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ENERGY AWARENESS OF MANUFACTURING COMPANIES IN PURCHASING AND USING CLOUD COMPUTING SERVICES

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Purpose: The use of cloud services grows rapidly, due in part to the development of Industry 4.0 concept and massive use of new artificial intelligence applications. It should be noted that this involves significantly increased electricity consumption. This increase is mainly concentrated in data centers, but the understanding energy efficiency practices on user sides is also necessary.
Design/methodology/approach: The research problem of the article was the assessing the level of managers awareness in manufacturing companies regarding the energy consumption of cloud computing services. As a first step literature study was performed out on the importance of carrying out energy efficiency measures and practices, especially related to the development of cloud computing services. The empirical part of the study was based on a quantitative method, the opinions of 300 IT managers were collected using a questionnaire designed for this purpose (the Cronbach's alpha 0.957).
Findings: The overall of the importance of the investigated energy efficiency practices is low and their perception slightly varies according to the size of the organization.
Research limitations/implications: Only a few selected from wide range of practices were surveyed restricted to the area of purchasing and IT management. Managers' opinions were questioned, the research did not include documents (e.g. procurement documents) to confirm opinions.
Practical implications: The future introduction of the obligation to conduct an energy audit in medium and small organisations can raise awareness of the need for energy management in the procurement and use of IT services. It should be motivated and supported by activities carried out by governmental and social organisations.
Social implications: Increasing awareness and action related to energy management in the purchase and IT services management has a positive impact on the environment, especially while their massive use.
Originality/value: The article points out the need for organizations to raise awareness of the environmental impact of using cloud computing services in the area of energy efficiency and consumption. This is important both for organizations and for the bodies responsible for stimulating sustainable development activities.
Keywords: energy efficiency, Cloud Computing, energy awareness, manufacturing companies, resilience.
Category of the paper: research paper.

1. Introduction

The resilience of energy systems is important for the energy management of organizations as it ensures the stability of fuel and energy supply, which is fundamental for the functioning of the economy and society. Resilience, or the ability of a system to resist disruptions, refers to the ability to withstand disruptions due to technical failures, weather phenomena, catastrophes and intentional actions, e.g. cyber-attacks (Xu et al., 2023). Resilience is achieved by ensuring the ability to adapt to disruptions and the ability to adjust to changing conditions.

Resilience is not considered in Polish crisis management and critical infrastructure protection legislation with the exception of the National Programme for the Protection of Critical Infrastructure (RCB, 2023). Resilience has been considered in cyber security legislation. The issue of resilience is addressed by EU regulation. The Directive on the Resilience of Critical Entities defines resilience as 'the ability of a critical entity to prevent, protect against, respond to, resist, mitigate and absorb an incident and to adapt and recover from an incident' (EU, 2022). The document details the framework and elements for building and enhancing the resilience of critical entities (Wróbel, 2022, p. 169). Corporate energy management from an organizational resilience perspective takes two perspectives - the first is to optimize resources towards delivering energy efficiency to the organization. The growing demand for energy can be a serious threat to the environment and lead to problems in the field of energy security. As the literature shows, energy efficiency is considered the best solution, beneficial from the point of view of energy cost savings, but also sustainable development.

