived as the main users of cloud solutions and large clusters, industries, and education.

The review of the literature in this area allows us to conclude that the issue of sustainability in cloud computing is a fresh issue that attracts the attention of an increasing number of researchers. This is due to the growing awareness of the role and impact of cloud computing on social and environmental issues. The obtained results also indicate that cloud computing, along with the Internet of Things, AI, blockchain, and Big Data, is one of the tools that fit into the framework of digital technologies and digital transformation, which currently influences the shaping of life in all its areas.

A further review of the literature, taking countries as a selection criterion, could be considered as a future direction for research in this area. It will make it possible to examine how sustainability in cloud computing is perceived depending on a given country or group of countries (e.g., those remaining at a similar level of development). It is also worth conducting research, taking different industries as a selection criterion, which will enable obtaining an image of what form sustainability in cloud computing takes depending on a given industry, which may ultimately enable, for example, the identification of good practices in the area of sustainability concerning cloud computing.

## References

Abbasi, R., Bashir, A. K., Almagrabi, A. O., Heyat, M. B. bin and Yuan, G., (2023). Efficient lossless based secure communication in 6G Internet-of-Things environments. *Sustainable Energy Technologies and Assessments*, *57*, 10-32.

Agazu, B. G., Kero, C. A., (2024). Innovation strategy and firm competitiveness: a systematic literature review. *Journal of Innovation and Entrepreneurship*, *13*(1), 264-283.

Ahmad, N., Hoda, N. and Alahmari, F., (2020). Developing a cloud-based mobile learning adoption model to promote sustainable education. *Sustainability*, *12*(8), 1-18 .

Akkad, M. Z., Rabee, R. and Banyai, T., (2022). Energy Efficiency Optimization of Last Mile Supply System with Reverse Logistics Consideration. *Acta Logistica*, *9*(3), 315-323.

Al-Sharafi, M. A., Iranmanesh, M., Al-Emran, M., Alzahrani, A. I., Herzallah, F. and Jamil, N., (2023). Determinants of cloud computing integration and its impact on sustainable performance in SMEs: An empirical investigation using the SEM-ANN approach. *Heliyon*, *9*(5), 123-140.

Ardito, L., (2023). The influence of firm digitalization on sustainable innovation performance and the moderating role of corporate sustainability practices: An empirical investigation. *Business Strategy and the Environment*, *32*(8), 5252-5272.

Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R. H., Konwinski, A. and Zaharia, M., (2009). Above the clouds: A Berkeley view of cloud computing. *Technical Report UCB/EECS-2009-28*, EECS Department, University of California, Berkeley.

Ashby, A., Leat, M. and Hudson-Smith, M., (2012). Making connections: a review of supply chain management and sustainability literature. *Supply chain management: an international journal, 17*(5), 497-516.

Augustyn, D. R., Wyciślik, Ł., Sojka, M., (2021). The cloud-enabled architecture of the clinical data repository in Poland. *Sustainability, 13*(24), 1-17.

Bai, F., Huang, Y., Shang, M. and Ahmad, M., (2022). Modeling the impact of digital economy on urban environmental pollution: Empirical evidence from 277 prefecture-level cities in China. *Frontiers in Environmental Science*, *10*, 161-180.

Chellappa, R., (1997). Intermediaries in cloud-computing: A new computing paradigm. INFORMS Annual Meeting, Dallas, 26–29.

Cheng, D. E., Ma, J., (2022). Research on Hospital Medical Waste Management under the Background of Internet. *Fresenius Environmental Bulletin*, *31*(2), 2203-2208.

Chidozie, B., Ramos, A., Ferreira, J. and Ferreira, L., (2024). The Importance of Digital Transformation (5.0) in Supply Chain Optimization: An Empirical Study. *Production Engineering Archives*, *30*(1) 127-135.

D'Amico, G., Szopik-Depczyńska, K., Dembińska, I. and Ioppolo, G., (2021). Smart and sustainable logistics of Port cities: A framework for comprehending enabling factors, domains and goals. *Sustainable Cities and Society*, *69*, 39-48.

