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Polish SMEs on the road to Industry 4.0 – opportunities, challenges and barriers to innovation

This article explores the implementation of Industry 4.0 within Polish small and medium-sized enterprises (SMEs), offering insights into the region's digital transformation patterns. By examining technology adoption patterns, we map the progression of Industry 4.0 among these firms. The study applied a mixed-methods approach, analysing Eurostat and IFR databases for quantitative data on digital technology and robotics use, and comparing Poland's digital maturity with other EU states. For qualitative insights, we conducted interviews and site visits with 12 industrial firms and 17 digital solution providers. Our analysis highlights two critical factors influencing Industry 4.0 adoption: the firm's global value chain position and the need to revise development models due to labour shortages. Polish firms predominantly automated distinct segments of their production, integrating robots with existing lines and tasks, and utilized systems that bridged older technologies with newer ones. Yet, they were hesitant to fully embrace comprehensive systems like intelligent factories, unlike Western firms that favoured automation in large-scale production due to labour scarcity and cost. A significant barrier identified for Polish SMEs was a deficient datafication level, evident from the inadequate practices in data collection, analysis and application. These firms often preferred reliance on experience over data-driven decision-making. Additionally, limited capital access hindered their ability to pursue advanced technological investments, impeding their innovation capacity. Polish industrial SMEs prefer a modular digitalization approach over comprehensive overhauls, reflecting a pragmatic strategy to tackle immediate issues and lay groundwork for future technological advancements.

Keywords: Industry 4.0, digital transformation, small and medium enterprises, manufacturing

JEL classification: L6

Introduction

After over a decade of the Industry 4.0 concept being present in public and academic debate, the argument regarding the benefits of implementing technologies related to Industry 4.0 is both voluminous and undifferentiated in its message as to its overwhelming benefits. Industry 4.0 can be most concisely understood as the integration of information and communication technology into the industrial development. Recently, it has been assumed that Industry 4.0 essentially refers to digital transformation in the manufacturing sector. Horváth and Szabó [2019, p. 120] note that one can view digital transformation as the broader idea, with Industry 4.0 nested within it. In this article, we will also adopt this perspective, using the terms Industry 4.0 and digital transformation within the manufacturing sector interchangeably. Industry 4.0 involves the implementation of technologies such as: additive or advanced manufacturing, augmented and virtual reality, automation and industrial robots, block-chain, big data analytics, cloud data and computing, cybersecurity, cyber-physical production systems, internet of services, internet of people, industrial internet of things, and simulation and modelling (digital twin) [Ghobakhloo, Iranmanesh, 2021].

Recent perspectives emphasize that digital transformation relies on the implementation of datafication technologies [Śledziewska, Włoch, 2021]. Specifically, these technologies allow for extracting value from rich data sources about a company's internal processes and external environment using artificial intelligence algorithms. Implementing these technologies require significant technical, infrastructural, and human resources, the use of new knowledge, competency reconstruction, and the introduction of broad organizational and process changes.

Importantly, introduction of these technologies is to bring increased competitiveness, efficiency, greater flexibility, organizational improvement, better decision-making [Horváth, Szabó, 2019], and adaptability to companies that embark on the path of digital transformation. For companies acting as suppliers, integration into the value chain and competitiveness resulting from the adoption of widely accepted global standards are also crucial [Da Silva et al., 2022]. Implementing digital technologies has become a business imperative, a sign of a company's progressive attitude and a foundation for creating new business models. There is also a consensus that the pace and level of Industry 4.0 technology implementations influence how companies deliver, create and appropriate value [Nwaiwu et al., 2020] due to principles such as decentralization, modularity and product personalization [Ghobakhloo, Iranmanesh, 2021]. Abdulnour et al. [2022] observe that "Industry 4.0 (I4.0) is increasingly presented as the new paradigm for improving productivity, ensuring economic growth, and guaranteeing the sustainability of manufacturing companies".

In this article we assume that it is important to recognize that the principles and application frameworks of Industry 4.0 are predominantly designed for the complexities of large-scale manufacturing, which can sometimes eclipse the distinct hurdles faced by smaller firms. Digital transformation, while challenging for all, particularly tests small and medium-sized enterprises (SMEs) in their journey towards Industry 4.0 adoption [Abdulnour et al., 2022]. At the same time, researchers consistently emphasize that the pace and level of technology implementation within the scope of Industry 4.0 in SMEs is especially relevant because they make up the vast majority of firms in most markets.

What specific challenges do SMEs face in implementation of Industry 4.0? For SMEs, a main concern is their tendency to avoid risks and experimentation with new technology, mainly because of limited financial, technical and skill resources [Horváth, Szabó, 2019; Estensoro et al., 2022]. Limited financial resources mean these businesses often plan for the short-term costs and benefits and are hesitant to invest in things that might not pay off until much later; consequently, SMEs are rarely the first to adopt new technologies. Instead, they prefer specific technological updates at the production level. Specifically, smaller companies are not inclined to engage in broad organizational and procedural changes leading to the creation of a smart factory, mainly due to financial reasons. However, they are more willing to engage in specific technological implementations at the production level [Masood, Sonntag, 2020].

A significant obstacle for SMEs is their constrained experience in adopting new technologies [Masood, Sonntag, 2020]. Yu and Schweisfurth [2020] demonstrated that knowledge about technology and its expected benefits significantly influences the implementation of Industry 4.0 technologies by SMEs. Interestingly, their analysis showed that, contrary to assumptions, neither the cost of technology nor the size of the company (number of employees or revenue) had a significant impact on the pace of implementation. However, production specifics mattered: the more diverse the products a company offered and the higher the level of automation it had already achieved, the more motivated it was to implement Industry 4.0 technologies. Additionally, the authors observed that "smaller SMEs focus more on operational aspects of technology implementation, while larger SMEs develop strategic planning, business formalisation and control systems to support the implementation process" [Yu, Schweisfurth, 2020, p. 78]. SMEs often lack adequate knowledge and digital skills, from the top management down to regular employees. This gap in knowledge means that leaders might not see the benefits of digital changes and might not even know where to start. As Mittal et al. observed [2018], SMEs are "often overwhelmed with decisions (i.e., strategic and operational) about what, why, when, where, who and how they can incorporate the different SM or Industry 4.0 technologies". Managers might struggle with how

to put these changes into practice, and employees might question or even resist them [Orzes et al., 2018].