The second perspective is based on the assumptions underlying Corporate Social Responsibility for organizations that use energy - the company consciously chooses and buys environmentally friendly products, saves common resources that are limited in amount as a result of wider access to knowledge or new resources, in order to seek the most innovative solutions for the benefit of society and the environment, the customer, when choosing products, may pay attention to whether the entity undertakes socially responsible actions and freely select products and services according to the criterion of whether the company meets its expectations. The potential of energy management (EM) varies depending on company-specific characteristics such as size, energy intensity, and type of production. In the case of manufacturing companies, there is a large untapped market potential in the form of services that provide a promising market solution for improving energy efficiency. But, not only do production processes have an impact on the level of energy consumption, the level of use of information and communication technologies is becoming increasingly important. The concept of Industry 4.0 contributes to increased energy consumption through the increased use of IT services, related to technologies such as Big Data, Digital Twins, Artificial Intelligence. Nevertheless it is possible to indicate the degree of energy maturity of the company in terms of EM. Energy management maturity models allow organizations to assess their level of maturity against a predefined set of parameters, enabling benchmarking and continuous improvement (Finnerty et al., 2017). The implementation of the chosen energy management maturity model, inherently identifies good practice and provides a progression path from the lowest to the highest level of maturity, which corresponds to the improvement effect of adopting a strategy and implementing energy efficiency measures (Pamula, 2021). The literature indicates several trends proposing EM assessment models, which differ in terms of approach, objectives, perspective and level of detail. Trianni (et al., 2019) distinguished four such trends. The first is a simple system for checking the fact of a non-system, without using metrics defining its maturity and effectiveness, as indicated by the ISO 50001 standard. The starting point of the second trend is the systemic perspective indicating the need to determine the level of maturity of the required steps in order to establish the system as such. The third trend focuses on matrices proposing assessment models that take into account a detailed list of activities, while none of them defines the critical factors on which the assessment is based. In turn, the fourth shows detailed characteristics of the energy management system, but does not indicate the factors for obtaining a comprehensive overview of EM activities. Trianni et al. (2019) proposed an innovative energy management assessment model based on a novel characterization of energy management practices. The model describes 58 practices based on the literature review. Following this model the energy practice in this paper is defined as “an energy management practice is a technique, method, procedure, routine or rule adopted at a precise stage of the industrial energy management setting in order to achieve the company’s energy efficiency objectives. It acts on technological, non-technological, or of support aspects, by improving the energy performance directly or indirectly in a specific area of the company” (Trianni et al., 2019). The Authors proposed 8 attributes of energy management practices. They have also categorized the types of energy management distinguishing the following types/areas: technology related, non-technology related, administrative, energy-performance related, informative, procurement, staff-related, support, engineering financial and managerial.

One of the important practices in the field of EE is conducting an energy audit. In Poland the Energy Efficiency Act of 20 May 2016 (Dz.U. 2021 r., poz. 2166) imposes an obligation on an entrepreneur within the meaning of the Act of 6 March 2018. Entrepreneurs' Law (Dz.U. z 2021 r., poz. 162), with the exception of a micro-entrepreneur, small or medium-sized entrepreneur, an obligation to carry out an energy audit of the enterprise every four years or to have one carried out. Therefore, this law applies to large entities, such as those that employed an average of at least 250 employees per year or achieved an annual net turnover from the sale of goods, products and services and financial operations exceeding the PLN equivalent of EUR 50 million and the total assets of its balance sheet as at the end of one of those years exceeded the PLN equivalent of EUR 43 million. (see Information from the President of the Energy Regulatory Office No. 46/2016). The Law on Special Solutions for the Protection of Electricity Consumers in 2023 (Dz.U. z 2022 r., poz. 2127), which came into force on 18 October 2022, required managers of public finance sector units (PSUs) to take measures aimed at reducing electricity consumption by 10 per cent. The intention behind the introduction of this regulation was to realise higher standards of energy efficiency improvements in the public sector and to strengthen measures that translate into a stabilised electricity market. An obligation to take measures to reduce by 10% the total electricity consumption of occupied buildings (or parts of buildings) and of the technical equipment, installations and vehicles used is incumbent on all entities that are public sector bodies.

Cloud Computing and energy consumption

Cloud computing has become a powerful, versatile and widely used technology that offers users reliable, customizable and adaptive computing environments (Islam et al., 2023). Many companies use infrastructure solutions and applications, which these are hosted on large systems and storage infrastructures located around the world. The increase in demand services in the cloud, it is necessary to develop extensive data centers, which significantly increases electricity consumption (Masanet et al., 2020). The fast growth of cloud computing over the past years is seen as trigger for digital transformation (Al-Rwaidan et al., 2023), but on the other hand it has a strong environmental consequences. Since cloud computing shifts energy consumption dynamics between providers and users (Bharany et al., 2022) the understanding energy efficiency practices on both sides is necessary. From the provider site (Astsatryan et al., 2017) the optimization of energy consumption can be achieved by consolidating resources based on real-time usage, using efficient networks, and taking into account the thermal conditions of nodes and computing devices. In the literature, one can find a number of solutions that could be applied to minimize energy consumption in large data centers using various machine learning techniques, heuristics, metaheuristics and statistical methods (Karimi-Mamaghan et al., 2022; Juan et al., 2023). A comparative analysis of such models was done by Panwar et al. (2022) and (Long et al., 2022) who also discuss data center energy efficiency evaluation metrics, as well as their benefits and drawbacks, so that users could select the most relevant metrics. Katal et al. (2022) discusses the challenges, concerns, and requirements that cloud data centers and organizations need to understand, along with various factors and case studies that influence the adoption of environmentally sustainable cloud practices.

