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Beyond CO_2 emissions – The role of digitalization in multi-dimensional environmental performance measurement☆

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ABSTRACT

The purpose of our paper is to investigate how digitalization can support environmental performance (EP) management – going beyond the CO_2 emission measurement. Digitalization can help increase company performance many ways, this paper focuses on its effect on EP.

Environmental performance is mainly assessed by output indicators, however, in our approach we prove that digitalization makes it possible to measure and manage multiple indicators by enabling better process visibility and extensive data collection.

Our methodology is based on statistical analysis, we analyze corporate EP according to a multi-dimensional model and prove that digitally advanced companies perform better in multiple dimensions of environmental sustainability.

We found that digitally advanced companies use various technologies to gather, store and process data which results in a significantly better application of environmental accounting and environmental management systems.

The originality of our paper is that next to a wide – not only technological – interpretation of digitalization we suggest and apply a multi-dimensional environmental performance measurement model.

1. Introduction

In the past years both academics and professionals turned towards digitalization (e.g., Industry 4.0, robotics, IoT etc.) and sustainability (e.g., circular economy, eco-efficiency, net zero goals etc.) which trends will be determinants of our future. Sustainability issues are becoming extremely important thanks to the increasing expectations of stakeholders (Sheth et al., 2011; Seuring and Müller, 2008; Silva et al., 2019; Feroz et al., 2021; Bendig et al., 2023; Broccardo et al., 2023) and digitalization has a great potential for improving efficiency and customer service capabilities of firms (Becker et al., 2009; Lenka et al., 2017; Nagy et al., 2018; Bendig et al., 2023; Feroz et al., 2021). Both sustainability and digitalization can support company competitiveness individually but considering them both offer an even greater opportunity as well as require new capabilities (Feroz et al., 2021) from the firm in terms of willingness to innovate and cooperate with stakeholders. Our study aims to explore the role of digitalization in advancing environmental performance on the corporate level. In our interpretation, digital development of a firm relies not only on its technological assets, but on the organization's attitude towards digitalization, along with the capabilities of the human resources. It is also important to present different green practices and their uptake in company practice for further policy and managerial implications. The novelty of our approach is that we define environmental performance not only in terms of the company's emissions but also based on a set of actions and environmental management practices it takes to achieve a higher level of sustainability. We apply and test a multidimensional environmental performance model in our work and link digitalization and environmental performance together to contribute to the ongoing discussion of this topic.

The paper is constructed as follows: first we introduce the focal problem and our specific approach to it. In the theoretical part we review the relevant literature and make conceptualization for the terms and concepts the paper uses. We introduce our interpretation on digitalization and the multi-dimensional model we intend to use to analyze environmental performance. We identify the research gap and formulate our hypotheses. The Materials and methods section shows the bases of

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the quantitative analysis that has been carried out. We introduce the database we used, the exact statistical methods and the results of the analysis. The Discussion section will contrast the results with the literature and answers the research questions and the hypotheses. In Conclusion we sum up the most important findings and we discuss the limitations of the study as well as setting possible future research directions.

2. Literature review

With this work we aim to provide valuable contribution to the current discussion of Hilty et al. (2011), Ollo-López and Aramendía-Muneta (2011), Melville (2010), Kayikci (2018), Chen et al. (2020), Sarkis et al. (2020), Bendig et al. (2023), Benzidia et al. (2021), Broccardo et al. (2023), Feroz et al. (2021), Ha et al. (2022); Li (2022), Li et al. (2020, 2023), Ukko et al. (2019) and Yang et al. (2023) about digitalization and its effects on environmental performance. For this reason, we give an overview of the works about the effects of digitalization on economic and environmental performance of firms. Then we identify the research gap, provide a theoretical framework for our multidimensional EP model and formulate our hypotheses.

2.1. Effects of digitalization on economic and environmental performance

Information and communication technology (ICT) has gone through an intense development and spread over the past decades. According to Weber and Kaufman's definition (Weber and Kauffman, 2011) ICT is understood "as technologies that support data and information processing, storage and analysis, as well as data and information transmission and communication, via the Internet and other means." We assume that the use of ICT is an entry-level into digitalization of a company. Digitalization means creating, developing or transforming certain business processes, functions, and possibly business models using digital technologies (Ha et al., 2022). Digital transformation occurs when the new digital model forces the companies to reconsider their value propositions (Șerban, 2017; Feroz et al., 2021).

A higher digital engagement can lead to superior company performance (Kuusisto, 2017) which can be based on digital capabilities (e.g., technological expertise) or leadership capabilities (e.g. change management) (Rossmann, 2018; Feroz et al., 2021; Li, 2022; Schuh et al. (2017) point out that digital development cannot be judged solely by the digitalization level of the production process, but that the entire company must be examined. Next to the technological preparedness, Gill and Van Boskirk (2016) involve soft factors into digital development, like company culture and organizational capability to execute digitalization strategy (Bendig et al., 2023).

Adapting digital technologies leading to productivity and economic growth has been widely discussed (Horvat et al., 2019; Klymenko et al., 2019; Șerban, 2017; Mammadli and Klivak, 2020). Digitalization also takes a main role in the transformation of the economy and became vital source of competitive advantage (Rossmann, 2018; Bendig et al., 2023) which increases financial performance (Alkaraan et al., 2022; Ukko et al., 2019). Adoption of digital technologies help organizations to increase knowledge sharing, improve profitability, enhance the competitive position on the market and comply with environmental regulations (Klymenko et al., 2019; Ordieres-Meré et al., 2020; Becker et al., 2009; Feroz et al., 2021). Digitalization can support transparency of processes on high level, with improved accuracy (Chen et al., 2020; Antoni et al., 2020).