Mittal et al. [2018] and Horváth and Szabó [2019] delved more systematically into the differences between MNEs and SMEs in the process of technology implementation. The former examined various studies to contrast SMEs and MNEs across seventeen criteria, underscoring their distinct opportunities within the framework of Industry 4.0. The dimensions were financial resources, use of advanced manufacturing technologies, software umbrella, research and development, nature of product specialization, consideration of standards, organization culture or leadership flexibility, company strategy, decision-making, organizational structure, human resources engagement, exposure to human resource development, knowledge and experience of the industry, alliances with universities or research institutes, important activities, dependence on collaborative networks, and customers and suppliers. The authors determined that SMEs have weaker network connections and fewer suppliers, making them more dependent on them.

Horváth and Szabó also noted that due to limited resources in the areas of skills, infrastructure, technology and budget, SMEs tend to be reactive and are reluctant to implement innovations with an ill-defined benefit catalogue. As a result, they show lower driving forces and higher barriers than MNEs in most dimensions of company operations. "MNEs and SMEs do not have equal opportunities in the context of Industry 4.0", conclude Horváth and Szabó [2019, p. 129]. At the same time, they noted that in some respects, SMEs might be in a better position when it comes to implementing Industry 4.0. This advantage arises mainly due to lower profitability expectations, less complex organizational factors enabling change, fewer technological dependencies, and lower barriers to cooperation. They often also see opportunities for themselves in market niches related to digital technologies.

A comprehensive discussion on barriers that that SMEs encounter in the implementation of Industry 4.0 technologies was presented by Orzes et al. [2018]. They analysed the experiences of 37 SMEs from Italy, Thailand and USA, concluding that current Industry 4.0 technologies are not tailored to the specific needs of SMEs. Moreover, most established models, theoretical frameworks and recommendations that should support implementation are developed for, or by, large enterprises. Judging the pace and scope of technological implementations in SMEs through the lens of these big companies misses the mark. "There is no clear method to evaluate I4.0 technologies against the needs and requirements of specific SME organizations" [Orzes et al., 2018, p. 2]. This viewpoint is shared by Mittal et al. [2018, p. 210], who write as follows: "Most maturity models, roadmaps, frameworks, etc. currently available for SM or Industry 4.0 consider mainly the needs and resources of MNEs, e.g., regarding the IT/OT infrastructure. Therefore, the reality of many

SMEs today is that their 'level 1' or starting point is often a disconnect from the average level of smartness (i.e., digitalization and (smart) automation capabilities".

The mismatch of the sociotechnical imaginary associated with the notion of Industry 4.0 to the real use cases and experiences of small companies often makes them feel unmotivated to translate these abstract concepts into practical actions which may be associated with uncertain return on costly investment. As noted by Amaral and Pecas [2021, p. 3], "this type of companies seems to fail to grasp or trust these notions without real, tangible examples. This results in an ineptitude of SMEs to embrace I4.0 as the larger firms, since the latter can afford to take more 'risks' related, for example, to R&D investment. Naturally, SMEs are positioned behind in the ladder of full implementation of I4.0, as already mentioned".

The aim of this article is to fill the research gap concerning the optimal paths for implementing Industry 4.0 in small and medium-sized enterprises, taking into account their specific challenges and barriers. In the first step, we analyse available data to characterize the level of implementation of individual digital technologies among Polish SMEs, treating it as an approximate indicator of the advancement of Industry 4.0 in Poland. Then, drawing on data from our qualitative study, we identify two specific factors shaping the implementation process of Industry 4.0 in this group of companies: (a) position in global value chains, (b) the need to change the existing development model due to a labour shortage. In the next part of the article, we show that Polish industrial SMEs adopt a modular or selective digitalization as a coping strategy. The value of our study lies in identifying an optimal approach for implementation of Industry 4.0 in SMEs, namely a modular digital transformation. It also highlights the importance of local conditions for implementing Industry 4.0, which originate from varieties of capitalism, and in particular – the semi-peripheral location of the country's economy, as well as macrostructural economic factors such as changes in the labour market.

1. Methodology

The analysis presented in the article uses data from Eurostat, which we supplemented with data from the International Federation of Robotics (IFR) for the analysis of robot implementations. Data from the Digital Economy and Society database at Eurostat are collected through surveys conducted among households and businesses. These statistics provide insights into the access, adoption, and utilization of digital technologies across all EU member states, covering aspects such as mobile internet access, social media usage, e-commerce, internet security, cloud services, digital skills, and information and communication technologies (ICT) specialist employment. Statistics related to ICT in this section are available

separately for households or individuals and businesses or enterprises. Data from IFR pertains to global statistics on industrial and service robot implementations.

The collected data allowed us to conduct an analysis of the level of digital technology adoption in Polish industrial enterprises. On the one hand, we present Poland in comparison to other EU member states, enabling us to determine in which areas Polish enterprises are advanced and in which areas they do not fully utilize their digital potential. On the other hand, we examined industrial production compared to other sectors. In the analysis, we also considered the aspect of digital competence among human capital, i.e., employees. Digital transformation is not only about digital technologies but primarily – as we emphasize in our publications – about a change in organizational culture and business models. The success of implementation depends on employees with the right competencies, who should receive training and support at every stage of their careers.

Interpreting the findings from the quantitative study, which repeatedly highlight the theme of technological lag in Polish industrial enterprises, is made possible by insights from the qualitative study. Empirical data was collected from October 2022 to March 2023. We conducted 20 qualitative interviews in 12 industrial companies, and in 11 of these companies, we also conducted on-site visits to their production facilities. The selection of companies for interviews was based on availability, with consideration for diversifying the companies in terms of size, production specificity, and geographic location. We also considered the companies' positions in national rankings of innovation or Industry 4.0 development.

In the second phase of the study, we focused on understanding the perspective of companies providing digital solutions to the domestic and international markets. We analysed the websites of selected companies to familiarize ourselves with their specificities, and then we conducted qualitative interviews with representatives from 17 of these companies, each lasting no less than an hour. In these interviews, we asked for an introduction to the characteristics of their solutions, as well as information about their cooperation with other companies and insights regarding the development of the Polish industry. We also utilized research notes from the on-site visits.

The transcripts of the conducted interviews were anonymized, and codes were assigned to individual interviews randomly (manufacturing companies P1–12; digital solution providers D1–17). We encoded and analysed the data using computer software for qualitative data analysis, extracting thematic threads related to the determinants, motivations, barriers, challenges, and specificities of Industry 4.0 implementations in Polish industrial companies. The results of the analysis were used to supplement and deepen the conclusions drawn from the quantitative analysis.

2. Results

Embarking on the exploration of the digital transformation journey within the Polish small and medium-sized enterprise sector reveals a nuanced landscape of adaptation and innovation. This section presents the empirical evidence garnered from our comprehensive study, aimed at unravelling the practical realities and strategic approaches undertaken by Polish SMEs in navigating the complex terrain of Industry 4.0. Through examination of data, interviews, and case studies, we shed light on the variegated experiences of these enterprises, uncovering the pivotal factors that influence their digital adoption pathways, the challenges they face, and the innovative strategies they employ to harness the potential of digital technologies.

