

INDUSTRY 4.0 SOLUTIONS AND COMPANY PERFORMANCE: EMPIRICAL EVIDENCE FROM MULTIPLE CASE STUDY OF AUTOMOTIVE INDUSTRY

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Purpose: Recent geopolitical, economic, and social changes worldwide directly impact the operations of manufacturing enterprises. This paper aims to highlight the potential outcomes achieved through the implementation of modern technological solutions within the scope of Industry 4.0 in organizations operating in the manufacturing sector. The presented results are part of wider research (Michna et al., 2021).

Design/methodology/approach: The research methods consist of a comprehensive literature review of the subject under study and the results of empirical research conducted in 2023 based on multiple case study in production companies in Poland.

Findings: The study presents the effects achieved by companies after implementing Industry 4.0 solutions, such as: production cost reduction, increase in profits, productivity and production efficiency and improvements in working conditions.

Research limitations/implications: The study was conducted in two selected manufacturing plants operating in the Polish market, with the limitation being the sample selection and the subjective assessment of the study participants.

Practical implications: The research results provide an overview of potential and achieved effects and changes in the functioning of the enterprise following the implementation of Industry 4.0 technologies. An additional categorization into effects achieved in socio-economic, environmental areas, and overall corporate governance allows for situating the organization's performance in light of recent legislative changes related to the Fit for 55 packages (Fit for 55, 2021).

Originality/value: The study can assist practitioners and specialists in Industry 4.0 in analyzing the potential effects of implementing new technological solutions and aid in planning future activities within the organization.

Keywords: Industry 4.0, Results, Performance, Production.

Category of the paper: Empirical research results.

1. Introduction

The last decade of research on the phenomenon of Industry 4.0 provides extensive information on various aspects of the implementation of modern solutions. From the types of technologies and new solutions (Berman, 2012; Chaudhuri et al., 2024; Frank et al., 2019; Lukoki et al., 2020; Manavalan, Jayakrishna, 2019; Oettmeier, Hofmann, 2017), through areas related to driving forces and barriers during implementation (Arnold et al., 2018; Michna, Kruszewska, 2021, 2022a; Müller, 2019; Neto et al., 2020; Stentoft et al., 2019; Türkeş et al., 2019; Vuksanović Herceg et al., 2020; Yilmaz et al., 2022), to changes in the competency model of employees (Beke et al., 2020; Hernandez-de-Menendez et al., 2020; Kannan, Garad, 2020; Michna, Kruszewska, 2021, 2022b, 2022b; Poszytek, 2021) and the functioning of enterprises (Basana et al., 2024; Çalış Duman, Akdemir, 2021; Dalenogare et al., 2018; Dev et al., 2020; Kamble et al., 2020; Wang, Hou, 2024). Base of (Dombrowski, Wagner, 2014) “the technologies of the future production will cause far-reaching changes for the socio-technical production system”. In today's reality, numerous economic, political, and social changes directly impact the operations of businesses. The results achieved by the organization reflect the direction of its development. Not only do financial aspects, such as turnover, profit, or asset size, play a crucial role, but the significance of all non-financial aspects of the company's functioning is also increasing. The CSRD directive (Corporate Sustainability Reporting Directive (EU) 2022/2464, 2022) introduced at the end of 2023 places reporting on sustainable development on par with financial reporting for businesses. The financial results of a company, along with aspects such as their impact on stakeholders (including customers, suppliers, employees, local communities), satisfaction, competence development, equality, environmental impact (including water, air, and ecosystems), and compliance with fundamental rights throughout the company's value chain, are among the many disclosures that will require organizations to provide accurate and comprehensive presentations in official annual reports in the coming years. All these elements are grouped into three categories known as ESG - Environmental, Social, and Governance aspects.

How does the implementation of Industry 4.0 solutions impact the organization's performance? In the literature on the subject, we can find numerous case studies and literature reviews regarding the effects brought about by the implementation of new technological solutions. The integration of advanced technologies is revolutionizing the landscape of production companies, ushering in a new wave of efficiency, flexibility, and competitiveness (Bal, Erkan, 2019; Caiado et al., 2022; Peukert et al., 2015; Soniewicki, Paliszkiwicz, 2019). Automation and smart technologies streamline production processes, minimizing downtime, reducing errors, and enhancing overall operational efficiency (Barbie et al., 2020; Chong et al., 2018; Dahmani et al., 2021; Hirsch-Kreinsen, 2014; Pfeiffer, 2016; Quan Chong et al., 2018). Collection and analysis of real-time data, empowering decision-makers with valuable insights for informed and timely decision-making (Chaudhuri et al., 2024; Lin et al., 2018). Smart