According to several authors digital development has uncertain (Feroz et al., 2021) or controversial effects (Yi and Thomas, 2007; Sarkis et al., 2020; Chen et al., 2020; Watts, 2015; Broccardo et al., 2023; Li, 2022; Li et al., 2023) on environmental performance. On one hand, the spread of ICT tools and digital technologies as well as the increase of their capacity and performance enhance the need for energy, and the large amount of electronic waste pollutes the environment (Yi and Thomas, 2007; Sarkis et al., 2020; Chen et al. (2020) call the attention to the negative effects of technology life cycle.

On the other hand, adopting digital technologies and consequently increasing efficiency of companies and/or production processes might save us energy, waste, pollution or workload (Bendig et al., 2023; Benzidia et al., 2021; Broccardo et al., 2023; Feroz et al., 2021; Li, 2022; Li et al., 2023). It was proved that IT supports the coordination of product design and manufacturing and strengthens the effect of environmental practices (Gimenez et al., 2015; Watts (2015) revealed that CSR reporting is a highly complex process and requires large amounts of data, which need to be stored, processed and analyzed, in which digital technologies can make a breakthrough. Assessing corporate performance may include qualitative and quantitative data and the sustainability perspective brings even higher complexity (Lindfors, 2021; Li et al., 2020; Li, 2022) which calls for advanced technology. The development of digital technologies contributed to increasing the effectiveness of environmental management practices (Wen et al., 2021; Broccardo et al., 2023).

Li (2022) and Li et al. (2023) conclude that the impacts of digital transformation on environmental performance are curvilinear. EP first increases in the early stages of digital transformation (by the use of technologies to optimize and manage resource use) later a rebound effect can occur when the handling of high amount of data might generate an overall negative effect on the environment (by using more energy, contributing to high amount of e-waste etc.)

2.2. Samples of environmental performance indicators

The most recent studies apply quantitative methods and find positive relationship between digitalization and environmental performance (Bendig et al., 2023; Benzidia et al., 2021; Broccardo et al., 2023; Feroz et al., 2021; Ha et al., 2022; Li et al., 2020; Ukko et al., 2019; Yang et al., 2023) or highlight the curvilinear nature of the relationship (Li, 2022; Li et al., 2023).

However, the environmental sustainability is measured differently in each study and this difference and lack of comprehensive set of indicators defines the research gap and main contribution of our study. Bendig et al. (2023) also mentions that "future research could draw on additional indicators to measure environmental performance to generate further insights" (Bendig et al., 2023). As a new contribution, we suggest and test a multidimensional environmental performance model for further investigation of the relationship of digitalization and environmental sustainability.

Broccardo et al. (2023) measured sustainability performance by the following mostly environmental sustainability related KPIs: Life cycle assessment use, Cost-benefit and sustainability analysis, Ecological Footprint, GRI Sustainability Reporting Standards, Energy Flow analysis, Green technology use, Green production, Green procurement, Green product design (Broccardo et al., 2023).

Bendig et al. (2023) use variables from Refinitiv's Environmental, Social and Corporate Governance (ESG) Index, thus EP contains the following topics: Pollution prevention, product stewardship, sustainable development (Bendig et al., 2023).

Four recent studies are based on different survey data from China: in the work of Li et al. (2020) environmental performance was measured by reduction of air emissions, reduction of wastewater, reduction of solid waste and improvement of the firm's environmental situation (Li et al., 2023). use three items to determine environmental orientation: weather the company considers its impact on the environment; weather promoting environmental sustainability is among the main goals of the company; and weather the company's employees agree with environmental protection measures (Li, 2022). measured EP by the following four statements in a survey: Our company reduces waste (air, water, solid) emission; our company decreases the consumption of hazardous/toxic materials, decreases the frequency of environmental accidents, decreases energy consumption. Yang et al. (2023) used six indicators to measure EP: reduction and treatment of waste gas, wastewater, dust smoke, solid waste, noise and light pollution, cleaner production.

The most comprehensive set of indicators are used by Ha et al. (2022) to investigate the environmental performance on the country level by EPI (Environmental Performance Index) which is based on two environmental dimensions: human health protection (HLT) and ecosystem protection (ECO). We can conclude that there is a lack of a comprehensive, not only output-oriented EP model, because digitalization allows the companies to measure and intervene into processes, before the output is realized.

2.3. Theoretical background of the multi-dimensional environmental performance model

As we reviewed the literature, we have seen that the effects of digitalization on environmental performance are mainly output-oriented, meaning that they concentrate mostly on emissions (to air, water, waste).

In our opinion, the impact of digital development is more comprehensive, with the change in the business model it is changing the importance of environmental management and the possibilities of environmental performance measurement. In our research, we therefore aim to apply a comprehensive, multi-dimensional model to assess environmental performance (Fig. 1).