3. Digitalization of industrial SMEs in Poland is low

The implementation of digital technologies that enable harnessing the potential of data to enhance production efficiency and the functioning of a company is a key element of digital transformation, also in the form of Industry 4.0. In this respect, Polish companies lag far behind the European Union leaders.

The level of digitalization in Polish enterprises can be assessed using the Digital Intensity Index (DII). This index serves as an approximate measure of digitalization adopted by Eurostat and is based on survey results conducted by statistical institutions in EU member states. Each company is classified into one of four digitalization groups: very low, low, high, and very high DII, based on the assessment of technological implementations in twelve areas. These areas include internet access, the implementation of information systems, the utilization of IoT (Internet of Things) technologies, the presence on social media, the use of artificial intelligence and cloud services, among others. A high DII score indicates that many companies in a given country have adopted advanced digital solutions and are using modern digital technologies. Enterprises with low or very low DII are less digitally advanced and may have limited capacity to harness the potential of digitalization. The Digital Intensity Index is a useful tool for assessing the digitalization level of enterprises. Its analysis suggests that there is room for improvement in Poland, especially in comparison to more digitally advanced European countries: the Polish industry lags behind the European Union average. A relatively small percentage of industrial enterprises in Poland achieve a high or very high DII. Scandinavian enterprises are the most digitally intensive, with Austria and Denmark particularly standing out in Central Europe.

Only large Polish enterprises are not lagging behind the EU average in terms of a high DII. Over 40% of large companies in Poland have a high digital intensity index, similar to Finland and Sweden. However, small and medium-sized enterprises are significantly less digitized compared to EU businesses as a whole. In Poland, only 11% of small businesses (compared to over 40% in Sweden and Finland) and 25% of medium-sized businesses (compared to around 70% in Sweden and Finland) have a high or very high digital intensity index. This may indicate that while Polish SMEs are (slowly) adopting digital solutions, the implementation does not take on a comprehensive character.

Against the backdrop of these low digitalization indicators among Polish SMEs, industrial enterprises face additional unfavourable circumstances. In general, industrial enterprises in Poland have a significantly lower level of digitalization compared to other sectors. Only 2% of industrial enterprises are classified as having a very high DII, and 10% fall into the high DII category. This means that only 12% of Polish industrial enterprises have implemented at least 7 out of 12 digital solutions included in the DII index. Only one in 62 industrial enterprises in Poland has a very high DII, while every tenth has a high DII. In comparison, in Sweden, this applies to approximately every tenth and nearly every second industrial enterprise, respectively.

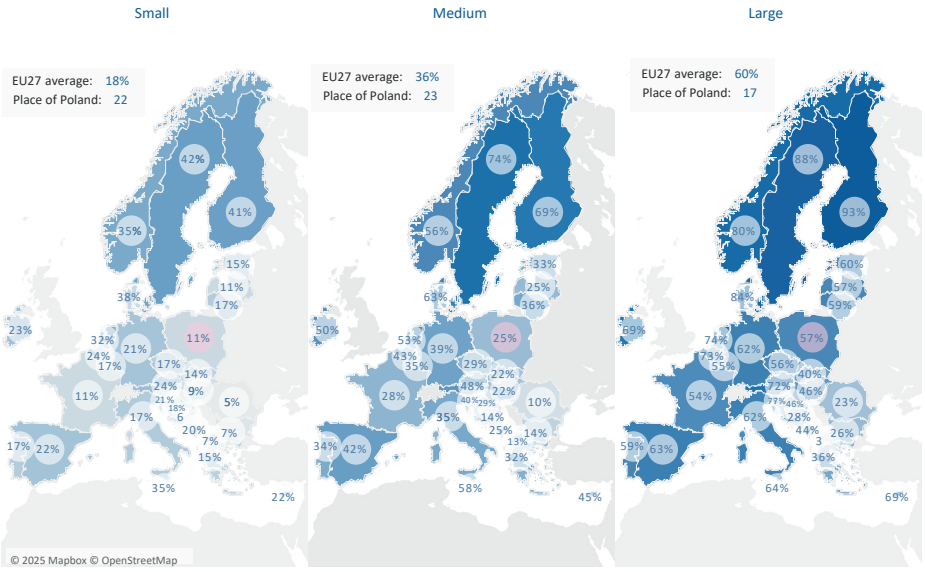

Figure 1. The digital intensity index of Polish companies

Source: [Eurostat].

The low level of digitization in Polish industrial enterprises is also confirmed by data on the adoption of specific digital technologies, often considered essential in the context of digital transformation. A good example is digital systems used for managing a company's resources or customer contacts. Only one in three industrial enterprises in Poland uses ERP systems. In the EU27 countries, on average, half of industrial enterprises have implemented this type of IT system. Poland has made progress compared to 2019, but still ranks 19th among the EU27 countries. The use of CRM systems by Polish industrial enterprises is not significantly different from the EU average. Positive factors contributing to this situation can be attributed to the inclusion of Polish companies in international supply chains and the need to adapt to foreign customer requirements, such as e-invoicing.

Table 1. The implementation of key Industry 4.0 technologies in manufacturing enterprises

Technology	Poland	EU27
ERP systems	34%	49%
CRM systems	32%	34%
industrial robots	14%	17%
Internet of Things	16%	30%
RFID	10%	17%
cloud computing services	28%	40%
big data	7%	10%
AI	2.3%	7.3%
3D printing	8%	12%
ICT security measures	94%	93%

Notes: Data for RFID for 2017, industrial robots, big data, 3D printing – 2020, ERP systems, CRM systems, IoT, cloud services, AI – 2021, ICT – 2022.

Source: [Eurostat].

However, when it comes to the adoption of technologies considered to be flagship technologies of Industry 4.0, Polish industrial companies achieve relatively low results compared to other European countries. Only one in ten Polish industrial enterprises uses robots, ranking Polish companies 21st in the EU27. In the EU, there are as many as 1,975,000 robots, accounting for 18% of the total number of robots worldwide. The largest number of robots is found in China, where they make up 32% of the total. In comparison, Poland's share in global robot utilization is only 0.5%. The installation of industrial robots is consistently increasing in both Poland and the EU, with the exceptions of 2009 and 2020. Compared to countries such as China, Japan, South Korea or the US, Poland lags significantly in terms of robotization. In terms of robot utilization by enterprises, Poland ranks 19th in the world, with 17,000 robots operating in the country in 2020.

