EasyChair Preprint

№ 13491

Energy Management and Digital Technologies: a Study Focusing on Their Relationship

Breno Gabardo Pallú, Nathalia Monteiro,
Sergio E. Gouvea Da Costa, Fernando Deschamps and
Edson Pinheiro De Lima

May 31, 2024

Energy management and digital technologies: a study focusing on their relationship

Breno Gabardo Pallu[1], Nathalia Juca Monteiro[23][0000-0002-2619-2667], Sergio E. Gouvea da Costa[1], Fernando Deschamps[2] and Edson Pinheiro de Lima[1]

[1] Universidade Tecnológica Federal do Paraná, Pato Branco, Brazil
[2] Pontificia Universidade Católica do Paraná, Curitiba, Brazil
[3.]Universidade do Estado do Pará, Belém, Brazil
nathalia.monteiro@uepa.br

Abstract. The 7th Sustainable Development Goal of the United Nations targets a twofold increase in energy efficiency improvement rates. However, the current global energy crisis from the Ukraine-Russia conflict adversely affects the manufacturing sector, the primary contributor to rising global electricity demand. In response, companies use energy management (EM) strategies to enhance efficiency and cut costs. Integrating technology information systems is a vital step in EM implementation, with digital technologies (DT) playing a key role in coordinating activities. This paper explores the relationship between energy management and digital technologies, delving into the technologies utilized for EM issues and their applications. Conducting a systematic literature review using Scopus, Science Direct, and Web of Science databases, the study focused on energy and Industry 4.0 keywords over the past five years (2018-2023). Of 1,117 initially identified publications, 417 remained after removing duplicates, and only 40 papers met the inclusion criteria. The research identified 14 digital technologies, categorized into eight groups based on Industry 4.0 design principles. These categories were also used to classify the application of digital technologies in EM, aiding in determining the appropriate DT investments for specific applications. The study's limitation lies in its reliance on a literature review, and the proposed categorization awaits validation in real-case scenarios, paving the way for future research.

Keywords: Energy management, Digital Technologies, Industry 4.0.

1 Introduction

Energy is a crucial issue for the manufacturing industry as it is one of the biggest energy users [1]. The Russian invasion of Ukraine resulted in the first global energy crisis, which hindered the recovery of global energy consumption after the COVID-19 pandemic [2]. Despite this, global demand for electricity increased by around 6% in 2021, with the industrial sector being the largest contributor to this increase [3].

More and more companies recognize the importance of energy management in enhancing energy efficiency. [4, 5], reducing costs and energy consumption [6].

Integrating a company's information systems is a crucial step in effectively managing energy [7]. With the advent of Industry 4.0, companies can leverage the advantages of digital technologies. Industries can be transformed by integrating production systems and intelligent processes, leading to a new era of technology [8].

Digital technologies are already being used for energy management, with the Internet of Things (IoT) being utilized to monitor power consumption [9] or to predict loads in a smart grid [10].

There is a relationship between energy management and digital technologies, as stated in the current literature. However, this connection needs more research. This paper aims to identify the digital technologies currently being used in energy management and present examples of how they are being used.

2 Method

To accomplish the objective of the research paper, a systematic literature review was realized, followed by a content analysis of the papers. Scopus, Science Direct, and Web of Science were used as the databases for the research.

To conduct a research study, two search axes were combined - Energy and Industry 4.0 - and combined eight keywords which are "energy selection", "energy management", "energy efficiency", "industry 4.0", "industrie 4.0", "smart factoring", "smart factor", and "smart manufacturing". Were only considered articles published in English, journals, or conference proceedings from the last five years (2018-2023).

After identifying 1,117 publications, 417 remained following the removal of duplicates. After applying filters to the title, abstract, and full paper, only 40 articles were used in the content analysis.

The results were grouped according to the design principles of Industry 4.0 identified by [11]: Interoperability, Virtualization, Decentralization, Real-time capability, Service orientation, Modularity, Smart product, and Corporate social responsibility. In this paper, seven principles were considered, except corporate social responsibility, because it requires studies of dimensions that were not analyzed in this paper.

3 Results

Fourteen digital technologies were identified by reading the papers, including the Internet of Things (IoT), Cyber-Physical Systems, Industrial Wireless Networks, Edge Computing, Cloud Manufacturing, Cybernetic Systems, Communication Systems, Sensors, Digital Twins, Autonomous robots/systems, Artificial Intelligence, Big Data, Blockchain, and 3D Printing. A table containing the technologies and their descriptions can be found in Table 1.