In stakeholder approach EP can be defined as "the extent to which companies meet the expectations of their stakeholders regarding environmental responsibility" (Ruf et al., 1998 in 34). For example, reduction of environmental externalities, the avoidance of negative health and safety issues are expected by the neighbors, employees, consumers and transparency is a demand of all stakeholders (Schultze and Trommer, 2012). However, CO_2 or GHG emissions seem to be the mainstream EP indicator in business practice and in research as well (Lee and Brahmasrene, 2014; Wang et al., 2015; Yi and Thomas, 2007; Higón et al., 2017). Our understanding of EP is that it is a multidimensional phenomenon and cannot be reduced to measures focusing only on the output, such as CO_2. In our study, we address this gap by examining environmental performance using a multidimensional model. Based on this understanding, EP is considered by Schultze and Trommer (2012) as a multidimensional construct that does not only include environmental *impacts*, but also *principles* of environmental responsibility and *processes* of environmental protection within the power of the company. This means that environmental impacts are part of environmental performance, showing the past and present performance of the company in some aspects, as defined by the ISO14001 standards: An "environmental impact" is an adverse or beneficial change to the environment resulting from the organization's environmental performance (ISO14001 Standard, 2015).

According to the multidimensional model, EP indicators can be categorized into four groups. First, indicators of the environmental performance can be categorized as *input* (e.g. fuel) and *output* (e.g. emissions to air) indicators. These are very closely related to environmental impacts and are assumed to be the most valid EP measurements.

The future impacts of a company can be assumed by the principles it adheres to in terms of sustainability and responsibility, and the environmental management practices it performs (Klassen and McLaughlin, 1996). The environmental impacts are predetermined by the strategic approach and environmental management practices a company applies. The indicators of this type of EP can be categorized as *strategic* and *outcome*-oriented indicators. Reporting about the environmental efforts is also an important part of environmental performance (strategic indicator), coming the interpretation of EP as meeting expectations of stakeholders. Reporting is crucial in terms of communication with stakeholders, since their perception of the company's EP results in actions which have economic consequences.

2.4. Formulating hypotheses

Our research questions focus on whether advanced digitalization in a company can result in better environmental performance. Based on the introduced theoretical framework we operationalize our research questions as followings (Table 1).

In the following section, we introduce the survey and the database we used for the statistical analysis to test our hypotheses.

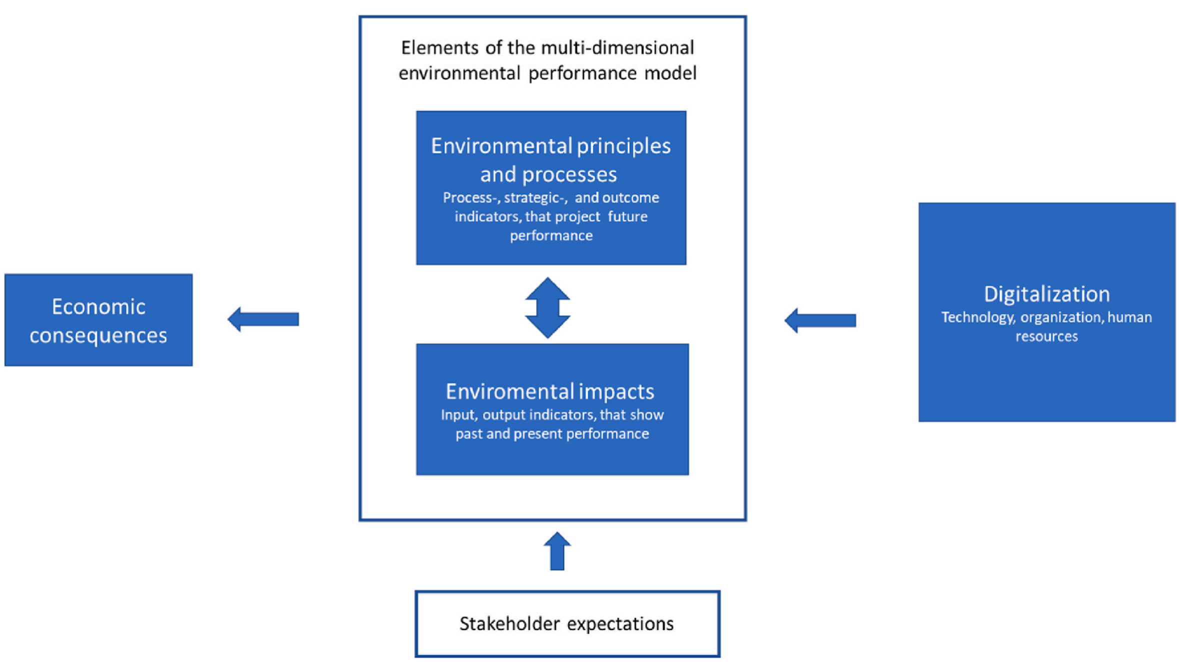

Fig. 1. The framework of analysis. Source: own edition.

Table 1
Operationalization of the research question. Source: own edition.