Only one in four Polish industrial enterprises utilizes cloud computing, ranking 17th among the EU27 countries. In Polish industrial enterprises, these technologies are most commonly used for office programming, while in the EU27 countries, the most common use is for file storage. Polish industrial enterprises are slow to adopt the Internet of Things technologies. One in five Polish industrial enterprises

implements IoT technologies, which is a weak result compared to the rest of the EU27 countries, where one in three industrial enterprises uses IoT. In Poland, this only applies to 16% of such enterprises. In the EU27 countries, IoT technologies are most commonly used for ensuring the security of objects, while in the Polish industry, they are used for monitoring or automating production.

The most concerning aspect is the low utilization of the potential of big data. In terms of utilizing big data, Polish industrial enterprises rank 18th among the EU27 countries. Data for analytics are mainly generated from the geolocation of mobile devices, smart devices, sensors, and social media in Polish industrial enterprises. Only 7% of Polish industrial enterprises have declared the use of data analytics, while in the information and communication sector, this percentage exceeds 20%. This indicates that industrially producing enterprises in Poland have much to do in terms of using data analytics to improve efficiency, competitiveness, and innovation. The AI revolution is bypassing Polish industrial enterprises.

Only 2% of Polish industrial enterprises implemented artificial intelligence systems in 2021. Overall, EU enterprises make relatively little use of this technology (8%). Denmark leads in this area, with almost one in three industrial enterprises using artificial intelligence. Larger companies are more likely to use AI – in Poland, one in five does, ranking 19th in the EU. Industrial enterprises implement AI in production processes, for ICT security, or in business administration organization. If a company uses AI, it is most commonly applied in production processes. It seems that the main barriers to the adoption of AI technology are high costs and a lack of specialized knowledge.

The above data pertains to industrial enterprises as a whole. Regarding the situation of small and medium-sized industrial enterprises, one can infer by comparing them to the previously discussed Digital Intensity Index, reasonably assuming that they achieve significantly lower adoption rates of the mentioned technologies than large enterprises, which generally do not deviate from the EU average. Polish industrial companies are less digitized than their European counterparts, and concurrently, Polish small and medium-sized enterprises are considerably less digitized than large ones. This prompts us to pay special attention to industrial SMEs in Poland.

These statistical descriptions were validated during the qualitative interviews: as a rule, the representatives of companies providing technological solutions emphasized very low levels of digitalization of the Polish companies, primarily manifested in a low level and slow pace of digital system implementations. One of the frequently cited reasons for this state of affairs was the limited business maturity of Polish companies, most of which began their history after 1989.

"Mature companies are in short supply in Poland because even thirty-year-old firms, in my opinion, are not as mature as those that are eighty or a hundred years old in the West. Poland has a relatively young economy. In general, we are

catching up. We have a significant technological debt in the Polish industry, and we need to make up for it" (D3).

As a result, the situation of Polish companies was characterized as a pursuit of the peloton in the context of significant technological lag in the implementation of more basic ICT (information technology) technologies. From the experiences of digital technology providers, it is evident that not many Polish companies demonstrate sufficient readiness to implement advanced solutions. As one of the interviewees noted, "in Poland, we want to build Industry 4.0 before we have even built Industry 1.0, 2.0, or 3.0". Often, industrial firms in Poland decide to adopt technologies based on trends without considering their actual applicability in their production cycles.

"Many people approach Industry 4.0 with enthusiasm, trying to introduce these technologies into their companies, sometimes even forcefully. Later, disappointment sets in when these solutions do not perform as expected. However, Industry 4.0 is not a magic wand that brings success on its own. These technologies are merely additional tools that require the right foundation and infrastructure to function effectively" (D5).

Many SMEs lack a strategic approach to Industry 4.0, hindering their progress and adaptation. While financial resources and robust internet infrastructure are undeniably vital, it is essential for companies to recognize the business justification for adopting technology, ensuring it aligns with their unique needs. Still, many companies fail to see the need for changes in their operational model, driven by a short-sighted belief that the current model must be good since it ensured the company's survival over the past three decades. Paradoxically, if such a company decides to adopt technology, it often sets unrealistically high expectations for quick and substantial returns on investment. However, because they are unwilling to invest in solutions that enable the full utilization of this technology (such as adapting the system to changing needs, adjusting other processes in the company to fit new systems), it often results not only in disappointment but even in the abandonment of already implemented technologies.

4. Industrial SMEs in Poland take mid-upstream positions in global value chains

Poland ranks a high fourteenth in the group of countries with the highest influx of Foreign Direct Investment (FDI). Poland has slightly weaker GVC connections compared to other Central and Eastern European countries. Foreign value-added accounts for no more than one-third of Poland's exports [Chilimoniuk-Przeździecka, 2018]. It is worth noticing that this share grew steadily and considerably in the

last 30 years and can be treated as a manifestation of transformation of the Polish economy towards integration with the European and global trade. The primary sources of these investments are other European Union countries, notably Germany and France. Between 2004 and 2020, the volume of FDI increased six-fold (from 8.2 billion to 24.8 billion USD) [UNCTAD, 2023]. The inflow of foreign direct investment into Poland has consistently been seen as a means of technology transfer, a factor that contributes to the modernization of the Polish economy and supports economic growth through various mechanisms. Currently, companies with foreign capital are deeply integrated into the specifics of the Polish industry. Yet only a small portion of these investments find their way to Polish small and medium-sized enterprises, with the majority going to large automotive or electronics plants. This effect is amplified by the fact that foreign capital was primarily invested in labour-intensive segments of production based on relatively lower labour costs.

"A decade ago, in countries like Germany and France, where the population was aging, and young people were reluctant to work in the industry, there emerged an idea to seek what yields the highest margins. The idea arose: let us focus on the end of the process and create the entire process, design the product, but let's avoid all the tedious work in the middle that often requires human labour. Let us outsource that to the East" (D15).

The Polish SMEs integrated into global value chains mostly function as suppliers who provide intermediate resources, which are then utilized in the production of goods and services in the next step of this network. Polish industrial companies typically occupy middle upstream positions within the value chain. Companies positioned at the beginning of the value chain (suppliers of raw materials, materials, or even components) tend to achieve lower profit margins compared to companies located at the end of the value chain (final sellers). This occurs because companies at the beginning of the value chain must compete with numerous other firms offering similar products and services. To succeed, they need to offer competitive prices and high-quality products and services. Moreover, they are more exposed to the risk of fluctuations in raw material and material prices, while being less susceptible to short-term changes in demand for end products.

Both the design and sale of the final product are often located outside of Poland. It is a rare occurrence for the entire production cycle to be executed by Polish companies based on Polish technological innovation.