Park et al. (2023) conducted research on the energy efficiency impacts of cloud computing from the user's perspective. They introduced a new industry-level measure of cloud computing based on IT services in the cloud. Using data from the U.S. economy between 1997 and 2017, the study revealed that cloud-based IT services significantly enhance users' energy efficiency, especially since the wide commercialization of cloud computing. The results indicated that this impact varies across different cloud service models, and the intensity of internal IT equipment. Specifically, software as a service (SaaS) was linked to improvements in overall energy efficiency, while infrastructure as a service (IaaS) was mainly associated with increased electricity efficiency in industries with heavy IT equipment usage. Additionally, SaaS contributed to more energy-efficient production, whereas IaaS primarily helped reduce energy consumption in IT infrastructure.

2. Method

The main research question of the study was *How important for manufacturing companies is the analysis of energy consumption of cloud computing services?*

The adopted solution method was the use of a quantitative method. The opinions of IT managers were collected using a survey tool.

Data collection and research sample analysis

The data used in this study were collected in 2023 through a quantitative survey, as part of ongoing research on the spread of cloud computing (CC) solutions in Polish manufacturing companies. The survey respondents were either IT managers (*Chief Information Officer* – CIOs) or, in the case of small enterprises, company owners responsible for implementing IT solutions. This selection of respondents ensured that they had knowledge about the IT services used in the company as well as the methods of their purchase and use. The survey was conducted using the CATI (Computer-Assisted Telephone Interviewing) method, targeting manufacturing companies with headquarters or production facilities in Poland. A professional agency, selected through a request-for-quotation process, administered the questionnaires.

The sample consisted of randomly selected manufacturing companies registered in the REGON database of Polish businesses. The companies were categorized by size based on the number of employees: micro (0-9), small (10-49), medium (50-249), and large (over 250). In addition to company size, data on the year of establishment was collected. Companies were drawn by REGON number, and approximately 88% of the sample was used (there was no need for subsequent draw), and the random selection process continued until either the survey was completed or the company declined to participate. The collected data was analyzed, with 300 records determined to be relevant for further examination. These records represented companies of various sizes (micro 12.33%, small 42.33%, medium 29.33%, and large 16.00%) located in Poland. It must be noticed that small and medium companies dominated in the group. Detailed information is provided in table 1 below.

Table 1.
The structure of the surveyed firms

Company Size	Micro	Small	Medium	Large
records	37	127	88	48
percentage	12,33	42,33	29,33	16

Source: own compilation.

In order to find an answer to the research question, a survey questionnaire was prepared. The study covered 7 selected practices related to the purchase of IT infrastructure and services and, as well as IT service management. In the survey, respondents were asked to rate the extent to which their organization considers the practices studied to be important. A ranking scale from level 1 unimportant to level 5 very important was used assess each practice. The research in this article focuses only on selected practices. The studied practices can be assigned to areas defined in the model proposed by Triani et al. (2019). Table 2 presents the practices that were investigated and operationalized into variables, the comment column indicates a reference to the practices defined in the model proposed by Triani et al. (2019) - the practices studied were grouped into two areas Procurement and IT Management/Informative. The first four of the best practices studied refer to the supplier selection process, while the next three refer to the use and management of already available IT services.

Table 2.
Investigated practices

Area	Variable	Best practice description	Comments
Procurement	BP1	Each component of the physical infrastructure necessary for CC is subject to an energy assessment and approved by the body responsible for energy management	**Practice 2** Adoption of adequate investment criteria of energy efficiency investment. **Practice 3** Adoption of energy performance contracting for energy-efficiency investments. **Practice 23** Energy efficient procurement of equipment, direct and indirect materials.
	BP2	Only the purchase of infrastructure equipment with significant energy consumption is subject to an energy assessment and approved by the body responsible for energy management	
	BP3	The selection of the cloud service provider takes into account its approach and measures of reducing the impact on the environment	
	BP4	Applications are selected, marked as Energy-aware software programming	
IT Management/ Informative	BP5	Actions are carried out to increase the efficiency of the existing software	**Practice 13** Documentation and record management regarding energy use. **Practice 38** Measurement of energy use. **Practice 40** Monitoring and evaluation of energy performance. **Practice 43** Optimize energy procurement based on energy data. **Practice 57** Reporting of energy performance
	BP6	Optimization tools for cloud computing (cloud native) are used	
	BP7	Tools for monitoring the operation of IT services related to performance and load balancing are used	

Source: own assumptions.