No. of research question	Research question	No. of hypothesis	Hypothesis	Methodology
RQ1	Do the digitally developed companies use multiple types of environmental performance measures?	H1	The digitally advanced companies measure their environmental performance in multiple dimensions with multiple indicators.	Statistical analysis
RQ2	Do the digitally developed companies achieve better environmental performance?	H2	The digitally advanced companies perform better in multiple dimensions of environmental sustainability.	Statistical analysis

3. Materials and methods

3.1. Database

The Hungarian Competitiveness Research Centre (HCRC) surveys corporate competitiveness in every five years. The database we use for testing our hypothesis with statistical analyses is from the HCRC. The results of the latest survey (HCRC, 2019) will be analyzed in this paper. We selected questions from the questionnaire we can use to measure the interdependency of digital preparedness and environmental performance. The database contains information of 209 companies which of 20% are large, 71% are middle-size and 9% are small companies (size classification is based on the Hungarian legislation: small companies have less than 50 employees and balance sheet total is smaller than 10 million €; middle-size companies have 50–250 employees and balance sheet total is between 10 and 43 million €). Regarding the industrial distribution of the sample, 53% of the companies operate in processing, 22% in retail, 8% in logistics services, 7% in construction, 5% in IT services, 3% in tourism and 1-1% in cultural and scientific research industry.

3.2. Statistical methods

When selecting an appropriate statistical methodology to analyze survey data we found that for analyzing the effects of different factors on the relationship of environmental performance and environmental management in firms (Hartmann and Vachon, 2018) used hierarchical regression. Wen et al. (2021) also used regression to find relationship between how industrial digitalization affects the adoption of different cleaner production technologies. Cecere et al. (2014) distinguishes the innovation potential of green ICT domains by applying cluster analysis. Also, cluster analysis was used by Remane et al. (2017) to classify firms along their digital impact and digital readiness. Since we were not looking for a causal relationship between the elements of digitalization but were assuming that different groups of companies with different levels of development could be distinguished based on the prevalence of the application of digital technologies, we chose the option of cluster analysis (Fig. 2). We selected 12 variables from the questionnaire to describe the development level of digitalization in a company. To use relevant and reliable variables we had to standardize the units of measures and exclude the ones with missing answers. Finally, our sample contains 205 companies. Tables 2 and 3 contains the final variables used for the analysis.

First, we applied factor analysis to see the interconnections of the variables. We applied Principal Component Analysis to see which variables move together. The Kaiser-Meyer-Olkin measure of sample adequacy is 0.805, while Bartlett's test for sphericity is not significant. These measures suggest that the factor analysis is an adequate method for variable reduction. In order to filter out variables that would affect more than one component at a time, we used Varimax rotation. We considered a variable to be an element of a component if its factor weight exceeded 0.25. If a variable appeared in more than one component, we considered it where its factor weight was greatest. Through Principal Component Analysis, we were able to identify three factors with eigenvalues greater than 1 (>1) that together explain 64.639 percent of the total variance.

When reviewing the literature on digital development stage of firms, we identified a gap, that digital development is mainly interpreted from technological point of view, and primarily in production. However, we want to emphasize that it has to be measured not only by the technologies used, but also by the readiness of the organization and the preparedness of human resources. In defining the principal components, we were able to enforce this view. We named the first component *IT coverage* since the group of variables covers the company-wide software adopted in the firm. We identified the existence of an ERP system substantial for information integration within a company, because the use

Table 2
Selected variables for describe digital development level (own edition).

Results of factor analysis	Variables	Factor weight
Component 1 *IT coverage*	Data storage system/OLAP	0.769
	ERP system	0.587
	Workflow system	0.856
	Document management/collaborative system	0.648
	Project management tools	0.782
	Process management tools	0.794
Component 2 *Digital applications*	Software robots	0.838
	Big data system	0.861
	Predictive analytics	0.859
Component 3 *Organization*	Existing written IT strategy	0.255
	The head of IT is in direct contact with senior management.	0.869
	The composition of the staff of the IT organization is outstanding in terms of capacity and competence.	0.754

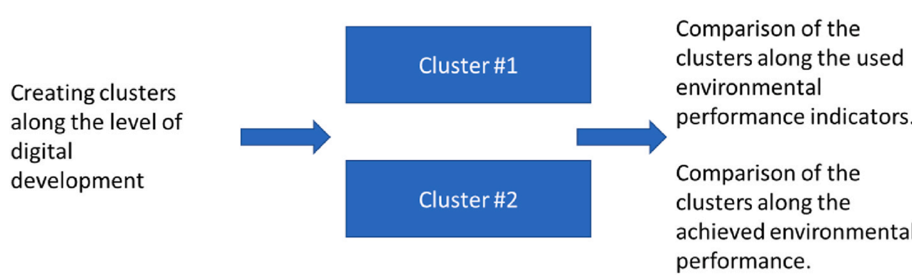

Fig. 2. Process of analysis. Source: own edition.

Table 3
The variables used in the HCRC survey according to multidimensional environmental performance model (own edition).

Environmental performance indicators	Variables
I. Operational indicators	
I./A Input oriented indicators	
Energy	Energy use/unit of product
Water	Water use/unit of product
Material use	Material use/unit of product
I./B Output indicators	
Waste	Amount of waste generated/unit of product
Pollutants	Emission of pollutants/unit of product
I./C Process indicators	
Environmental criteria for suppliers	Communicated environmental standards for suppliers
Environmental performance and CO2 emission measurement	Existing environmental performance measurement.
	Existing CO2 emission measurement.
I./D Outcome oriented indicators	
Training of employees	The company organizes environmental training for employees.
Environment-related criteria in employee performance measurement	The company applies environment-related criteria in the performance evaluation of employees.
Environmental auditing	The company audits its environmental activities.
Environmental accounting and expenditures	Dedicated accounting system for environmental expenditures.
II. Strategic indicators	
Sustainability strategy	Sustainability is at the heart of the company strategy.
Environmental policy, goal setting	The company has written environmental policy.
	Environmental performance goals were set in the company objectives.
Environmental management systems	The company has environmental management system (e.g. ISO14001, EMAS)
Sustainability reporting	The company publishes a public environmental/sustainability/CSR report.