"The primary constraint is that Poland produces very few things from A to Z and at a high technological level. While many components are manufactured for various industries, very few products are made entirely from start to finish, and even fewer are designed in Poland. This is a significant problem because the highest technologies often require decisions to be made outside of Poland, and even when they are made, the machinery arrives in Poland without the involvement

of Polish engineers or technical expertise. From my perspective, it is also rare in Poland to encounter someone actively engaged in technology development" (D5).

The position of a company in the value-added chain can have a significant impact on its digital maturity. Companies located at the beginning of the value chain usually have lower profit margins, which can result in a reduced inclination to invest in digital innovations. Polish SMEs also tend to adapt to the particular needs of business customers introducing selected functions of digital systems, e.g., electronic invoicing, without implementing more advanced procedural or organizational changes.

Importantly, the position of Polish industrial companies in international value chains largely determines the nature of their production, which is based on small batches of products manufactured at short intervals. The situation has its advantages. The focus on short series allows Polish small and medium-sized enterprises to respond more quickly to customer needs and precisely tailor their production (e.g., producing specific spare parts based on customer-provided designs. This flexibility is the foundation of the competitive advantage for Polish SMEs. Because Polish SMEs are geared towards frequent machine changeovers, they can respond faster to declining demand, reducing potential losses. Additionally, diversified production aimed at multiple customers also helps mitigate risk. However, short-run production places significant demands on management, which must be dynamic and responsive to market signals. This explains why Polish SMEs are prompt in implementing management systems, as confirmed both by Eurostat data and our qualitative interviews. Native technology providers play a crucial role in this implementation process, tailoring their offerings to the needs of smaller businesses. Manufacturing execution systems (MES) come to the aid, supporting the management of rapidly changing production batches and aiding in planning variable material or semi-finished goods demand.

At the same time, short-run production, largely stemming from the position of Polish companies in the GVC, poses challenges in terms of implementing digital transformation. Production processes are subject to continuous changes, and the cost and time of changing equipment between production batches reduce efficiency. The process also requires more labour, and work often takes place in difficult or even hazardous conditions. As noticed by a representative of one of the manufacturing companies from the metal industry:

"We specialize in 'high mix, low volume' production, which means a wide variety of products and short, small orders. The average order size is below ten units. It is essential to remember that our current technologies are very labour-intensive and not so easy to automate, nor are they straightforward to adopt the latest solutions related to automation or even process autonomy" (P10).

Furthermore, short production series mean that not every company experiences an increase in efficiency when implementing digital transformation. This especially

applies to companies that produce short runs of highly personalized products. Many companies find it more cost-effective to utilize the machine park of external contractors. At the same time, for medium-sized companies with more complex production processes, the introduction of ERP and MES systems becomes increasingly important.

"Analysing our observations from the past few years, we have come to the conclusion that it is better to invest in systems. Robotics is the last consideration, especially if we do not have large production runs. In the case of custom production, such as machines tailored to a specific project, the cost of reconfiguration can be comparable to the time needed to complete all other machining operations. It is better to utilize the services of other companies that already have the appropriate machinery" (P9).

5. Workforce shortage is the main motivation for Industry 4.0 implementation

The main challenge currently faced by Polish companies is the burnout of a developmental model based on competitiveness derived from relatively low wages. In Poland, there is relatively high employment in production, although it has been declining since 2010.

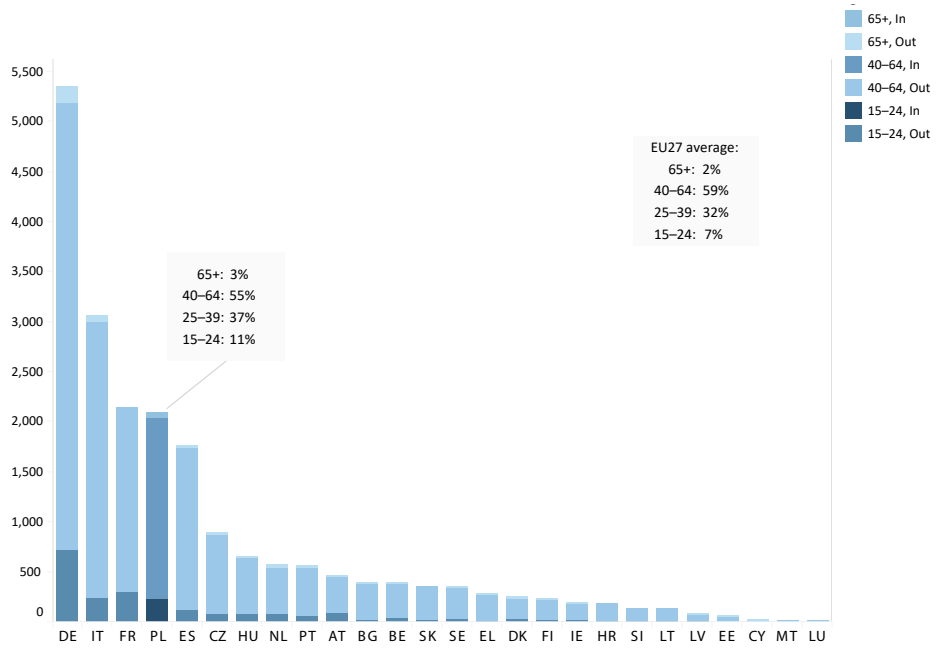

Figure 2. Number of persons employed in manufacturing (thousands of persons)
Source: [Eurostat].

Employment primarily relies on individuals aged 40–64 (55%), which is a relatively lower proportion compared to the EU average. Wages have been increasing faster than employment since 2014. This growth rate is higher than in other countries in the region, indicating that Poland is losing its advantage (labour-intensive production based on relatively low production costs) on which it has built its competitiveness so far.

As one of the technology providers noted, Polish industrial companies need to find another source of competitive advantage than low worker wages. A way out of this situation could be the implementation of technologies ensuring higher productivity and production stability, from ERP systems to intelligent robotic systems.

"It is not the same as it was 15 or 20 years ago when a production efficiency that was twice as low in Poland made it worthwhile because the wages were still four times lower" (D15).

A related challenge is the decreasing motivation of young workers to take on difficult, dirty, often hazardous, and frequently repetitive jobs in manufacturing. "Today, one has to do everything to become an attractive employer", noted the owner of one of the surveyed industrial companies. Rising social aspirations discourage young people entering the job market from taking on professions that require excessive physical effort, in challenging and health-damaging conditions (such as noise and air pollution). Young workers are also particularly averse to shift work.