David, A., Yigitcanlar, T., Li, R. Y. M., Corchado, J. M., Cheong, P. H., Mossberger, K. and Mehmood, R., (2023). Understanding local government digital technology adoption strategies: A PRISMA review. *Sustainability*, *15*(12), 1-43.

Devi, T., Ganesan, R., (2019). Environmental Benefits of Enhanced Hecc-Elgamal Cryptosystem for Security in Cloud Data Storage Using Soft Computing Techniques. *Ekoloji Dergisi*, *107*, 163-176.

Dura, C. C., Iordache, A. M. M., Ionescu, A., Isac, C. and Breaz, T. O., (2022). Analyzing performance in wholesale trade Romanian SMEs: Framing circular economy business scenarios. *Sustainability*, *14*(9), 1-34.

Duran, D. C., Gogan, L. M., Artene, A. and Duran, V., (2015). The Components of Sustainable Development - A Possible Approach. *Procedia Economics and Finance*, *26*, 806–811.

Dziembek, D., (2019). Adaptation of Cloud Computing in Polish Enterprises. In T. Parys (Ed.), *Informatyka i zarządzanie na przełomie wieków. Metody, narzędzia, systemy, zastosowania* (pp. 75–102). Wydawnictwo Naukowe Wydziału Zarządzania Uniwersytetu Warszawskiego.

Fan, X., Wang, Y. and Lu, X., (2022). Digital transformation drives sustainable innovation capability improvement in manufacturing enterprises: Based on FsQCA and NCA Approaches. *Sustainability*, *15*(1), 1-26.

Feng, H., Wang, F., Song, G. and Liu, L., (2022). Digital transformation on enterprise green innovation: Effect and transmission mechanism. *International Journal of Environmental Research and Public Health*, *19*(17), 448-464.

Foster, I., Zhao, Y., Raicu, I. and Lu, S., (2009). Cloud Computing and Grid Computing 360-Degree Compared. *Cloud Computing and Grid Computing 360-Degree Compared*, *5*, 419-433.

Fu, H. P., Chang, T. S., Yeh, H. P. and Chen, Y. X., (2019). Analysis of factors influencing hospitals' implementation of a green e-procurement system using a cloud model. *International journal of environmental research and public health*, *16*(24), 19-43.

Furth, B., Escalante, A., (2010). *Handbook of Cloud Computing*. Springer.

Garfinkel, S., (2011). The cloud imperative. *Technology Review*, *114*(6), 74-76.

Gupta, M., Jauhar, S. K., (2023). Digital innovation: An essence for Industry 4.0. *Thunderbird International Business Review*, *65*(3), 279–292.

Gupta, S., Alharbi, F., Alshahrani, R., Kumar Arya, P., Vyas, S., Elkamchouchi, D. H. and Soufiene, B. O., (2023). Secure and lightweight authentication protocol for privacy preserving communications in smart city applications. *Sustainability*, *15*(6), 1-21.

Hector, R., Umar, M., Mehmood, A., Li, Z. and Bhattacharyya, S., (2021). Scalable object detection for edge cloud environments. *Frontiers in Sustainable Cities*, *3*, 177-202.

Huth, A., Cebula, J., (2011). The basics of cloud computing. *United States Computer*, 1-4.

Introduction to Cloud Computing. Dialogic, (2017). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.dialogic.com/~/media/products/docs/whitepapers/12023-cloud-computing-wp.pdf (accessed on 5 May 2024).

Kalenyuk, I., Bohun, M. and Djakona, V., (2023). Investing in intelligent smart city technologies. *Baltic Journal of Economic Studies*, *9*(3), 41–48.

Khan, M. J., Ullah, F., Imran, M., Khan, J., Khan, A., AlGhamdi, A. S. and Alshamrani, S. S., (2022). Identifying challenges for clients in adopting sustainable public cloud computing. *Sustainability*, *14*(16), 1-27.