supply chain management ensures better coordination, reducing lead times, optimizing inventory, and enhancing overall supply chain resilience (Caiado et al., 2022; Veile et al., 2020). The implementation of IoT devices and sensors allows companies to predict and prevent equipment failures, minimizing disruptions and costly downtime (Manavalan, Jayakrishna, 2019). With advanced technologies, production can be tailored to meet individual customer needs, fostering greater customer satisfaction and loyalty. Through the adoption of smart manufacturing practices, companies can optimize resource utilization, minimize waste, and achieve cost savings across various aspects of production. Automation and advanced analytics contribute to improved quality control, ensuring that products meet or exceed stringent quality standards. The integration of humans and machines in the production process leads to more collaborative and safer work environments, with employees focusing on higher-value tasks (Adem et al., 2020; Dutta et al., 2021; Leso et al., 2018; Vrchota et al., 2019). Industry 4.0 positions production companies on a global stage, enhancing their competitiveness by leveraging cutting-edge technologies to meet market demands efficiently. In conclusion, the implementation of Industry 4.0 marks a paradigm shift for production companies, unlocking a multitude of benefits that propel them into a future of smarter, more efficient, and sustainable manufacturing. As technology continues to evolve, embracing Industry 4.0 seems to be not just a choice but also a strategic imperative for companies aspiring to thrive in the modern industrial landscape (Barton, 2021; Culot et al., 2020; Erol et al., 2016; Motyl et al., 2017; Veile et al., 2020).

2. Methods

Empirical data were obtained from two companies operating in the manufacturing industry. One of the companies is located in the Podkarpackie Voivodeship, while the other is in the Wielkopolskie Voivodeship in Poland. Both companies produce, among other things, elements and components used in the automotive sector. The criteria for selecting companies for the multiple case study were: the manufacturing sector - both organizations represent the manufacturing industry and produce rubber parts; the aspect of Industry 4.0 - the organizations are actively involved in the implementation of Industry 4.0 solutions; and the size of the company - both belong to large organizations, following the guidelines of the current accounting law. Qualitative research in the form of case studies was conducted from November to December 2023. In each of the organizations, a review of available documentation published on the websites of both companies was carried out, including certificates of implemented management systems, descriptions of organizational activities, and specifications of manufactured products. Additionally, the study also focused on the implemented work principles and the organizational structure of the company. The study involved individuals working at the managerial level, including the organization's president, directors,

and department managers representing organizational units such as product development, quality, production, and environmental protection. For the purposes of this publication, we selected results obtained from studying leaders managing similar areas. Specifically, in the first company, the surveyed individual manages the occupational health and safety and environmental aspects, while in the second organization, participant manage the quality and environmental areas. During the interviews, notes were taken, which were subsequently compiled in a research journal.

Table 1.
Factors - effects of implementing Industry 4.0 solutions

	Factors		Source
Governance	Reduction cost of	production	1. Ghobakhloo et al., 2022
		product development	
		inventory	
		scrap & rework	
		purchasing base materials	
		energy	
	Increase of	waste disposal	2. Müller, 2019
		profit	
		customer satisfaction	
		speed of delivery	
		responsiveness	
		flexibility of supply	
		product range offerings	
		the level of sales	
	Improving	market share	3. Neto et al., 2020
productivity			
production efficiency			
production flexibility			
reliability of supply			
Social	order fulfillment capabilities	4. Kagermann et al., 2013	
	the quality of products and services		
	access to data		
	working conditions		
	worker safety		
	employee health		
	labor relations		
Environment	employee morale	5. Arnold et al., 2016	
	employee qualifications		
	employee engagement		
	work pressure		
	the environmental situation of the organization		
	efficiency in the use of resources		
	sustainable development		
Improving in	solid waste	6. Stock, Seliger, 2016	
	liquid waste		
	greenhouse gas emissions		
	wasted electricity		
	the use of hazardous/harmful/toxic materials		
	environmental impact		
Improving in	the environmental situation of the organization	7. Müller et al., 2018	
	efficiency in the use of resources		
	sustainable development		
	the quality of products and services		
	access to data		
	reliability of supply		
Improving in	the quality of products and services	8. Sarkis, Zhu, 2017	
	access to data		
	reliability of supply		
	order fulfillment capabilities		
	the quality of products and services		
	access to data		
Improving in	the quality of products and services	9. Herrmann et al., 2014	
	access to data		
	reliability of supply		
	order fulfillment capabilities		
	the quality of products and services		
	access to data		
Improving in	the quality of products and services	10. Stock, Seliger, 2016	
	access to data		
	reliability of supply		
	order fulfillment capabilities		
	the quality of products and services		
	access to data		
Improving in	the quality of products and services	11. Michna, Kruszewska, 2020, 2021	
	access to data		
	reliability of supply		
	order fulfillment capabilities		
	the quality of products and services		
	access to data		

Source: Own work.