3. Findings and Analysis

To check the internal consistency or reliability of a scale or measurement instrument as the first step Cronbach's alpha test was performed. The Cronbach's alpha value obtained was 0.957, indicating a high level of consistency between the scale items and showed that variables were highly correlated (in all cases $R > 0.8$). This suggests that the questionnaire used in the study was reliable and valid for measuring the energy awareness of manufacturing companies. Performed principal component analysis showed all correlation statistically significant (> 0,7) with determinant 0,001, KMO value 0.945 (taking into account significance < 0,001). It was also found that one component was responsible of 79% of variance. Table 3 presents descriptive statistics. The Mean value for all investigated practices were similar and vary from 2,27 to 2,47), the median for each practice awareness was equal 2. Figure 1 and table 4 presents detailed data for each practices.

Table 3.
Descriptive statistics and PCA results

Area	Variable	Mean	Standard deviation	Communalities Extraction
Procurement	BP1	2,37	1,388	0,728
	BP2	2,43	1,375	0,745
	BP3	2,38	1,461	0,814
	BP4	2,27	1,370	0,800
IT Management/Informative	BP5	2,47	1,516	0,821
	BP6	2,37	1,416	0,859
	BP7	2,37	1,379	0,813

Source: own compilation.

The differences in the assessment of the perceived importance of the practices studied were not very large. For more than 40% of the companies, none of the investigated practices was important. More than 50% demonstrates some type of awareness. The level of importance varies slightly for each practice. The respondents rated the most important practice BP2 (*Only the purchase of infrastructure equipment with significant energy consumption is subject to an energy assessment and approved by the body responsible for energy management*). It concerns the purchase of equipment with significant energy consumption. Therefore, it may indicate a greater focus on a single large action than supervision of purchases of services used ‘en masse’, in which only this ‘en masse’ use constitutes significant use of energy. On the other hand, the respondents considered the least important practice BP3 *(the selection of the cloud service provider takes into account its approach and measures of reducing the impact on the environment)* that indicates actions aimed at transferring activities in this area to business partners. 15% of respondents pointed out practice 5 (*Actions are carried out to increase the efficiency of the existing software*) as very important that allow to conclude that existing software was audited in some way, and some actions were taken to improve energy efficiency of IT services. At the same time, it should be noted that only 7% of companies indicated practices BP1 (*Each component of the physical infrastructure necessary for CC is subject to an energy assessment and approved by the body responsible for energy management*) and BP4 (*Applications are selected, marked as Energy-aware software programming*) as very important, which may indicate greater involvement in searching for energy efficiency in already possessed application and hardware resources.