Krstić, M., Agnusdei, G. P., Miglietta, P. P. and Tadić, S., (2022). Evaluation of the smart reverse logistics development scenarios using a novel MCDM model. *Cleaner Environmental Systems*, *7*, 582-604.

Kumar, C., Marston, S., Sen, R. and Narisetty, A., (2022). Greening the cloud: a load balancing mechanism to optimize cloud computing networks. *Journal of Management Information Systems*, *39*(2), 513–541.

Li, X., Garraghan, P., Jiang, X., Wu, Z. and Xu, J., (2017). Holistic virtual machine scheduling in cloud datacenters towards minimizing total energy. *IEEE Transactions on Parallel and Distributed Systems*, *29*(6), 1317–1331.

Liu, F., Tong, J., Mao, J., Bohn, R., Messina, J., Badger, L. and Leaf, D., (2011). NIST cloud computing reference architecture. *NIST special publication*, *500*, 292-295.

Madhavaiah, C., Bashir, I., (2012). Defining Cloud Computing in Business Perspective: A Review of Research. *Metamorphosis: A Journal of Management Research*, *11*, 50–65.

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J. and Ghalsasi, A., (2011). Cloud computing — The business perspective. *Decision Support Systems*, *51*(1), 176–189.

Mesjasz-Lech, A., Kemendi, Á. and Michelberger, P., (2024). Circular manufacturing and Industry 5.0. assessing material flows in the manufacturing process in relation to e-waste streams. *Engineering Management in Production and Services*, *16*(1), 114-133.

Moore, J., Mascarenhas, A., Bain, J. and Straus, S., (2017). Developing a comprehensive definition of sustainability. *Implementation Science*, *12,* 53-74.

Nunes, V. A., Barbosa, G. F., (2020). Simulation-based analysis of AGV workload used on aircraft manufacturing system: a theoretical approach. *Acta Scientiarum. Technology*, *42,* 40-61.

Oke, A. E., Kineber, A. F., Alsolami, B. and Kingsley, C., (2023). Adoption of cloud computing tools for sustainable construction: A structural equation modelling approach. *Journal of Facilities Management*, *21*(3), 334-351.

Pandey, V., Sircar, A., Bist, N., Solanki, K. and Yadav, K., (2023). Accelerating the renewable energy sector through Industry 4.0: Optimization opportunities in the digital revolution. *International Journal of Innovation Studies*, *7*(2), 171–188.

Park, J., Han, K. and Lee, B., (2023). Green cloud? An empirical analysis of cloud computing and energy efficiency. *Management Science*, *69*(3), 1639–1664.

Patchell, J., Hayter, R., (2021). The cloud's fearsome five renewable energy strategies: coupling sustainable development goals with firm specific advantages. *Journal of Cleaner Production*, *288*, 58-71.

Pilipczuk, O., (2021). Transformation of the Business Process Manager Profession in Poland: The Impact of Digital Technologies. *Sustainability*, *13*, 1-20.

Plummer, D. C., Bittman, T. J., Austin, T., Cearley, D. W. and Smith, D. M., (2008). Cloud Computing: Defining and Describing an Emerging Phenomenon. *Gartner*, 1-9.

Rajeswari, M., (2019). Overview of cloud computing and its types. *Electronic Journal*, *6*, 61–67.

Ruggerio, C. A., (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of The Total Environment*, *786*, 35-52.

Rydecki, J., Chłąd, M., (2023). Sustainability in Global Supply Chains: A Consumer-Centric Perspective. *Global Journal of Entrepreneurship and Management*, *4*(2), 11-28.

Saah, D., Tenneson, K., Matin, M., Uddin, K., Cutter, P., Poortinga, A., Nguyen, Q. H., Patterson, M., Johnson, G. and Markert, K., (2019). Land cover mapping in data scarce environments: challenges and opportunities. *Frontiers in Environmental Science*, *7*, 339-350.

Samyukthaa, L. K., Vinothraja, R., (2022). Challenges and Approaches in Green Data Center. *Journal of Advanced Applied Scientific Research*, *4*(1), 95-105.