Table 1. Digital technologies and their description.

Code	Digital Technology	Description
1	IoT	Interconnection of physical devices, machines, and objects through the internet
2	Cyber-Physical Systems	Cybernetic and physical subsystems that assist in the collection, transmission, and analysis of data
3	Industrial Wireless Networks	Communication systems that enable connectivity among devices, machines, and systems in industrial environments through wireless technologies
4	Edge Computing	An approach that involves data processing and analysis happening closer to where the data is generated, instead of sending it to remote processing centers
5	Cloud Manufacturing	The hardware, software, and data resources are stored and accessed remotely through the internet
6	Cybernetic Systems	They are interconnected systems that involve the interaction among mechanical, electronic, and software components, along with constant feedback to control and regulate performance
7	Communication systems	Machine-to-machine communication
8	Sensors	Devices for monitoring systems (some in real-time)
9	Digital Twin	Virtual replicas of physical assets, processes, or systems
10	Autonomous robots/systems	Sets of technologies that operate independently
11	Artificial Intelligence	Creation of systems that can simulate human thought processes, with or without explicit programming
12	Big Data	Sets involving the collection, storage, and analysis of complex and varied information in large volumes
13	Blockchain	Distributed ledger technology that creates an interlinked chain of blocks to store information securely and transparently
14	3D Printing	Technology that enables the creation of three-dimensional objects from digital models using successive layers of materials such as plastic, metal, or ceramic

Table 2 outlines the various scenarios related to energy management where digital technologies can be utilized.

Table 2. Energy management applications and the associated technologies.

Applications	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Automation/Control	X	X	X	X	X	X	X			X	X			
Systems/Technologies integration	X	X	X	X	X	X	X			X	X			
Data analysis	X	X	X	X	X	X	X				X	X	X	X
Remote monitoring	X	X	X	X	X	X	X	X	X			X		
Online monitoring	X	X	X	X	X	X	X	X	X			X		
Autonomous maintenance	X					X	X			X	X	X	X	
Traceability	X	X	X		X	X		X				X		
Management systems					X						X	X	X	X
Interconnections in energy supply											X	X	X	
Cybersecurity	X	X									X	X	X	
Benchmarking	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy management systems					X						X	X	X	X

Table 2 mentions benchmarking, which is the practice of comparing performance, processes, or metrics with recognized standards as a reference. It is not possible to identify technologies solely for the purpose of benchmarking. Therefore, digital technologies were not associated with this application.

4 Discussion

Data analysis is crucial in energy management and is facilitated by various digital technologies. Large data sets are analyzed using data analysis methods to create models that can be converted into applications or tools that promote significant energy savings [12]. Additionally, such analysis can be employed to develop energy monitoring systems like the one suggested by [13] for electrical load forecasting.

Big data has been the most widely used digital technology in energy management applications. It can be utilized in various ways, as mentioned in [14] and [15]. Using big data, new energy industrialization can be implemented in areas such as energy power and energy storage systems [16].

IoT, cloud manufacturing, and artificial intelligence are the top digital technologies utilized. They have been employed in eight out of the twelve applications identified. Asadi et al. [17] researched IoT's impact on manufacturing performance. However, high energy consumption poses a significant obstacle to implementing IoT in supply chains [18]. This indicates a correlation between energy and the use of this technology.

The application of artificial intelligence in energy-related areas encompasses energy monitoring systems [19], bioenergy [20], and energy efficiency [21].

5 Conclusion

The manufacturing industries can benefit from the association between energy management and digital technologies, as they can improve the company's energy performance.

Although there are benefits, the relationship between the two components of energy management and digital technologies requires further investigation. This work aims to bridge this gap by identifying the digital technologies used in energy management and presenting common applications.

The study accomplished its objectives by thoroughly reviewing 40 academic papers. The review described fourteen different technologies and identified twelve potential applications. Data analysis was the most commonly used application for these technologies, with big data being the technology with the greatest potential for various applications.

As this study was conducted through a systematic literature review, it has certain limitations based on its research protocol. Therefore, the results require further investigation through real case studies to provide more detailed information about the relationship. Additionally, the study did not investigate the corporate social responsibility dimension of Industry 4.0.

Based on the limitations of the work, it is recommended that future research should conduct case studies in companies to investigate the relationship between digital technologies further and identify the benefits of their utilization. It is also recommended to observe how these technologies can improve a company's corporate social responsibility through actions in energy management.

