

Article

Sustainable Printing 4.0—Insights from a Polish Survey

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Abstract: The transformation trend towards digital technology to achieve sustainability targets and meet legal regulations has been visible in many industries. The printing sector has already been increasingly boosting sustainability performance through digitalization to automate workflows of processes. The goal of this paper is to initially diagnose a sustainable performance of Printing 4.0 (Industry 4.0 in the printing sector). To achieve this goal, qualitative interviews were carried out with representatives of 11 printing companies. Results of the diagnostic study showed that advanced technologies have had a positive impact on sustainability in the analyzed printing companies due to a higher awareness of sustainability. It was observed in the surveyed sample that interviewees confirmed such an assumption. These companies that tailor their operational activities toward digitalization have more quickly noticed a positive effect on their sustainable businesses. This survey has served as a basis for more extensive research.

Keywords: Industry 4.0; digital technology; sustainable development; sustainability; sustainable printing; printing sector; interviews



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1. Introduction

The printing industry has been aware of the importance of sustainability for more than a decade. One important driver for printing companies' sustainability awareness is the expectations of customers. Sustainability in the printing industry is widely considered in economic [1,2] and environmental terms (mostly focusing on hazardous materials, pollution, and waste management or eco-design) [3–7]. Environmental considerations are usually supported by economic assessments [8] and some studies have treated the topic more broadly from an environmental management point of view only [9,10]. Some papers focused solely on economic issues have also considered the digital economy, the main pillar of Industry 4.0, but the sustainability dimensions have not been fully covered [1]. There are only few research articles that consider social issues or that show a preference for a holistic approach considering the triple bottom line (TBL) [11]. These works are focused on sustainability assessment frameworks applied to specific companies [12,13]. Individual scientific papers considering social dimensions have been focused on the link between pollution and workers' health in the printing industry [14]. There is also a lack of research diagnosing the adoption of sustainability concepts in the printing industry. Servitization (product-service systems) as a concept seems to be an emerging trend that strengthens sustainability in the printing industry [15,16].

Industry 4.0 (I4.0) is a relatively new trend and strategic initiative with certain technological advancements, which was introduced by the German government in 2011 [17,18]. However, it could be viewed as a logical successor of previous concepts such as computer integrated manufacturing, flexible manufacturing systems, etc. [19–21]. Nowadays, similar programs are running in other developed countries and there are many labels for Industry 4.0 that are applied in a variety of industries [22]. Examples of national initiatives are:

US, ‘Advanced Manufacturing Partnership’; China, ‘Made in China 2025’; and UK, ‘Smart Factory’, among others. There are several definitions of elements of Industry 4.0, but most broadly it is agreed that its pillars are cyber–physical systems (CPSs), (industrial) Internet of Things (IIoT), big data, collaborative and cognitive robotics, flexible automation, sensors, cloud computing, computer modelling and simulations, and additive manufacturing (3D printing) [23–26]. The I4.0 concept has been emerging from new technological possibilities. Therefore, it clearly shows the technology-driven nature of I4.0, treating businesses as investments, calculating investment and operations costs, and expecting some benefits at the same time.

Several studies have also been conducted to highlight Industry 4.0 issues specific to economies or regions [27,28]. Several authors have reviewed the literature and discussed these benefits, but also the concerns, critical success factors, uncertainties, etc. emerging from the relatively early phases of the I4.0 technologies lifecycle. These works have demonstrated that Industry 4.0 is not only beneficial for different areas (financial, environmental, social), but that it should be also carefully analyzed whenever introduced as it implies costs, energy consumption, electro-waste generation, employment threats, technophobia, etc. [29–34].

It can be noted that I4.0 not only generates benefits, but also requires a careful analysis of its concerns (Table 1). Both benefits and concerns may be clearly considered according to the following TBL categories: economic, environmental, and social [35,36]. Therefore, the general question arises as to what the real impact of I4.0 on sustainability is, both in terms of pros and cons. Liao et al. [25] clearly painted the picture that advanced information and manufacturing systems for a sustainable economy is one the main themes in research agenda for Industry 4.0.

Table 1. Expected benefits and concerns of Industry 4.0 from sustainability perspectives.