This study focuses on one element of the conducted research, namely, on the effects obtained after the implementation of selected Industry 4.0 solutions in the surveyed companies. The study participants were asked to assess the extent to which the implementation of Industry 4.0 solutions influenced various factors, which are listed in the table below. A five-point Likert scale was used for evaluation, where: 1 indicated that the implementation had no impact on the factor, 2 - had a slight impact, 3 - had a moderate impact, 4 - had a relatively significant impact, and 5 - had a very significant impact. All factors potentially affected by the implementation of Industry 4.0 solutions were selected from previous literature reviews and classified according to the ESG framework (factors related to the environment, social factors, and factors related to corporate governance) similarly as “Triple Bottom Line” proposed by (Kiel et al., 2017).

3. Results

The first of the surveyed companies is one of the largest Polish manufacturers of rubber pneumatic springs for trucks and buses. Additionally, it provides services in vulcanization and the repair of conveyor belts, as well as rubber coating of drums. The company has a certified management system for quality in accordance with ISO 9001:2015 and IATF 16949:2016, as well as an environmental management system in line with ISO 14001:2015. The organization has been operating in the market for over 30 years and boasts a wide range of products, having reached approximately 6000 customers with its offerings. In the study, this organization was represented by a managing leader responsible for the area of environment and occupational health & safety management. As part of new technologies, the organization primarily employs automation of material flows in the warehouse area. It implements IoT in many locations, focusing at the moment on sensing areas related to excessive resource consumption but also on automatically acquiring data regarding resource utilization, machine settings, and production processes. The company also has terminals in the production area that facilitate daily work for employees, enabling control and settings of machines. Based on direct information from the survey participant: *Our company is heavily investing in sensors to significantly relieve and automate data from production lines. This is a substantial topic, and work on it is still ongoing. We started to work on utilizing large datasets and analytics, but it's progressing gradually. We use mobile technologies and have terminals at workstations.*

The second organization is a global supplier of rubber products, rubber-metal products, and rubber products combined with other materials. It offers a wide range of products for the household appliances, agriculture, construction, and automotive industries. It has been supplying its products for over 90 years. This company also holds certified quality, environmental, and occupational health and safety management systems according to ISO9001 and IATF16949, ISO14001 and ISO45001. This organization was represented by a quality and environment manager. Industry 4.0 solutions are implemented in this organization in areas such as: human resources management, procurement, production, production planning, and the department of technology and new product development. These changes relate to production processes, materials, logistics, as well as the product itself. In recent years, the organization has implemented automated documentation flows primarily related to the circulation of personnel, financial, and logistic documents. In the production hall, some processes have been automated, replacing human labor with robots or automatic loading. Employees have been reassigned to other tasks. *We have automatic loading of elements during the injection molding process. We are implementing robots, for example, on the deburring line. Just a few years ago, people worked there, and now we have an automated line, and everyone considers it standard. In the glue application process, we use robots. For me, Industry 4.0 is a broader project.*

During the design of injection molds, simulations are used to optimize material flows during the injection molding process. Words of research participants: *We conduct injection molding simulations for molds. We check hot runners, which, during mold design, allow material recovery - optimization of material consumption.* Company working on technologies such as RFID (Radio-Frequency Identification) and NFC (Near Field Communication) to be employed in their products. The plant's ambition is to implement Manufacturing Execution Systems (MES) and have all machines operate in a network, although the organization acknowledges significant challenges in this regard, mainly due to limitations in the current machinery park. Based on direct information from the survey participant: *Now, we are implementing an advanced planning module – the production plan is supposed to retrieve customer orders and all data from the System. Another example is an automatic monitoring system for maintenance. This is already implemented. Employees no longer have to manage this manually.*

In summary both participants represent the same organizational area within the company and have similar responsibilities within their scope of duties. Additionally, both companies are large enterprises operating in the same industry and offer products made from the same raw material. Therefore, the primary method applied for this research was comparative analysis. All tables and charts below contain the survey results for both participants, where C1 represents data from the employee of the first company, C2 for the participant from the second company and the average value for both surveyed cases.