of it can ensure that company processes are under control and are monitored, data is collected, and structured reports are available. ERP systems have an important role in integrating information from all other ICT tools used by firms. We were also looking for other systems operated besides the ERP to get more information, to distribute it more effectively within the company, as well as to be able to analyze it. For this reason, we involved in the analysis of whether the firm uses workflow, process, project or document management systems. Workflow system requires the companies to well define the administrative processes, problem solving routes and how tasks are allocated to employees. The rapidly growing databases necessitate at companies to apply alternative data storage systems, like cloud, which in capacity and availability can replace traditional data warehouses and servers.

The *Digital applications* component gathered some advanced technologies such as artificial intelligence, IoT, social media analytics, cloud computing, software robots, big data and predictive analytics systems which can also determine the digital development stage of a company. The biggest achievement of digitalization is making it possible to collect data about almost everything the company wants to, especially the core processes, and becoming able to analyze them to use it later in decision making. In terms of applications, we were looking for specific solutions that build on the presence of extensive IT in the organization. Predictive analytics is a higher-level application and requires an appropriate data management and analytical infrastructure. The third component, *Organizational* issues are whether there is a written IT strategy at the company or not, and if IT has a formalized role within the company. In realizing this strategy besides the IT infrastructure, the human resource and its skills are very important.

We used the above introduced variables to run cluster analyses to define the digital development level of the sample companies. The results of the cluster analyses will be introduced in the Analysis chapter.

3.3. Environmental performance

As a second step of our work, the environmental sustainability related variables were selected from the HCRC database. As we identified previously, many EP assessment models use output focus, so with the intention of filling this research gap, in our analysis we applied 16 variables (Fig. 3) for illustrating environmental performance of the clusters and integrated them into the multidimensional environmental performance (MD-EP) model (Schultze and Trommer, 2012). For easier understanding and for practical reasons we organized the variables into a PDCA cycle, which is a base principle in environmental management (ISO14001 Standard, 2015).

The *planning* phase of the cycle contains the strategic level indicators that show the attitudes of the company toward the environment: their strategy, commitments, goals and objectives and environmental management practices.

The second, *do* phase contains the operational indicators, with four subcategories. Process indicators (1) refer to the near future, for example by setting standards, changing processes, use of new technology, recycling activities, implementing green transportation or green procurement etc. These tools of environmental management are the intermediaries between strategic level and the actual environmental impact. Input indicators (2) and output-oriented indicators (3) refer to environmental aspects, which cause impacts on the natural environment through energy and resource consumption (renewable and non-renewable), water consumption, land use, waste generation, and air, soil, water and noise pollution. Also, the physical impacts of companies' products and services are considered. The input-oriented indicators we choose refer to the performance of the company compared to its main competitor in terms of energy, water and material use. We categorized the amount of waste generated and emission of pollutants compared to the competitor as output indicators. Setting environmental criteria for suppliers is considered as a process-oriented environmental performance indicator.

The *check* phase is represented by the outcome-oriented indicators (4) showing the impacts of environmental responsibility. Operational outcomes indicate the level of attention a company pays to environmental responsibility and the integration of environmental issues into management processes (Schultze and Trommer, 2012) with focus on measuring the impacts on stakeholders, e.g., customers, employees, investors and society as a whole. This also includes economic impacts. The outcome-oriented indicators are described by the environmental training organized for employees, the environmental criteria applied in employee performance evaluations, environmental auditing and accounting.

The *act* phase contains the sustainability reporting and starts the continuous improvement cycle again. With this multidimensional set of indicators, we can have a comprehensive view of the company's environmental performance.

The variables of the HCRC categorized among the different indicator categories are shown in Table 3.

4. Analysis and results

As a first step of the analyses, we classify the sample companies based on their digital development, second, we analyze the environmental performance of the different clusters.

4.1. Results of the cluster analyses on digital development

The variables measuring companies' digital development was preliminary tested by Pearson's correlation coefficient to exclude commonality. Since in only two cases were r is higher than 0.7, the