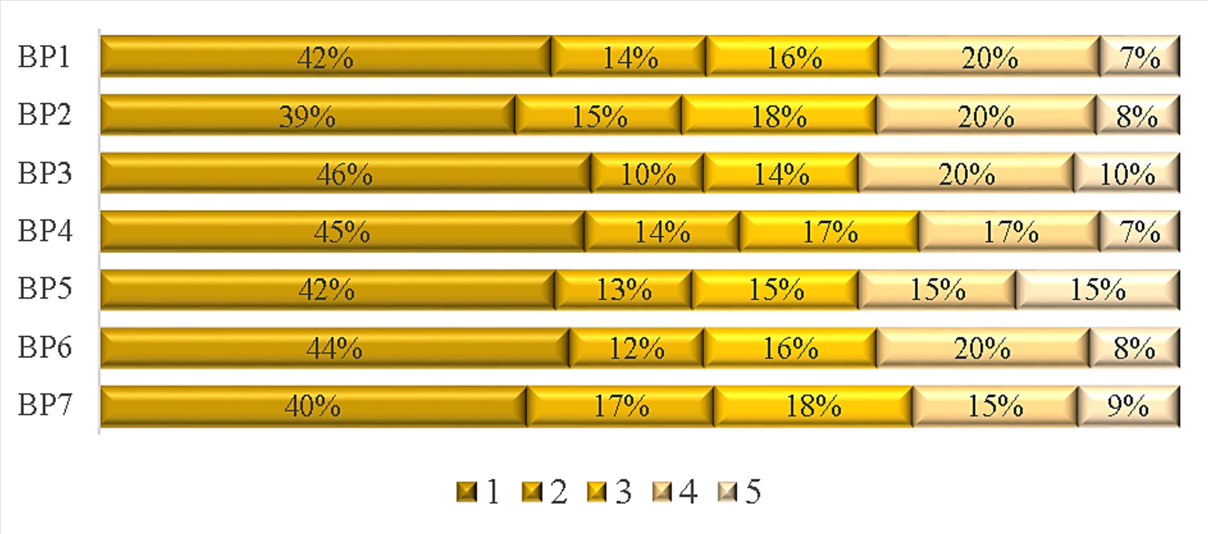

Figure 1. Assessment of investigated practices (ranking scale from level 1 unimportant to level 5 very important).

Source: own compilation.

Taking into account the presented results it can be concluded that analysis of energy consumption of cloud computing services but the awareness is low and not sufficient taking into account the energy crisis and the growing trend of using IT services.

Table 4.
Assessment of the practices

Area	Best Practice	Assessment				
		1 unimportant	2	3	4	5 very important
Procurement	BP1	**42,0%**	14,3%	16,0%	20,3%	7,3%
	BP2	**38,7%**	15,3%	18,0%	20,3%	7,7%
	BP3	**45,7%**	10,3%	14,3%	20,0%	9,7%
	BP4	**45,0%**	14,3%	16,7%	16,7%	7,3%
IT Management/ Informative	BP5	**42,3%**	12,7%	15,3%	14,7%	15,0%
	BP6	**43,7%**	12,3%	16,0%	19,7%	8,3%
	BP7	**39,7%**	17,3%	18,3%	15,3%	9,3%

Source: own compilation.

The next stage of the research process was to examine the impact of company size on the perception of the importance of analysis of energy consumption of cloud computing services. A statistically significant difference ($p \leq 0.001$) was found after applying the Kruskal-Wallis test. In particular, pairwise comparisons showed a significant difference between all pairs except micro to small and medium to large companies. The new constructs were calculated as a mean value of all variables (MeanTotal), mean value of variable BP1 to BP4 representing best practices in purchasing processes (MeanPrct), mean value of BP5 to BP6 representing best practices in IT management (MeanITMng). The data was not normally distributed so non parametric test were used for further investigation. The statistical relationships between the composite variables MeanTotal, MeanPrct MeanITMng were calculated and statistically significant correlations were confirmed for variables.

Table 5.
Average assessment of the procurement & IT Management practices according to company size

	All	Procurement	IT Management/Informative
Total	2,38	2,36	2,10
micro	1,53	1,53	1,66
small	2,08	2,07	1,97
medium	2,88	2,82	2,40
large	2,90	2,93	2,22

Source: own compilation.

Table 5 and Figure 2 present detailed results. For small, medium and large companies practices related to the of Procurement of IT services were considered slightly more important than those related to Management/Informative area.

Figure 2 present the comparison of the average assessment of the importance investigated practices by micro, small, medium and large enterprises. The highest rating was given by medium-sized and large enterprises, the lowest by micro companies. Micro-enterprises rated the practice BP6 (*Optimization tools for cloud computing (cloud native) are used*) as the highest and BP4 (*Applications are selected, marked as Energy-aware software programming*) as the lowest, while small companies rated BP2 (*Only the purchase of infrastructure equipment with significant energy consumption is subject to an energy assessment and approved by the body responsible for energy management*) at the highest and BP3 (*The selection of the cloud service provider takes into account its approach and measures of reducing the impact on the environment*) at the lowest, medium-sized companies rated BP5 (*Actions are carried out to increase the efficiency of the existing software*) at the highest and BP 4 (*Applications are selected, marked as Energy-aware software programming*) at the lowest, and large companies rated it BP5 (*Actions are carried out to increase the efficiency of the existing software*) at the highest and BP6 (*Optimization tools for cloud computing (cloud native) are used*) at the lowest.