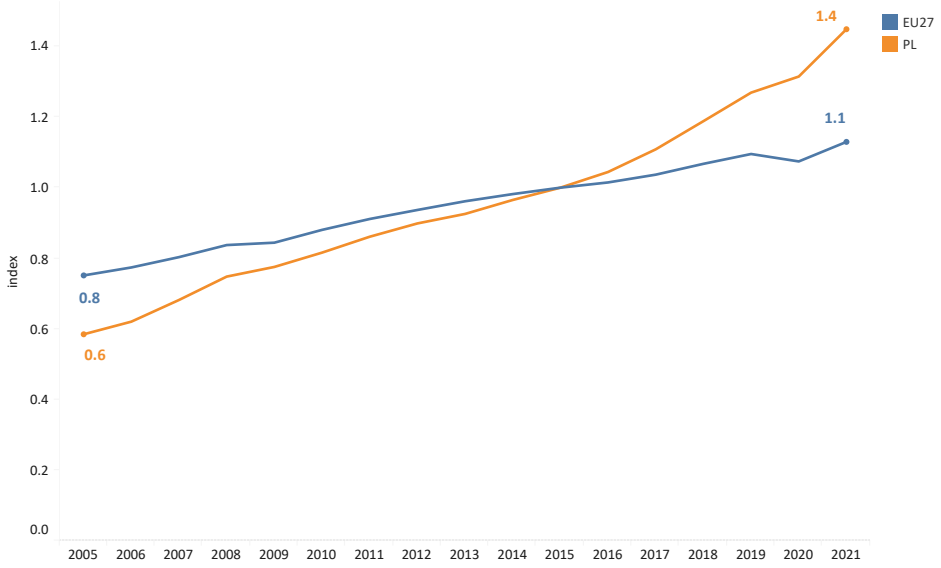

Figure 3. Index of wages and salaries per index of employment in manufacturing (2015 = 100)
Source: [Eurostat].

"Especially young people do not want to engage in such monotonous tasks as transferring jars on the assembly line. They prefer someone else to do this kind of work. These jobs are considered boring, uninteresting, exhausting, and harmful to the spine. Moreover, the younger generation is not willing to work in three shifts" (D3).

High employee turnover in industrial also partially results from the reluctance to perform work that is considered unsatisfying in terms of professional and personal development. "If you want to retain an automation specialist, buy them a robot", succinctly explained a representative of one of the companies integrating robotic solutions.

"Jobs in maintenance departments are becoming increasingly unattractive. Our clients face challenges in ensuring the right personnel, so they take various actions to counteract this. One trend is to combine maintenance work with projects or innovation implementation. Individuals working in maintenance are engaged both as executors and supervisors of external implementing companies. Another trend we observe is an attempt to make the work more attractive by introducing new tools and means, such as maintenance management systems and the use of virtual reality. The goal is for those responsible for maintaining machinery or technological processes to interact with modern and appealing technologies" (D2).

Some industrial companies openly acknowledge that their motivation for replacing human labour with machines in certain areas of their operations is driven by the desire to ensure greater operational stability. From this perspective, digitalization serve to enhance the safety and repeatability of the production process and to become less dependent on the variable availability of workers. "Introducing robots can be not only cheaper but also more predictable, especially in the context of pandemics and other crises" (D8).

Noteworthy, in the analysed companies digital transformation typically do not lead to employee layoffs; instead, they trigger a restructuring of employment within a given manufacturing facility. Individuals performing repetitive and routine tasks are reassigned to other roles that may require some degree of skill adjustment or competency enhancement. Workers are transferred to positions that are less "dirty, difficult, and dangerous", where they are tasked with overseeing machines and systems; "the machine follows orders, and the human becomes a machine park supervisor" (D13).

"You can count on one hand the situations where the introduction of automation or robotization led to a reduction in employment in a given manufacturing facility. In most cases, these employees are reassigned to other tasks, to different areas that have not yet been automated or for some reasons will not be automated at this time" (D2).

This restructuring of employment allows for the avoidance of job loss due to automation and enables the continuous improvement of employees' skills, adapting

them to changing market demands. The implementation of new technologies becomes a benefit for both companies and workers, as it provides new opportunities for professional development and skill enhancement. Robots and automated systems take over tasks that are physically demanding, mentally exhausting, or harmful to health. One of our respondents aptly noted that especially robotization makes work in manufacturing facilities more "humane". According to a manager from one of the surveyed companies, employees quickly understand that the priority should be "working smarter, not harder" (P2), and digitization greatly facilitates this approach.

For most of the examined companies, digital transformation of production processes, as well as digitization of business processes, are solutions that enable better management of human resources in the era of demographic crisis, which results in a reduced pool of workers in the labour market. However, the key factor for the success of digital transformation is the employees who have the skills to work in digitizing enterprises. Polish companies are facing a labour shortage not only in absolute terms: they especially lack employees who can actively participate in the company's digital transformation due to their adequate digital and technical skills.

The data confirms that Polish businesses may encounter difficulties in adapting to new technologies and harnessing their potential due to a lack of employees with the necessary skills. Polish employees have lower digital competencies compared to workers from other European Union countries. This is evident both from the Human Capital Index and from a detailed analysis of ICT and non-ICT worker skills. 69% of ICT workers possess advanced digital skills, whereas only 31% of non-ICT workers and 13% of physical workers do so. Poland ranks 24th in terms of digitalization of human capital according to the DESI index. Interestingly, only one in five industrial companies in Poland provide training to enhance the digital skills of their employees. Furthermore, not many industrial companies invest in training ICT specialists. Poland holds a high 5th position in terms of employing ICT professionals in industrial firms, with one in three companies doing so. However, the challenge lies in the increasing salary expectations of candidates, and to a lesser extent, their availability. In other EU countries, the most common issue is the limited number of applications for ICT specialist positions.

The implementation of new digital technologies requires a significant organizational effort: streamlining or changing production processes, training the workforce, and sometimes even altering business strategies. However, the most crucial factor in digital transformation is the quality of human capital: the skills of employees, their knowledge, and the willingness of management to embrace change.

"Our technology is innovative and demands substantial commitment from the customer. To implement it, the necessary investment resources, courage, and implementation skills are required" (D2).