Table 2.
Results for governance factors - effects of implementing Industry 4.0 solutions

		Factors	C1	C2	Medium
Governance	Reduction cost of	production	4	5	4,5
		product development	3	2	2,5
		inventory	4	2	3
		scrap & rework	3	3	3
		Purchasing base materials	3	2	2,5
		energy	3	4	3,5
		waste disposal	2	3	2,5
	Increase of	profit	4	5	4,5
		customer satisfaction	4	3	3,5
		speed of delivery	4	3	3,5
		responsiveness	4	4	4
		flexibility of supply	4	3	3,5
		product range offerings	4	2	3
		the level of sales	3	4	3,5
		market share	4	3	3,5
		productivity	4	5	4,5
		production efficiency	4	5	4,5
	production flexibility	4	3	3,5	
	Improving	reliability of supply	4	3	3,5
		order fulfillment capabilities	4	3	3,5
		the quality of products and services	4	4	4
		access to data	4	4	4
		reliability of supply	4	3	3,5
		order fulfillment capabilities	4	3	3,5

Source: Own work.

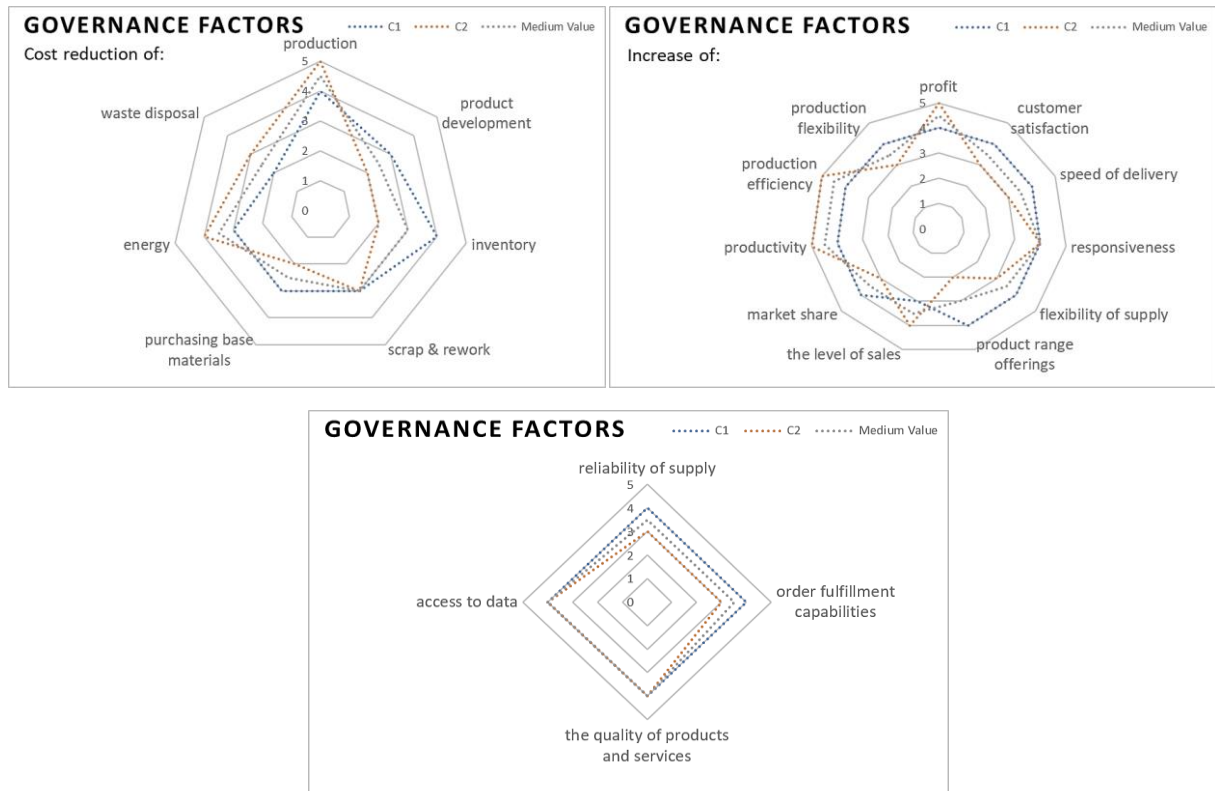


Figure 1. Results for the governance factor group.

Source: Own work.