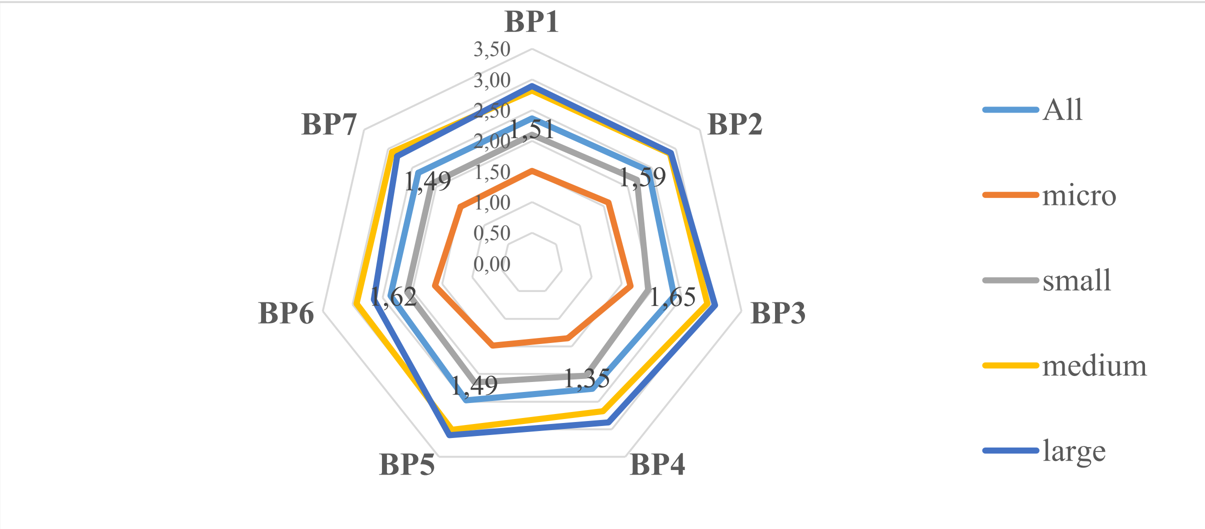

Figure 2. Mean value of the best practices assessment by micro, small, medium and large companies.
Source: own compilation.

4. Discussion and conclusion

The overall of the perception of the importance of the investigated practices is low and it varies according to the size of the organization. The low importance rating level of the surveyed micro and small enterprises may indicate that there is no interest in all researched practices services and problems in relation to their use at the time the research was conducted. These organizations (micro and small) usually do not perceive need to use IT resource management systems, however, access to digital services and cloud manufacturing seems to be a way such organizations will function in the near future (Gharibvand et al., 2024). The results of the survey indicate that medium and large companies show a greater recognition of energy awareness.

Our society's increasing dependence on critical computer systems means that even short periods of downtime can result in significant financial losses and, in some cases, even put human lives at risk. A key challenge is to handle the business continuity of companies, enabling them to return to operation quickly after a disaster (Wood et al. 2010). Optimized use of IT services, including cloud computing services, is a condition for business continuity, which is using these services increasingly intensive. The disaster-recovery mechanisms in clouds are cheaper than the traditional ones and is also more convenient and user friendly (Wood et al., 2010). In principle, cloud computing has the potential to become an energy-efficient technology (e.g. for ICT), as some academics say (Berl et al., 2010) provided that the potential for its significant energy savings, which has so far been focused on hardware aspects, can be fully referenced to system operation and network aspects.

On the other hand, the Cloud is associated with high energy consumption (Mastelic et al., 2014) In 2020, energy demand in the data centre domain was predicted to increase to 5% of global energy production by 2025 (Deepika, Prakash, 2020). Such alarming figures call for a rethink of an organisation's energy efficiency. However, the analysis of the current state is required, before introducing any changes. This article analyses the perception of cloud computing services and the awareness of manufacturing companies regarding energy consumption. The results obtained in the study conducted by Trainni et al. (2019) indicated increasing the attention on the purchase activities in terms of energy procurement optimization, however, these studies did not concern the use of IT services.

Mandatory audits of large companies and reporting by public entities make them consider extending this approach to other companies. An analysis of these mandatory documents indicate comparison of current state to future one with higher concern to energy efficiency. Basic suggestion extracted from these documents are monitoring electricity consumption and investing in more energy-efficient equipment. As the paper discuss the best practices conducting an energy audit in medium and small organizations can be suggested as important practice to be applied as it can raise awareness of the need for energy management in the procurement and use of IT services. Currently only large companies in Poland are obliged to have an energy audit every four years. Other organizations are the subject neither to audits nor to reporting. For this reason, there are no documents available on the basis of which conclusions can be drawn about the behaviour of companies – whether the purchase decision is based only on the price of the equipment, or perhaps also on energy intensity and other factors (e.g. availability of spare parts).