TBL Perspective	Expected Benefits	Concerns
Economic	Increased revenues and profitability More accurate planning Shortened lead times Increased reliability of machines	Cost-intensive Possibility of offering new products and services Difficulties with determining full financial benefits and economic efficiency (this can be achieved by using one of I4.0 technologies: computer simulation modelling)
Environmental	Increased energy efficiency Decreased manufacturing scrap waste Decreased materials usage Decreased emissions	Increased industrial and post-industrial waste Increased energy consumption Decreased availability of raw materials
Social	Increased of safety More ergonomic environment (tasks fitted to persons)	Human–robot interaction (HRI) issues Threat of unemployment Privacy issues

I4.0 impacts on economy, society, their barriers, and limitations have been studied by many authors [37–41] with a particular focus on skills, human resources, and leadership issues [27,42]. It has been proven that Industry 4.0 is an important enabler of companies’ sustainability with respect to both large and small and medium enterprises [43]. Comprehensive reviews of the literature on sustainability and I4.0 relations using bibliometrics [29,44] have been conducted and have proposed answers for important questions on sustainable Industry 4.0, such as:

- How can applications of I4.0 support sustainability goals?
- How can I4.0 technologies, tools, and solutions be integrated with the implementation of sustainability practices on a theoretical and practical basis?

The goal of this paper is to enrich those answers by providing a diagnosis of the selected printing companies. These companies were selected as they show a high sus-

tainability awareness and provide a great context for improving the processes of I4.0 applications. The printing industry has been moving forward to achieve Industry 4.0 paradigms, including applications of deep learning [45] or servitization [16]. The process of printing itself has raised many environmental concerns, and environmental sustainability has been important in this industry for many years [8,12,46]. It was pointed out that research on sustainable Industry 4.0 has been growing exponentially, but none of the referenced reviews considered the specifics of the printing industry. It has also been impossible to address this problem by finding studies from industries showing similar characteristics to those of printing.

It is notable that sustainability in the printing industry has been considered partially in the literature on sustainability and Industry 4.0 with a focus mainly on environmental issues, e.g., the use of more ecological paper, paints, and other resources; the reduction of volatile organic compounds; the use of renewable energy; etc. [12]. The literature has not covered the social aspects and systemic views of the whole industry. It has also not considered Industry 4.0 itself, which, as a concept, may have both positive and negative impacts on the sustainability performance of printing companies. For this reason, this paper has addressed several findings from a diagnostic survey focused on adoption of the utilization of sustainability concepts and Industry 4.0. The survey, which was performed in the printing industry in Poland, has also diagnosed the needs of the companies. Its main goal was to find links between specific sustainability concepts and specific Industry 4.0 technologies, i.e., to answer the question of which I4.0 technologies support sustainability and which ones do not.

The concept of sustainable printing 4.0, highlighted as the main theme of this research, was coined by merging two concepts applied to the printing, i.e., sustainability and Industry 4.0. The sustainable part refers to the need to apply tools and methods contributing to sustainability, while “Printing 4.0” indicates that the area of application for those tools is printing companies that also apply Industry 4.0 technologies. In this case, printing is understood as a branch of the industry, and not purely as a process of printing itself. Sustainable printing 4.0 is the concept in which Industry 4.0 technologies applied by the printing industry contribute to the sustainability of the industry in question. In order to further develop this concept, it is necessary to diagnose the level of adoption of sustainability and Industry 4.0 concepts among printing companies. Such a diagnosis should find the answer to questions such as: What is the level of adoption of specific tools, techniques, methods, and technologies from these two areas? It should also indicate if there are some dependencies among them, as some specific aspects may demonstrate synergistic effects, while others may demonstrate anergistic effects.

Six research questions were formulated based on the above presented considerations on Industry 4.0 and sustainability in the printing industry. The focus of these questions was three-fold:

- status of Industry 4.0 implementation in a company;
- status of implementation of sustainability practices in a company;
- dependences between Industry 4.0 and sustainability practices in the printing sector.
- The following detailed questions were considered:
 - What is the awareness level concerning the Industry 4.0 technologies and sustainability practices in your company?
 - Which Industry 4.0 technologies are currently used in your company or which do you plan to implement in the future?
 - Which sustainability practices are currently used in your company or do you plan to implement in the future?
 - In which areas of your company’s business activities do you use Industry 4.0 technologies and sustainability practices?
 - Which obstacles did you encounter when implementing/using Industry 4.0 technologies and sustainability practices in your company?

- Do Industry 4.0 technologies and sustainability practices currently contribute to your company or will they in the future?