In the governance factors group, both participants indicate that the implementation of Industry 4.0 solutions had the greatest impact in terms of reducing production costs, increasing the organization's profit, productivity, and efficiency. It also influenced greater access to data and the improvement of the quality of products and services provided by these organizations.

The first participant also highlighted the effect of reducing inventory costs and increasing the range of product offering, while for the second participant these elements were not important.

Table 3.

Results for social factors - effects of implementing Industry 4.0 solutions

	Factors	C1	C2	Medium	
Social	Improvement of	working conditions	5	4	4,5
		worker safety	4	4	4
		employee health	3	4	3,5
		labor relations	3	3	3
		employee morale	3	2	2,5
		employee qualifications	4	4	4
		employee engagement	3	3	3
		work pressure	3	3	3

Source: Own work.

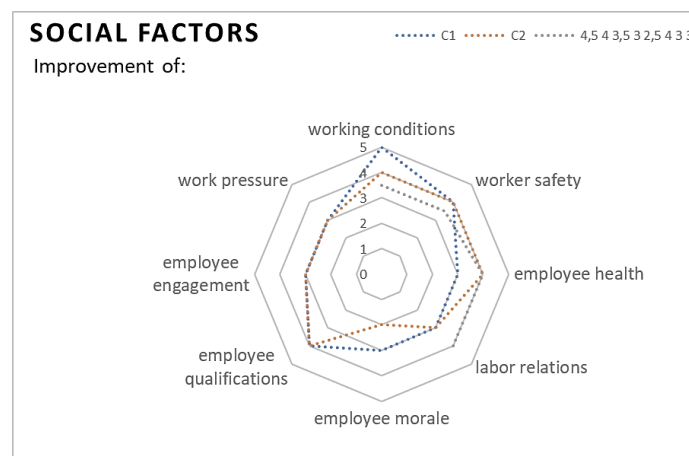


Figure 2. Results for the social factor group.

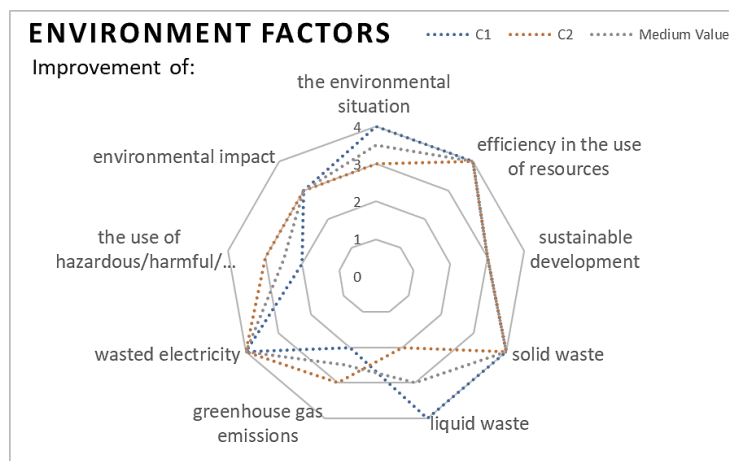
Source: Own work.

Also, regarding social factors, participants agree that the implementation of Industry 4.0 solutions has contributed to improving working conditions in their organizations. Improvement in safety and an increase in employees' qualifications were also highlighted as significant aspects. The least significant appears to be the impact on boosting employee morale. A participant from the second organization considered this factor to have had only a slight impact.

Table 4.*Results for social factors - effects of implementing Industry 4.0 solutions*

		Factor	C1	C2	Medium
Environment	Improvement of	the environmental situation	4	3	3,5
		efficiency in the use of resources	4	4	4
		sustainable development	3	3	3
		solid waste	4	4	4
		liquid waste	4	2	3
		greenhouse gas emissions	2	3	2,5
		wasted electricity	4	4	4
		the use of hazardous/harmful/toxic materials	2	3	2,5
		environmental impact	3	3	3

Source: Own work.

**Figure 3.** Results for the environment factor group.

Source: Own work.

In the case of environmental factors, participants indicate that the achieved effects primarily concern improvements in managing and reducing the amount of solid waste, wasted electricity, and generally, in better utilization of available resources.

Considering all the elements from each of the presented groups of factors - managerial, social, or environmental - according to the surveyed participants, Industry 4.0 solutions have the greatest impact in their organizations on reducing production costs, increasing profits, productivity, production efficiency, and improving working conditions. To a lesser extent, they contribute to reducing the costs of developing new products, purchasing basic materials, or lowering waste costs. From a social and environmental perspective, Industry 4.0 solutions in their organizations also did not influence the increase in morale among employees, the reduction of the use of hazardous substances, and did not significantly impact the reduction of greenhouse gas emissions. Table 5 gather exemplary responses obtained during the study. The collected information mainly pertains to the results achieved within the organization.