References

1. Tesch da Silva, F.S., da Costa, C.A., Paredes Crovato, C.D., da Rosa Righi, R.: Looking at energy through the lens of Industry 4.0: A systematic literature review of concerns and challenges. Comput Ind Eng. 143, 106426 (2020).
2. International Energy Agency: World Energy Outlook 2022. (2022)
3. International Energy Agency: Electricity Market Report - Jan 2022. (2022)
4. Backlund, S., Thollander, P., Palm, J., Ottosson, M.: Extending the energy efficiency gap. Energy Policy. 51, 392–396 (2012).
5. Sola, A.V.H., Mota, C.M.M.: Influencing factors on energy management in industries. J Clean Prod. 248, (2020).
6. Schulze, M., Nehler, H., Ottosson, M., Thollander, P.: Energy management in industry – a systematic review of previous findings and an integrative conceptual framework. J Clean Prod. 112, 3692–3708 (2016).
7. May, G., Taisch, M., Kelly, D.: Enhanced energy management in manufacturing through systems integration. In: IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society. pp. 7525–7530. IEEE (2013)
8. Medojevic, M., Díaz Villar, P., Cosic, I., Rikalovic, A., Sremcev, N., Lazarevic, M.: Energy management in industry 4.0 ecosystem: A review on possibilities and concerns. Annals of DAAAM and Proceedings of the International DAAAM Symposium. 29, 0674–0680 (2018).

9. Wang, W., Yang, H., Zhang, Y., Xu, J.: IoT-enabled real-time energy efficiency optimisation method for energy-intensive manufacturing enterprises. Int J Comput Integr Manuf. 31, 362–379 (2018).
10. Alharthi, S., Johnson, P., Alharthi, M., Jose, C.: IoT/CPS Ecosystem for Efficient Electricity Consumption : Invited Paper. In: 2019 10th International Green and Sustainable Computing Conference, IGSC 2019. Institute of Electrical and Electronics Engineers Inc. (2019).
11. Dikhanbayeva, D., Shaikholla, S., Suleiman, Z., Turkyilmaz, A.: Assessment of industry 4.0 maturity models by design principles, (2020).
12. Tawalbeh, L., Delgado, J., Solis, S., Juarez, T., Tietjen, J.D., Muheidat, F.: Energy Consumption and Carbon Emissions Data Analysis: Case Study and Future Predictions. In: Procedia Computer Science. pp. 616–623. Elsevier B.V. (2023).
13. Hossain, M.S., Chowdhury, I.A.: DATAEMS: Design and development of a data analysis-based energy monitoring system. e-Prime - Advances in Electrical Engineering, Electronics and Energy. 6, (2023).
14. Jamwal, A., Agrawal, R., Sharma, M., Kumar, V., Kumar, S.: Developing A sustainability framework for Industry 4.0. In: Procedia CIRP. pp. 430–435. Elsevier B.V. (2021).
15. Li, C., Chen, Y., Shang, Y.: A review of industrial big data for decision making in intelligent manufacturing, (2022).
16. Hong, J., Liang, F., Yang, H.: Research progress, trends and prospects of big data technology for new energy power and energy storage system. Energy Reviews. 2, 100036 (2023).
17. Asadi, S., Nilashi, M., Iranmanesh, M., Hyun, S.S., Rezvani, A.: Effect of internet of things on manufacturing performance: A hybrid multi-criteria decision-making and neuro-fuzzy approach. Technovation. 118, (2022).
18. Yu, Z., Khan, S.A.R., Mathew, M., Umar, M., Hassan, M., Sajid, M.J.: Identifying and analyzing the barriers of Internet-of-Things in sustainable supply chain through newly proposed spherical fuzzy geometric mean. Comput Ind Eng. 169, (2022).
19. Maretto, L., Faccio, M., Battini, D.: A Multi-Criteria Decision-Making Model Based on Fuzzy Logic and AHP for the Selection of Digital Technologies. In: IFAC-PapersOnLine. pp. 319–324. Elsevier B.V. (2022).
20. Shi, Z., Ferrari, G., Ai, P., Marinello, F., Pezzuolo, A.: Artificial Intelligence for Biomass Detection, Production and Energy Usage in Rural Areas: A review of Technologies and Applications. Sustainable Energy Technologies and Assessments. 60, (2023).
21. Zhou, W., Zhuang, Y., Chen, Y.: How does artificial intelligence affect pollutant emissions by improving energy efficiency and developing green technology. Energy Econ. 131, 107355 (2024).