The research enriches the existing literature by demonstrating the importance of I4.0 technologies that have potential to contribute significantly towards achieving economic, environmental, and social sustainability through surveys and analyses across the printing sector. The paper should also allow developing an understanding of the relations among I4.0 technologies across different dimensions of sustainability showing both synergistic and anergistic effects. Those technologies applied in the future can help making investment decisions about their implementation in the industrial practice while meeting the Global Goals simultaneously. Therefore, it is suggested that this study be conducted to gain data on current I4.0 implementation status vs. sustainability, which printing companies would benefit from exploring/diagnosing sustainable Industry 4.0, because the current literature does not present their (companies') interactions to each other sufficiently. Therefore, this study was dedicated/designed to fill in the literature research gap.

2. Materials and Methods

The article presents the results of a pilot diagnostic study of a specific group of respondents from the printing and packaging industry, broadly understood. Eleven printing companies were selected to be the respondents for this diagnostic study. The authors selected companies whose characteristics in terms of size and turnover reflect the general structure of the printing sector in Poland [47]. The study was conducted in small- and medium-sized enterprises (SMEs), as well as in large enterprises located in Poland. Due to the fact that one of the main objectives of this paper was to analyze the relationships between applied sustainable development (SD) practices and I4.0 technologies in printing companies, the authors made a preselection and considered the companies' utilization of SD practices and I4.0 technologies, even in a limited scope. The diagnostic survey was taken on the sample set of four large, five medium, and two small enterprises.

An in-depth diagnostic survey was used as the research method and a structured interview was conducted using the prepared online interview questionnaire. The interview was designed using the MS Forms application, as well as all interviews being conducted using MS Forms during online synchronous teleconferences. Two interviewers participated in each interview to verify the gathered data conformity. Interviewees received questionnaires upfront, so they were prepared. Post-interview authorization by interviewees was also conducted. The data collected in this way were also saved in the MS Forms application.

The duration of the interview was 1 h and 15 min on average (the longest, 1 h and 30 min; the shortest, 50 min). Interviewees were recruited from among top-level managers who have knowledge both of the technological advancements of the company and its sustainability practices. Survey respondents were high-level specialists in the organization or often the owners, CEOs themselves, and were mostly senior managers in their organizations. They are involved in high-level strategic decisions about current and future implementations in the field of development of a company. Detailed metrics of the interviewees are presented in Appendix A (Table A1).

The printing and packaging industry in Poland is very broad. This research focused on those companies that are involved in the production of such printing products such as self-adhesive labels, heat-shrinkable labels, wrap-around labels, wet-glue labels, in-mold labels—printed using several printing techniques such as flexographic, offset, and rotogravure, as well as packaging like cups, caps, bottles, containers, and similar products printed by dry-offset printing technique. However, while this current elaboration was a pilot diagnostic survey for printing and packaging companies in Poland, other printing companies that offer products like books, flyers, and other printing products will also be considered in further research.

3. Results

This part of the paper contains answers to the previously presented research questions regarding Industry 4.0 technologies and sustainability practices.

3.1. What Is the Awareness Level Concerning the Industry 4.0 Technologies and Sustainability Practices in Your Company?

This question was divided into two versions; the first question was intended for top- and senior-level management and the second one for middle-level management. The results of this analysis have shown that four of 11 of the top- and senior-level management have practical experience in the field of Industry 4.0 technologies. Additionally, eight of 11 of middle-level management have a cursory awareness in this field as well as six of 11 of top- and senior-level management. The same graph shows that there was still one of the 11 with a lack of awareness at the top and senior management level, and two of the 11 had a lack at the middle management level (Figure 1). A similar analysis was conducted to investigate the level of sustainability awareness. The same level groups were examined: top- and senior-level management and middle-level management. These outcomes are presented in Figure 2.