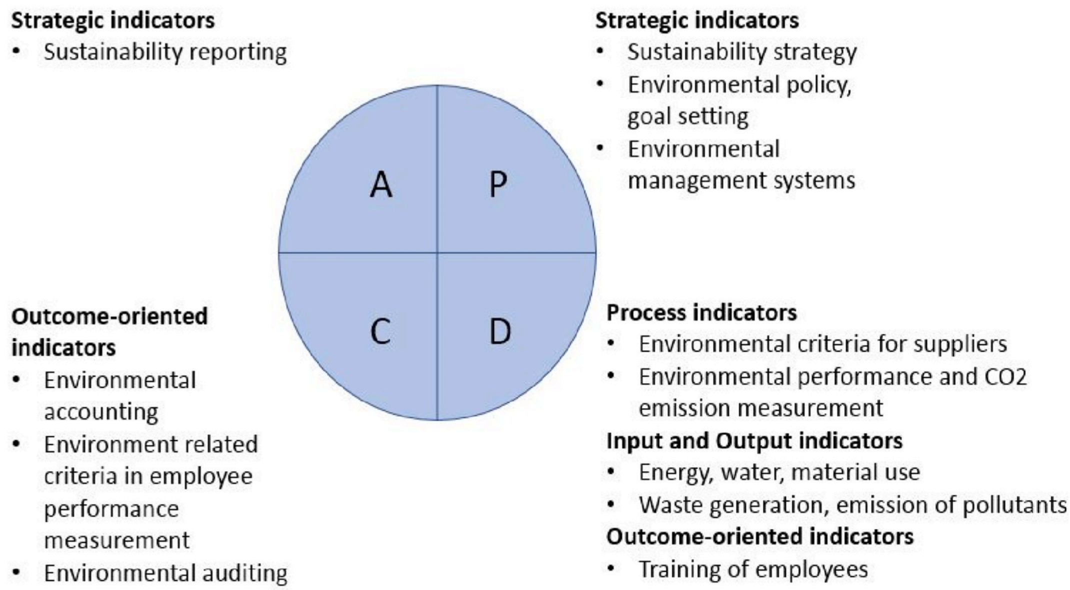

Fig. 3. Environmental performance indicators in PDCA context. Source: Own edition.

correlation level of variable is acceptable (Sajtos and Mitev, 2007) and the remaining twelve variables can be used for further analysis. After selecting the appropriate variables, two different cluster analyses were applied by using SPSS in order to increase the validity of the methodology. The first, hierarchical cluster analysis (between-groups linkage method) provided two clusters with the population of 127 and 89 companies. According to the literature, hierarchical cluster analysis can be used on large sample with reasonable reliability (Sajtos and Mitev, 2007). To test the reliability of this classification, a K-mean cluster analysis was also carried out, producing also two clusters containing 128 and 88 companies. We compared the results of the two cluster analyses and defined final cluster membership based on the common results. This allowed us to create a cluster with 122 (Cluster 1) and another with 83 members (Cluster 2).

Regarding the clusters' demographic characteristics, Cluster 1 contains 9% small, 66% middle-size and 25% large companies. The top3 industries represented in the cluster are process industry (48%), retail (25%) and construction (7%). Regarding Cluster 2, it consists of 7% small, 82% middle-size and 11% large companies. The top3 industries in Cluster 2 are process industry (63%), retail (17%) and logistics services (12%). To exclude the distorting effect of company size or industry on digital preparedness and environmental performance, we tested the correlation between the company size and all variables as well as industry and all variables. Correlations exceeded 0.371 in none of the cases, so we can say that better digital preparedness and environmental performance are not results of big company size or being part of a specific industry.

The digital development level of the two ultimate clusters were compared and are shown in Table 4. We run cross-table analyses to obtain this comparison and to assure the reliability of the results, we applied Cramer's V on a 5% significance level. We found significant differences in digital development between the two clusters, and based on these results, we defined Cluster 1 as Digitally advanced and Cluster 2 as Digitally lagging (Table 4).

Regarding all the aspects selected for assessing digital development of the sample companies, we can see significant differences between the advanced and the lagging cluster firms. Although the written IT startegy is available at lagging companies as well, the implementation of this strategy is in arrears. Although the difference of ERP adoption is significant between the two cluters, a large share of lagging companies use ERP systems, which is an entry level towards digitalization, so is promising for the future development. There is a big gap between the adoption of digital applications, but it is a good sign, that many of the Digitally lagging companies already use ERP. Regarding the organizational aspect, the half of the Digitally lagging cluster has formal IT strategy, which is also promising, but companies have to improve and educate their employees to persuade them towards adopting digital innovations.

Table 4
Results of clusters' digital development (own edition).

Principal components	Variables	Digitally advanced cluster (1)	Digitally lagging cluster (2)	Sig.
Component 1 *IT coverage*	Data storage/OLAP	75.9%	8.3%	0.001
	ERP system	79.6%	53.3%	0.001
	Workflow system	63.9%	6.7%	0.001
	Document management/ collaborative systems	79.6%	18.3%	0.001
	Project management tools	75.9%	18.3%	0.001
	Process management tools	63.9%	18.3%	0.001
Component 2 *Digital applications*	Predictive analytics	18.%	5%	0.015
	Software robots	18.5%	5%	0.015
	Big data system	18.5%	1.7%	0.002
Component 3 *Organization*	Written IT strategy	82.4%	48.3%	0.001
	The head of IT is in direct contact with senior management.	4.58	3.23	0.001
	The composition of the staff of the IT organization is outstanding in terms of capacity and competence.	4.44	2.33	0.001

4.2. Environmental performance of clusters

In this section we analyze corporate environmental performance based on the MD-EP model of the different clusters. In this step of the analyses, clusters were compared by SPSS, applying 5% significance level and reliability was tested by Phi and Cramer's V. 15 of the 16 variables provided statistically significant results, which makes the discussion possible (Table 5).

Plan – Strategic indicators: Digitally advanced companies agree (4.33) with the statement that sustainability is at the heart of their strategy. 73 percent of them have environmental policies and they also set environmental goals in writing. 73% of Cluster 1 companies have environmental management systems, while only 14% of Cluster 2 companies. This can be connected to the size and financial possibilities of the companies, and also, their position in the supply chain. Implementing and certifying environmental management systems is resource intensive and usually companies use these systems when their partners in the supply chain request so. 63% of digitally advanced companies apply green procurement, e.g., set criteria for their suppliers, which suggest that they are part of green supply chains.