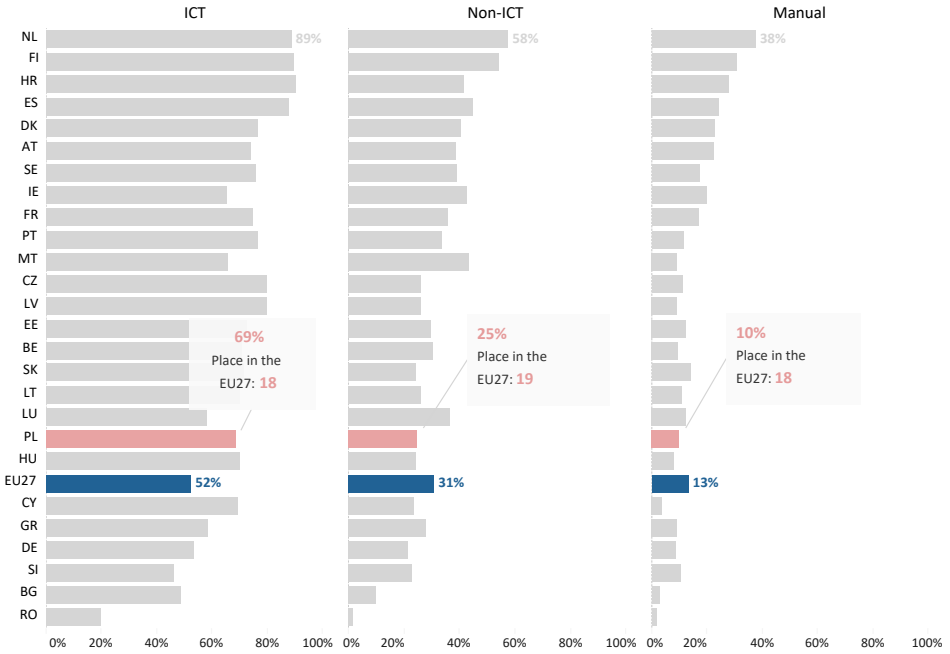

Figure 4. Comparison of employees with above-basic digital skills in EU27 countries

Notes: Data for 2021.
Source: [Eurostat].

During qualitative interviews, representatives of industrial firms and technology providers emphasized that the limited availability of appropriately skilled workers is also influenced by the long-standing crisis in vocational and engineering education that has affected Polish education during the systemic transformation. One representative of an industrial firm put it bluntly: "It seems that as a country, we have lost the ability to provide technical education".

There is also a specific deficiency in data literacy, especially regarding the importance of data utilization for company operations, observed at various organizational levels. Eurostat data shows a low level of big data technology implementations in Polish companies. During the interviews representatives of technology companies particularly highlighted the insufficient knowledge about rendering data utilization into value generation among management representatives. This translates into a lack of actions in developing digital transformation strategies and building an organizational culture conducive to implementing new technologies. Resistance to change is often encountered, notably from IT departments, if they are distinct within a given company. Their employees usually focus on cybersecurity issues and often lack competencies in data-related work and an understanding of digital transformation mechanisms. Frontline workers

often resist changes because they do not understand their significance and fear their impact on job security. In the surveyed companies, engineers, mechanics, and automation specialists played the role of change drivers. They perceived changes as opportunities for professional advancement and viewed new solutions as instruments to improve their own and other employees' work quality.

6. Industrial SMEs in Poland undertake modular digital transformation

In the prior section, we approached Industry 4.0 objectively as an innovative production paradigm based on digital technologies, signifying a comprehensive technological revolution – the fourth industrial revolution. However, beyond the technology, Industry 4.0 carries a narrative shaping business expectations and attitudes. It is not just a tech suite; it is a vision of an automated, integrated, market-responsive future. This narrative influences how companies view their capabilities, make choices, and perceive barriers. In this context, it is important to emphasize that the concept of Industry 4.0 is not ideologically neutral [Pfeiffer, 2017]. Its narrative and implications are deeply intertwined with broader socio-economic and political discourses, potentially influencing not just technological choices, but also organizational structures and business strategies. It is closely linked to a specific political-economic development strategy adopted by the German government several years ago. This concept quickly spread in the business discourse in Europe, especially in the Nordic countries. At its core, it assumes that we are dealing with a linear process of technological and industrial development: to enter the phase of Industry 4.0, one must go through phases 1.0, 2.0, and 3.0. Often, this concept is used in a value-laden manner: a company that cannot reach the level characteristic of Industry 4.0 is seen as backward, unable to leverage development opportunities, and ultimately destined for elimination from the market [Fuchs, 2018]. It may be ventured that the way the concept of Industry 4.0 is described in the media, by consulting firms, and public institutions can indeed discourage efforts towards modernization. Especially for small and middle companies, the implementation of new digital technologies appears as a costly and time-consuming process that requires advanced digital skills from production workers and management [Orzes et al., 2018; Amaral, Peças, 2021; Abdulnour et al., 2022; Da Silva et al., 2022]. Companies often struggle to translate abstract terms like "digitization", "datafication", "platformization", "Industry 4.0" (or even "5.0") and the use of AI into everyday production practice. They also fail to grasp the necessity of radically rearranging processes and organizations,

which are perceived as an integral part of the concept of the "smart factory" and the associated successful digital transformation.

The interviews we conducted revealed that for Polish industrial companies, especially small and medium-sized ones, the label "Industry 4.0" was often seen as limiting. For some companies, Industry 4.0 is seen as an imperative – they have a sense that without the introduction of digital systems and robotics or automation, their company will lag behind. However, this is not necessarily tied to a strategic approach. As a result, implementations are often carried out in a non-systematic manner and do not align with the company's business strategy, leading to their abandonment when they do not deliver quick and substantial profits. A paradox of digital technology implementations is the often-present increase in product quality accompanied by a decrease in productivity, leading to customer disappointment expecting a rapid and measurable return on investment. Yet most of the manufacturing companies which took part in our research rejected this perspective, pointing out that technological development often takes on a branching (rhizomatic) or networked form: solutions that can be puristically considered characteristic of Industry 3.0 – such as robots – become the impetus for datafication of a specific segment of the production process and subsequently, the overall digitization of the entire production process.

In attempting to address the mandate of digital transformation, Polish industrial companies typically adopted a selective or modular approach to digital change. They put in impressive efforts to implement new digital technologies, but seldom can boast of implementing comprehensive solutions that fit the model scenario of a production facility functioning based on intelligent automation. Digitization processes are often fragmented and cautiously introduced in selected segments of the production process; however, even then, they represent a significant step towards digital transformation.

Polish companies usually have limited investment capital, which affects their willingness to experiment with new technologies and their readiness to incur costs associated with their implementation. As a representative of one of the surveyed companies accurately pointed out, "we cannot afford to change everything all at once" (P9). In most of the surveyed companies, there is a significant technological debt; few companies can afford to replace their entire machinery fleet. Instead, companies purchase newer machines and systems, which they then integrate with older machines and systems using bridging solutions. Technological debt may make it challenging to introduce datafication-based integration of production processes, but it does not make it impossible. The datafication of the production process often does not require large or highly complex datasets; typically, simple but well-calibrated data is needed.