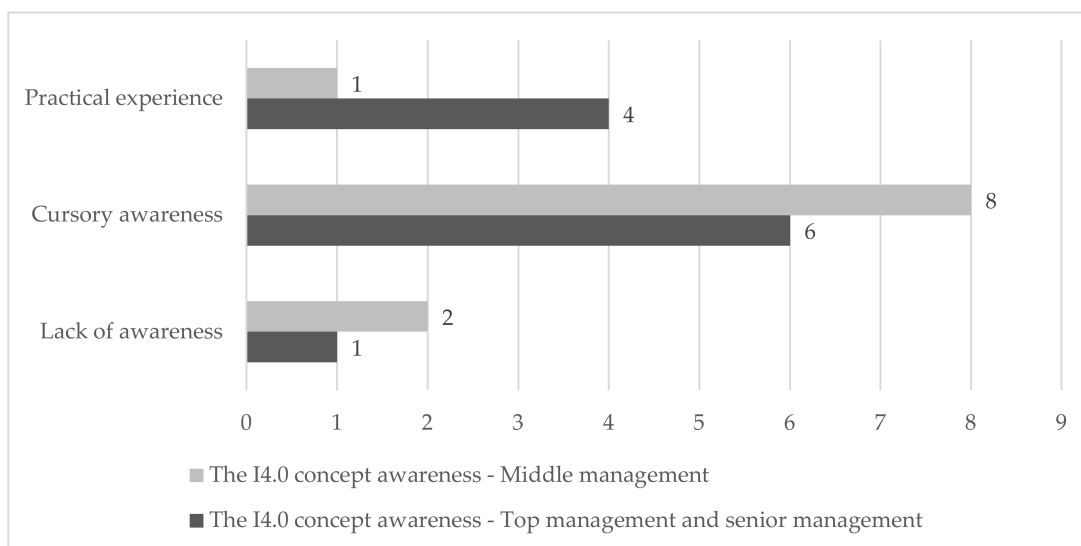


Figure 1. Awareness levels concerning Industry 4.0 technologies.

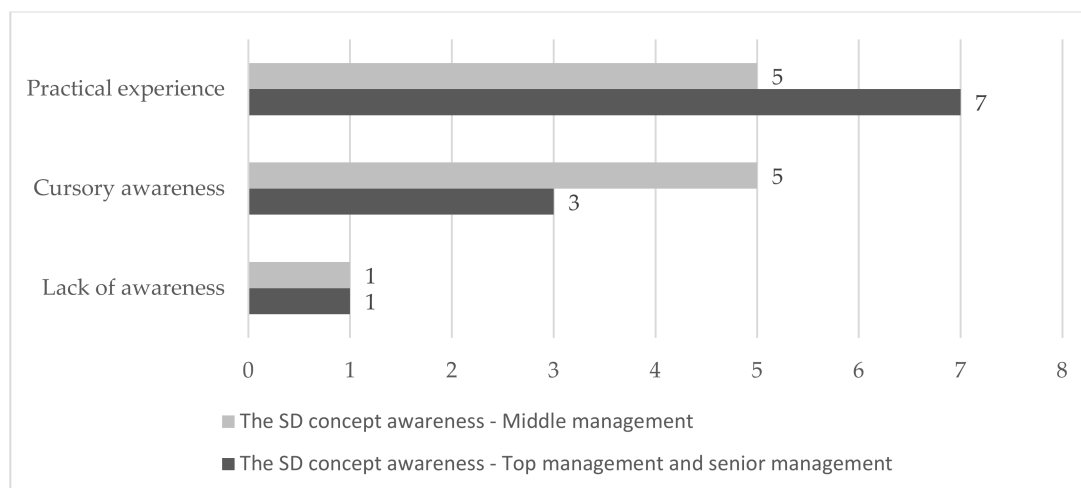


Figure 2. The awareness level concerning sustainability practices.

The results of this investigation showed that in the field of sustainability, both top and senior-level management, as well as middle-level management, have better practical experience than awareness of the Industry 4.0 concept. These two analyses proved that in printing companies the sustainability approach has been learned earlier than the Industry 4.0 approach. It means that some sustainability activities in those printing companies were known much better than Industry 4.0 technologies. This relates to the main activities of analyzed companies where business-to-business (B2B) customers are mostly the bigger players from food manufacturers, and they have been required to carry out such activities from the sustainability perspective.

3.2. Which Industry 4.0 Technologies Are Currently Used in Your Company or Which Do You Plan to Implement in the Future?

Based on the research, the most popular I4.0 technologies in the printing industry are the following: Cloud Computing, Cybersecurity, Internet of Things, and System Integration, as presented in Figure 3. This is due to the fact that most of the production preparation processes in the printing industry are carried out through cloud-based systems, e.g., graphic reproduction preparation. The process of preparing a graphic reproduction may involve many participants, such as marketing and advertising agencies, graphic designers, brand owners, prepress and printing forms' manufacturers, printing houses, and many other similar entities. It is important for all such work to be carried out on the same graphic files, and, therefore, all units must work on the cloud. A high level of system integration and security are critical. For this reason, the respondents mentioned these technologies as the ones that they currently use in their companies.