This research paper has also some limitations. General limitation comes from perception-based study coming from the nature of the method. The opinions of managers were examined, but the research did not cover the documents due to a lack of access to them. For the procurement area it could have been data obtained from the study of historical documents, like contracts with suppliers that could possibly show a real way what actions would have been taken by organizations in this area. Data from ITSM systems could be helpful while accessing current activities performed by IT staff. As only the opinions were investigated it must be noticed that respondents were IT managers in case of the procurement managers were asked it could have possibly reflect other issues, undiscussed in this paper. The reason for this is the way medium and large manufacturing companies operate where the user of the equipment does not make the purchase himself. A person who needs a certain infrastructure places an order with the relevant unit, where orders and purchases are made, often in bulk. IT managers make purchases according to their knowledge of the needs of the employees and the quality of the equipment, adjusting them to the financial possibilities of the company. The limitation that also indicates the need for further research is examining only 7 selected practices were surveyed considering 2 areas Purchasing and IT management/Informative areas. Also this research did not cover the purpose of IT-service usage – weather it is devoted strictly to support production processes, or to services supporting administrative activities.

The use of cloud services will show an increasing trend (Katal et al., 2023). The development of AI contributes significantly to this and manufacturing companies will have to look for energy savings not only in the manufacturing process itself. IT services are performed by compute-intensive servers within huge data centres, but it is the final users who decide on the intensity of their use. At the moment, only the European Union has planned measures to regulate this consumption. Given the ever-increasing population of our planet, the greenhouse effect and energy derived from non-renewable sources, this is another important point in the public discussion requiring a decision at the highest level.

Further research could focus on more specific practices, those that have the greatest effect while generating the lowest possible cost – this mapping of first steps can support small and medium-sized companies to implement best practices to reduce energy consumption and support company resilience related to energy market volatility. Further in-depth research and analysis of individual energy efficiency practices should also be included in energy audit schemes and carried out to determine their potential and possible impact on company welfare.

References

1. Al-Rwaidan, R., Aldossary, N., Eldahamsheh, M., Al-Azzam, M., Al-Quran, A., Al-Hawary, S. (2023). The impact of cloud-based solutions on digital transformation of HR practices. *International Journal of Data and Network Science*, *7(1),* 83-90. doi: 10.5267/j.ijdns.2022.12.003
2. Astsatryan, H., Narsisian, W., Kocharyan, A., Da Costa, G., Hankel, A., Oleksiak, A. (2017). Energy optimization methodology for e- infrastructure providers. *Concurrency and Computation: Practice and Experience*, *29*(10), e4073. DOI: 10.1002/cpe.4073
3. Berl, A., Gelenbe, E., Di Girolamo, M., Giuliani, G., De Meer, H., Dang, M.Q., Pentikousis, K. (2010). Energy-efficient cloud computing. *The computer journal*, *53*(7), 1045-1051. https://doi.org/10.1093/comjnl/bxp080
4. Bharany, S., Sharma, S., Khalaf, O.I., Abdulsahib, G.M., Al Humaimeedy, A.S., Aldhyani, T.H., Maashi, M., Alkahtani, H. (2022). A systematic survey on energy-efficient techniques in sustainable cloud computing. *Sustainability*, *14*(10), 6256. https://doi.org/10.3390/su14106256
5. Deepika, T., Prakash, P. (2020). Power consumption prediction in cloud data center using machine learning. *Int. J. Electr. Comput. Eng.(IJECE)*, *10*(2), 1524-1532. DOI: 10.11591/ijece.v10i2.pp1524-1532
6. Finnerty, N., Sterling, R., Coakley, D, Keane, D., Keane, M.M. (2017). An energy management maturity model for multi-site industrial organisations with a global presence, *Journal of Cleaner Production*, *Vol. 167,* 20 November 2017, https://doi.org/10.1016/j.jclepro.2017.07.192
7. Gharibvand, V., Kolamroudi, M.K., Zeeshan, Q. (2024). Cloud based manufacturing: A review of recent developments in architectures, technologies, infrastructures, platforms and associated challenges. *Int. J. Adv. Manuf. Technol., 131*, 93-123, https://doi.org/10.1007/s00170-024-12989-y
8. Islam, R., Patamsetti, V., Gadhi, A., Gondu, R.M., Bandaru, C.M., Kesani, S.C., Abiona, O. (2023). The future of cloud computing: benefits and challenges. *International Journal of Communications, Network and System Sciences*, *16*(4), 53-65. doi: 10.4236/ijcns.2023.164004.
9. Juan, A.A., Keenan, P., Martí, R., McGarraghy, S., Panadero, J., Carroll, P., Oliva, D. (2023). A review of the role of heuristics in stochastic optimisation: From metaheuristics to learnheuristics. *Annals of Operations Research*, 320(2), 831-861. https://doi.org/10.1007/s10479-021-04142-9
10. Karimi-Mamaghan, M., Mohammadi, M., Meyer, P., Karimi-Mamaghan, A.M., Talbi, E.G. (2022). Machine learning at the service of meta-heuristics for solving combinatorial