Table 5.
Information related to results obtained after the implementation of Industry 4.0 solutions

Group	Sentences from company C1	Sentences from company C2
Speed & Efficiency	<i>The implemented solutions have, for example, allowed us to pack and send more parcels in the logistics area than before. There are no longer such mistakes, and overall, we have accelerated work processes and increased warehouse efficiency.</i>	<i>In our industry, there is constant pressure on prices, and as a result, on what we call 'efficiency'. For it to be cost-effective, the process must be highly efficient, and this is the reason for the majority of innovations in the plant. Everyone in the company talks about this automation, but we encounter the fact that automated processes must pay off, and they must pay off quickly.</i>
Availability & accuracy of data	<i>Above the packing stations, we installed cameras, and just this fact, along with informing the customer that we have a complete visual record of what has been packed and how it was packed, reduced our complaints by 90%.</i>	<i>What results have been achieved? Above all, data accuracy has increased. In the machining processes, data is read, and there is no possibility of scanners making mistakes. In the production and logistic areas data is collected, and we use a barcode system.</i>
Independency	<i>For example, when we want to find out how much energy a specific area consumes, we no longer want to come in on weekends or remember to take manual readings. We are moving in this direction to be independent of people.</i>	<i>We have never done it in a way that when we implement automation, we lay off people – we always transfer them to a new project. No one has been let go due to improvements. Sometimes, certain inspections are too complicated, and a human presence is still necessary.</i>
Integration	<i>Last year, we introduced a project to save energy in the compressed air installation, and we had to do it manually, coming in on weekends. We no longer want to come in on weekends, so we are pressing the executives to automate this, so that the data is simply read automatically.</i>	<i>A shift to a job involving process control instead of performing processes - time savings for all of us. I have access to data. Previously, someone had to grapple with Excel; now we have everything integrated.</i>
Employees	<i>The biggest challenge is always the mindset among all people, convincing them. Also, the costs of sensors and certain improvements are high. I think these two things are the most significant. Often, we hear "why do we need this? What's the point?" Sometimes, we want to push away certain things that, in the end, we will have to accept. It's good that we have a sizable leadership group that enforces these changes.</i>	<i>Production employees still feel the threat (replacement by robots). Managers see the benefits. If the work is simpler, robots would be better. Production workers are afraid, and they also resist, but based on our experiences, the resistance is now less.</i>

Source: Own work.

4. Summary and conclusion

The main goal of this article was to present the effects that organizations achieve after implementing new technologies understood as Industry 4.0 technologies. The presented results include the subjective assessment of employees based on their experience and observations over the past years. As a research method, a multiple case study was adopted, along with an analysis of available documentation and a comparative analysis of responses to the question:

On a scale from 1 to 5, please assess to what extent the implementation of Industry 4.0 solutions has affected specific factors. The information obtained from interviews with study participants and the result on a 5-point Likert scale in response to the posed question confirms analyses available in the literature (Bal, Erkan, 2019; Mogos et al., 2019), indicating that the implementation of modern technologies not only impacts the reduction of production costs but also directly contributes to the increase in profits achieved by the organization. The words of one of the study participants: *...there is no other way; either a person quickly understands it, or they are out of business*, unequivocally indicate that the awareness of the necessity for changes, seeking more efficient solutions, increasing productivity, and thereby enhancing production and sales capabilities is the direction in which organizations are heading. Another important aspect highlighted by the study participants is the socio-psychological aspect related to personnel. The resistance of employees and their fears of being replaced by robots are evident in both surveyed organizations. Undoubtedly, this is one of the factors on which the implementation of Industry 4.0 has a direct impact. One of the participants stated: *There must be a satisfactory balance between a socio-psychological approach - people must have jobs. Automation and robotization, Industry 4.0 – it doesn't cure everything. There is a need for sharp-minded people.* The implementation of industry solutions in the surveyed organizations did not have a significant impact on the cost reduction of developing new products or purchasing basic materials, nor did it result in emission reduction.

This research was not free from limitations. The presented results are limited to two specific cases, two specific companies operating in polish manufacturing sector and are subjective opinions of employees working in specific conditions and occupying higher-level management positions. Moreover, it is recommended to investigate the presented subject on a wider range of organizations and at various levels of positions within the organization.

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