Do – Operational indicators: Environmental performance measurement, CO_2 emission measurement does not show significant difference between the clusters, in both cases relatively small amount (around 30%) of the companies use these processes.

Digitally advanced companies perceive that in terms of energy, water consumption and material use they performed better than their competitors, while digitally lagging companies perceived that their performance is basically the same as the competitors'. Waste and pollutant emissions show very similar results. Training of employees is done by 58% of Cluster 1 and 36% of Cluster 2 companies.

Check – Operational indicators: Environmental auditing and accounting is a tool frequently used by Cluster 1 companies and they report that their expenditures on the environment are higher than their competitors'. Environmental criteria are quite rarely used by any of the clusters in the performance measurement of employees.

Act – Strategic indicators: Sustainability reporting is a strength of Cluster 1, done by 54% of companies, while only 17% of Cluster 2 companies publish reports on sustainability efforts.

5. Discussion

There have been scientific papers connecting digitalization and environmental sustainability before but either they used a technology-oriented digitalization approach (Becker et al., 2009; Weber and Kauffman, 2011; Chen et al., 2020; Wen et al., 2021) or interpreted environmental performance only through certain output-oriented indicators (Ishida, 2015; Higón et al., 2017; Gimenez et al., 2015; Bendig et al., 2023; Benzidia et al., 2021; Broccardo et al., 2023; Feroz et al., 2021; Ha et al., 2022; Li, 2022; Li et al., 2020, 2023; Ukko et al., 2019; Yang et al., 2023). We contribute to this topic by using a broader perspective to discuss digital development and environmental performance. In digitalization literature, we found that papers interpret digital development based mainly on the technological background (Weber and Kauffman, 2011), but we pointed out that digitalization is dependent on the organization's culture and adaptive capabilities as well as the preparedness of human resources, too (Schumacher et al., 2016; Schuh et al., 2017; Verbeeten and Boons, 2009). The multidimensional environmental performance model allowed us to investigate the companies from an environmental sustainability point of view based on a comprehensive set of indicators. Our research has statistically proved that digitally advanced companies have significantly better environmental performance. The reason for it can be that these firms have better access to data, collect and analyze them more extensively, than companies with average or low digital preparedness. Good quality data supports the companies in being aware of processes, and this transparency allows them a high level of efficiency (Tseng et al., 2021). Transparency also means that companies can intervene right at the time inefficiency occurs (Birkel and Hartmann, 2020).

To implement innovative IT and digitalization projects or apply environmental performance measures similar skills, culture and capabilities are necessary in the company: an effective change and HR management, an inclusive corporate culture and the need for continuous improvement. The concepts of both digitalization and sustainability can contribute to the firm's competitive position (Birkel and Hartmann, 2020; Molina-Azorín et al., 2009; Broccardo et al., 2023).

By analyzing the environmental performance of the two clusters, we could not find evidence to suggest that digitalization might have controversial effects on the environment (Yi and Thomas, 2007; Chen et al., 2020). On the other hand, we can state that advanced digitalization supports companies in gathering data about energy and resource consumption, supports pollution-measurement and management (Feroz et al., 2021) which provides a base for optimization and efficiency.

Digitally advanced companies use various technologies to gather (ERP, document management), store (data storage, OLAP) and process data (project and process management, workflow, big data analytics, software robots), which results in a significantly better application of environmental accounting and environmental management system, as Melville (2010) and Jin et al. (2021) state. The latter findings exceed the ascertainment of Watts (2015) who proved the importance of IT in CSR reporting.

Certified management systems, reporting and auditing are all quite resource-intensive (Watts, 2015), which are proven by the higher expenditures on environmental protection by Digitally advanced cluster. The use of these tools might be connected to the transparency requirements of the upstream and downstream partners in the supply chain (e.g., suppliers and customers) (Sheth et al., 2011; Seuring and Müller, 2008; Feroz et al., 2021). The use of green procurement (setting environmental criteria for suppliers) proves the upstream involvement of suppliers in the supply chain.

Overall, our results support the works of the mentioned researchers, who highlight that digitalization can enable and further organizational practices and processes that improve environmental and economic performance (Wen et al., 2021; Chen et al., 2020; Klymenko et al., 2019; Şerban, 2017; Dahlmann et al., 2008; Bendig et al., 2023; Benzidia et al., 2021; Broccardo et al., 2023; Feroz et al., 2021; Ha et al., 2022; Li, 2022; Li et al., 2020, 2023; Ukko et al., 2019; Yang et al., 2023).

After conducting the analyses and comparing the results with the literature, we will examine our preliminary hypotheses. The first

Table 5
Environmental performance indicators of Cluster 1 and 2. Note: % means that this % of companies in the given cluster uses a method.