Modular transformation is an approach that does not require the elimination of isolated organizational structures. It focuses on creating functional systemic overlays that support communication, coordination and collaboration. This approach stimulates innovative impulses at various organizational levels and moves away from the concept of centralized standardization of IT systems. Importantly, module boundaries are not defined by formal organizational divisions, such as branches or departments, but by the specifics and distinctiveness of technological and business processes while integrating them throughout the organization. The gradual introduction of implementations also helps reduce the fear of change and allows for adjustments in implementation to achieve better results. The analysis of the interviews indicated that this model of digital transformation is particularly suited to the situation of Polish small and medium industrial enterprises. Both representatives from these enterprises and digital technology suppliers recognize this suitability.

"Our solutions are based on a modular structure, which means we offer many different functionalities embedded in our application. In practice, implementations often have a partial character, focusing on the implementation of a specific element that is most needed by a given company" (D1).

Modular transformation is gradual and evolutionary in nature. Most often, companies undertake individual digital initiatives that are easy to implement and yield quick, visible benefits. These initiatives can include process automation projects, the implementation of monitoring systems, or the introduction of basic IT solutions.

"We do not yet have sufficient capital or experience, and generally, we lack employees who can take a systemic view. That is why we design the structure of our production plant in such a way that we can modify it if necessary. We are entering the transformation slowly, step by step. This way, we reduce risk" (D10).

Polish companies tend to automate individual segments of the production process more often, integrating modern robots with automated production lines or manual labour, and implementing production management systems that allow for the integration of older technological solutions with the latest technologies. They also less frequently opt for holistic solutions like the smart factory. Meanwhile, Western companies focus on mass production, which lends itself better to automation and robotics and requires less labour, which is becoming increasingly scarce due to rising labour costs and growing social aspirations.

Countries like Germany and France prefer robotization and the production of repetitive series, while Poland specializes in the production of heavier and more complex series, which are harder to automate. The resistance to introducing new technologies and robotization in manufacturing plants is not solely due to a lack of knowledge among employees but also because Poland receives orders for less repetitive series that are transferred by other countries specializing in mass and

repetitive production. These countries are technically aware that repetitive production is easier, simpler, and cheaper, allowing them to pay higher wages to their workers. Poland, on the other hand, is often referred to as the "welding shop of Europe", signifying its specialization in more complex and non-standard productions (D11).

Importantly, technology providers often emphasized with a fair amount of satisfaction that even isolated technological changes implemented in one area of a company begin to affect its overall functioning, encouraging the expansion of implementations.

"When someone observes the effectiveness of a point solution, they start to want it for themselves. Then, other departments in the organization express a desire to use this solution, while also realizing that we have another solution that can help them even more. This marks the beginning of another stage, with new champions emerging – individuals who are very positive about change and are essential for its implementation" (D14).

Technology providers particularly emphasize the trend of economizing on additional hardware and software that could contribute to a more efficient utilization of digital systems. A holistic approach supports the preparation of a digitalization strategy with defined objectives, values, and implementation methods. They argue that industrial companies must realize that digital transformation is a complex process encompassing technological, process-related, cultural, and organizational changes.

"An example of this is when a company has implemented a system in one area but not in another. When employees move from an area with a system to one without, they feel its absence and realize that the system would help them solve problems. Thus, the system becomes a powerful source of data that is operationally used in production. Moreover, the introduction of the system changes how production communication works. Thanks to the system, data is transmitted in real-time in both directions – operators have access to the current plan and are informed about any changes in real-time. Managers also see what is happening in production in real-time. Communication regarding maintenance is also changing – breakdowns and problems are reported in the system, and information is relayed almost instantly via televisions and other notification methods. Previously, this required running around, writing notes, making phone calls, and waiting. It is evident that the factory is now much better connected at various levels. Along with the implementation of the system, the roles of managers and analysts also change. Instead of spending a lot of time creating reports, they now focus on working with data, seeking optimization, and improving processes. The workload shifts from report creation to data analysis. This is a significant change that becomes apparent after the system is implemented" (D4).

Manufacturing companies clearly identify several benefits stemming from introduction of digital technologies, such as operational efficiency and problem solving, enhanced production monitoring, and, more importantly, role transformation connected with shift in workload. The introduction of digital systems changes the fundamental roles of managers and analysts. Rather than being bogged down by the tedious task of report creation, they can focus on more value-added activities such as data analysis, seeking optimizations, and enhancing processes. Modular digitalization offers manufacturing companies a pathway to become more efficient, connected, and data-driven. It not only improves current operations but also paves the way for further innovation and optimization.

Conclusions

The study sheds light on the current level of Industry 4.0 implementation among Polish SMEs, serving as a vital benchmark for understanding the digital evolution of such businesses within the region. Our findings suggest that the advancement of Industry 4.0 in Poland can be mapped through the observable patterns of technology adoption in SMEs. Two paramount factors were identified that play a crucial role in the adoption process of Industry 4.0 by Polish SMEs. Firstly, the enterprise's position in the global value chains significantly affects their readiness and approach to digital transformation. Secondly, the pressing need to amend the ongoing development model, primarily driven by labour shortages, acts as a catalyst for change. It is notable that instead of a broad, sweeping digital overhaul, Polish industrial SMEs predominantly favour a modular or selective digitalization approach. This strategy seems to be a pragmatic response to address immediate challenges while simultaneously building a foundation for future advancements.

The analysis underscores the imperative nature of local conditions in determining the path and pace of Industry 4.0 adoption. The unique aspects related to Poland's semi-peripheral economic positioning, coupled with its distinctive capitalist variety, significantly influence the way SMEs approach and experience digital transformation. This study also accentuates the intertwining of digital advancement with larger economic factors, most prominently the labour market's dynamics. Such connections indicate that the push for Industry 4.0 is not solely a technological endeavour but is deeply rooted in broader economic structures and trends.

In conclusion, the research not only narrows down the existing knowledge gap concerning the conditions for implementing Industry 4.0 in Polish SMEs but also offers a lens to appreciate how regional nuances and macroeconomic realities intertwine to shape the digital trajectory of businesses. Future endeavours in

this domain would benefit from recognizing and addressing these multifaceted determinants.

From the practical point of view, it is important to emphasize that current discussion on Industry 4.0 focuses on standard patterns (use cases) of digital transformation, primarily on the creation of intelligent factories characterized by advanced vertical and horizontal integration of digital systems and the incorporation of cutting-edge digital technologies. Such an approach, which emphasizes the scale of the endeavour and the required funding, can, however, intimidate smaller companies and may not be well-suited to their needs and business models. Meanwhile, for SMEs, the introduction of basic ERP or MES systems or the automation of specific production processes, like robotic automation, can bring significant benefits.

The widespread dissemination of knowledge regarding the advantages of implementing new technologies tailored to the specific needs of SMEs, considering their position in value chains is crucial for the development of modern industry in Poland. This dissemination should take the form of modular or selective transformation based on relatively simple and financially accessible solutions for small and medium-sized enterprises.

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