optimization problems: A state-of-the-art. *European Journal of Operational Research*, *296(2),* 393-422. https://doi.org/10.1016/j.ejor.2021.04.032
11. Katal, A., Dahiya, S., Choudhury, T. (2023) Energy efficiency in cloud computing data centers: a survey on software technologies. *Cluster Comput., 26*, 1845-1875 https://doi.org/10.1007/s10586-022-03713-0
12. Long, S., Yuan Li, Y., Huang, J., Li, Z., Li, Y. (2022) A review of energy efficiency evaluation technologies in cloud data centers. *Energy and Buildings*, *Vol. 260.* https://doi.org/10.1016/j.enbuild.2022.111848
13. Masanet, E., Shehabi, A., Lei, N., Smith, S., Koomey, J. (2020). Recalibrating global data center energy-use estimates. *Science*, *367(6481),* 984-986.
14. Mastelic, T., Oleksiak, A., Claussen, H., Brandic, I., Pierson, J.M., Vasilakos, A.V. (2014). Cloud computing: Survey on energy efficiency. *Acm computing surveys (csur)*, *47*(2), 1-36. DOI:10.1145/2656204
15. Pamuła, A. (2021). *Cyfryzacja w działaniach na rzecz efektywności energetycznej w firmach sektora MŚP*. Łodź: Wyd. UŁ.
16. Panwar, S.S., Rauthan, M.M.S., Barthwal, V. (2022). A systematic review on effective energy utilization management strategies in cloud data centers. *J. Cloud. Comp., 11*, 95, https://doi.org/10.1186/s13677-022-00368-5
17. Park, J., Han, K., Lee, B. (2023). Green Cloud? An Empirical Analysis of Cloud Computing and Energy Efficiency. *Management Science, Vol. 69, Iss. 3,* https://doi.org/10.1287/mnsc.2022.4442
18. RCB (2023). Narodowy Program Ochrony Infrastruktury Krytycznej – Tekst jednolity 2023. Warszawa: Rządowe Centrum Bezpieczeństwa.
19. Trianni, A., Cagnb, E., Bertolotti, M., Thollander, P., Andersson, E. (2019). Energy management: A practice-based assessment model. *Applied Energy, Vol. 235,* pp. 1614-1636, https://doi.org/10.1016/j.apenergy.2018.11.032
20. Ustawa z dnia 7 października 2022 r. o szczególnych rozwiązaniach służących ochronie odbiorców energii elektrycznej w 2023 roku w związku z sytuacją na rynku energii elektrycznej (Dz.U. z 2022 r., poz. 2127).
21. Wood, T., Cecchet, E., Ramakrishnan, K.K., Shenoy, P., Van der Merwe, J., Venkataramani, A. (2010). Disaster recovery as a cloud service: Economic benefits & deployment challenges. In: *2nd USENIX Workshop on Hot Topics in Cloud Computing (HotCloud 10)*.
22. Wróbel, R. (2022). Budowa i wzmacnianie odporności podmiotów krytycznych w Polsce (Building And Strengthning Resilience Of Critical Entities In Poland). *Zeszyty Naukowe Pro Publico Bono, no. 1(1),* pp. 163-176. DOI: 10.5604/01.3001.0016.1967
23. Xu, X., Chenguang, H., Chenya, S., Jian, M. (2023). Research on System Resource Optimization of Distribution Network Producer-Consumer System Considering Resilience and Economy. *IEEE Access*, *11*, 63947-63957. Doi: 0.1109/ACCESS.2023.3286371