Environmental performance indicators	Digitally Advanced Cluster (1)	Digitally Lagging Cluster *(2)*	Sig.
Plan - Strategic indicators			
Sustainability strategy	4.33	3.62	0.001
Environmental policy, goal	73.3%	48.1%	0.002
setting	72.2%	50.8%	0.006
Sustainability reporting	53.8%	17.3%	0.001
Environmental management	73.6%	14.3%	0.001
systems	4.03	3.56	0.009
Do - Operational indicators			
(1) Process indicators			
Environmental performance	37.1%	30.8%	0.431
measurement system and CO2 emissions	32.4%	28.8%	0.653
Environmental criteria for suppliers	61.1%	35.6%	0.002
(2) Input oriented indicators			
Energy	3.85	3.13	0.001
Water	3.83	3.13	0.001
Material use	3.86	3.20	0.001
(3) Output oriented indicators			
Waste	3.87	3.05	0.001
Pollutants	3.99	2.88	0.001
Check - (4) Outcome oriented indicators			
Training of employees	58.1%	36.5%	0.011
Environmental accounting	61.9%	21.2%	0.001
and expenditures	3.98	3.12	0.001
Environment-related criteria in employee performance measurement	37.1%	25%	0.128
Environmental auditing	60.6%	33.3%	0.001

hypothesis, that digitally developed companies can measure their own EP in multiple dimensions with multiple indicators, was confirmed. In strategic, outcome and partly input-related indicators digitally developed companies were more active users, and in almost all aspects, performed better than the digitally lagging firms.

Our second hypothesis, that digitally advanced companies achieve better environmental performance, is supported by the results. Our analysis demonstrates that digitally advanced companies are significantly more effective in using a more diverse set of environmental management tools than the digitally lagging ones.

Overall, according to our analysis, we confirmed that digitalization is not only a technological question, but also involves the readiness of the organization and human resources. We also statistically confirmed that advanced digital preparedness allows companies to apply a sophisticated, multi-dimensional EP management system and not only focusing on output-oriented indicators. Digital development supports a better EP in strategic, input and process-oriented indicators, too.

6. Conclusions

Sustainability and digitalization are among the most important and most researched topics of our times. With our research, we made a dual theoretical contribution to these topics: on one hand, we proved that digitalization allows companies to apply a multidimensional environmental performance model, because digital technologies can provide data for the increasing number and even more complex indicators. On the other hand, we pointed out, that higher digital preparedness also results in significantly better EP, in most of the strategic, input, process and output-oriented indicators analyzed.

However, the research has limitations. The database we used was prepared for the purposes of competitiveness research, which means that we had access to a limited set of indicators, there could have been many more.

Regarding the future research plans, we only pointed out the positive relationship of digitalization and environmental performance, but the causal relationship has to be analyzed further.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Judit Nagy reports financial support was provided by National Research, Development and Innovation Fund of Hungary.

Data availability

The authors do not have permission to share data.

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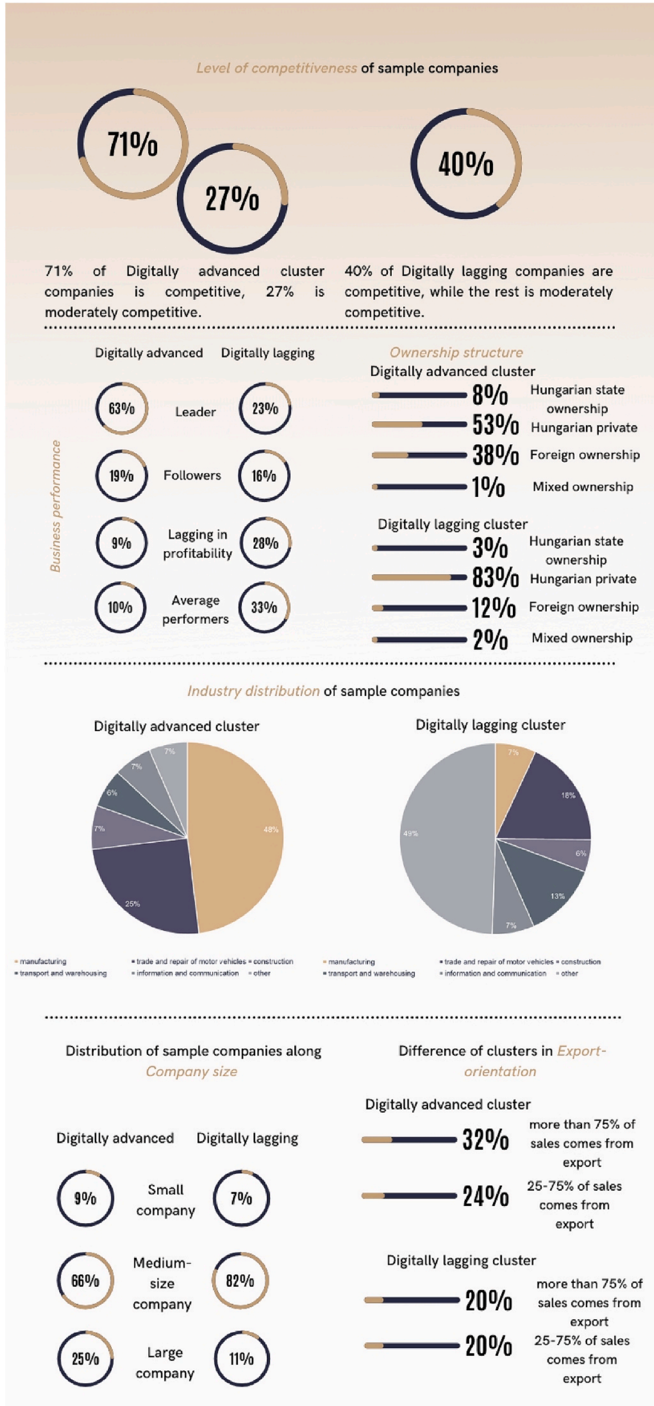
Appendix 1. Additional comparison of Digitally advanced and Digitally lagging clusters



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