Snyder, H., (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339.

Song, C., Qiu, Z. and Yang, L., (2023). How does digital financial inclusion affect green economic development? A perspective from regional competitions. *Elementa: Science of the Anthropocene*, *11*(1), 1-23.

Soni, G., Kumar, S., Mahto, R. v, Mangla, S. K., Mittal, M. L. and Lim, W. M., (2022). A decision-making framework for Industry 4.0 technology implementation: The case of FinTech and sustainable supply chain finance for SMEs. *Technological Forecasting and Social Change*, *180*, 90-97.

Su, J., Su, K. and Wang, S., (2022). Evaluation of digital economy development level based on multi-attribute decision theory. *Plos One*, *17*(10), 188-202.

Sun, Z., Liu, J. and Tansuchat, R., (2023). China's Digital Economy and Enterprise Labor Demand: The Mediating Effects of Green Technology Innovation. *Sustainability*, *15*(15), 1-24.

Szczepańska-Woszczyna, K., Kurowska-Pysz, J., (2016). Sustainable business development through leadership in SMEs. *Engineering Management in Production and Services*, *8*(3), 57-69.

Vaquero, L. M., Rodero-Merino, L., Caceres, J. and Lindner, M., (2009). A break in the clouds: towards a cloud definition. *SIGCOMM Computer Communication Review*, *39*(1), 50–55.

You, L., Zhang, G. and Wang, L., (2020). Research on the Development of Marine Information Technology in the Era of Big Data. *Journal of Coastal Research*, *106*, 624-627.

Zhang, Q., Cheng, L. and Boutaba, R., (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7–18.

# AKTUALNE PERSPEKTYWY ZRÓWNOWAŻONEGO ROZWOJU W CHMURZE OBLICZENIOWEJ: KOMPLEKSOWY PRZEGLĄD

**Streszczenie:** Technologie informatyczne już od wielu stanowią jeden z głównych elementów życia, zarówno w odniesieniu do ludzi jak i przedsiębiorstw. Wraz z powstaniem Internetu a następnie jego upowszechnieniem, dokonała się rewolucja cyfrowa w efekcie której trudno wyobrazić sobie rzeczywistość bez komputerów, telefonów, przeglądarek internetowych czy komunikatorów. W tej grupie, coraz bardziej znacząca role odgrywa chmura obliczeniowa, umożliwiająca przechowywanie i przetwarzanie dużej ilości danych, które są dostępne za pośrednictwem Internetu.

Jednocześnie coraz bardziej rosnąca świadomość odnośnie zrównoważonego rozwoju i jego roli jaką obecnie odgrywa, powoduje, że od kilku lat, kwestia ta eksplorowana jest w kontekście chmury obliczeniowej. Dlatego też celem niniejszego artykułu jest dokonanie systematycznego przeglądu literatur dotyczącego kwestii zrównoważenia w chmurze obliczeniowej. Badanie objęło publikacje naukowe pochodzące z dwoch baz – Scopus and Web of Science, a sam przegląd dokonany został w oparciu o procedurę PRISMA. Po przeprowadzeniu wstępnej analizy ilościowej, dokonano szczegółowego przeglądu publikacji w celu określenia roli i wpływu zrównoważenia chmury obliczeniowej na poszczególne obszary, w których jest ona stosowana co stanowi o nowości artykułu. Uzyskane wyniki pokazują, że po pierwsze zrównoważenie chmury obliczeniowej to zagadnienie, które obecnie zyskuje na popularności, co przejawia się rosnącą liczbą publikacji naukowych. Ponadto charakteryzuje się różnorodnym wpływem na kwestie społeczne i środowiskowe, w zależności od obszaru w jakim chmura obliczeniowa jest stosowana. Ponadto z przeglądu wynika, że chmura obliczeniowa postrzegany jest jako jeden z głównych elementów transformacji cyfrowej.

**Słowa kluczowe:** chmura obliczeniowa, zrównoważenie, zrównoważony rozwój, zielony, systematyczny przegląd literatury