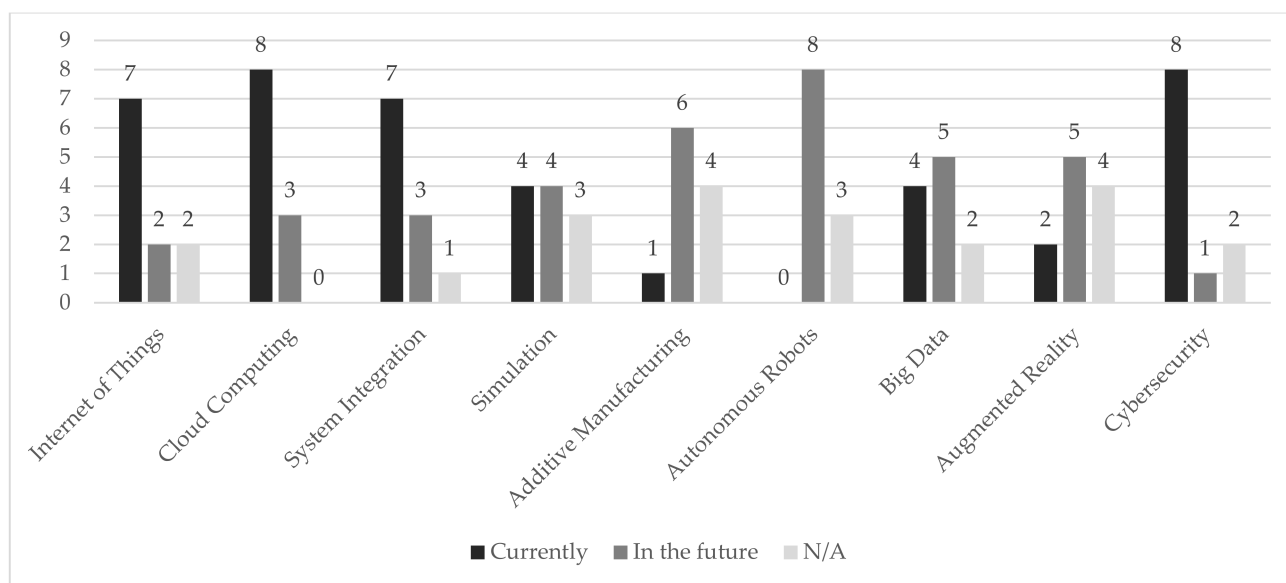


Figure 3. Industry 4.0 technologies currently used or planned to implement in the future.

The I4.0 technologies that respondents are interested in the future are: Autonomous Robots, Additive Manufacturing, Big Data, and Augmented Reality. A key issue is that in the printing industry, production processes are not integrated, e.g., with flexographic printing technology it is a roll-to-roll process, where at each stage the material in the form of a roll is processed step by step. Therefore, in such a case, printing companies are not interested in Autonomous Robots. Additive Manufacturing is still a technology that is used to a limited extent by printing companies, if at all—for example, to create packaging prototypes for which labels are later designed. Augmented Reality is a technology that has just been gaining importance very recently, and its application in printing may be different. It is used in the creation of new, intelligent labels and packaging, where it serves as a form of entertainment, but also—along with NFC tags or unique QR codes—for product security

and as a guarantee of originality. For more information, visit the Active & Intelligent Packaging Industry Association—AIPIA website: <https://www.aipia.info/> (Accessed on 27 September 2021).

Big Data is the I4.0 technology that the respondents also indicated that they are interested in, but for the future, because presently many printing companies still have problems collecting data for analysis and optimization of their processes. Importantly, many respondents stated that they are not interested—either now or in the future—in implementing technologies such as Additive Manufacturing, Augmented Reality, or Simulation. As already mentioned, the degree of integration of manufacturing processes in printing companies is not as high as, for example, in the automotive industry, which can explain why printing companies are not interested in such technologies. It is possible that the time has come for printing companies to implement solutions based on I4.0 technologies.

3.3. Which Sustainability Practices Are Currently Used in Your Company or Do You Plan to Implement in the Future?

As a result of this research, it was found that the most frequently used sustainability practices or sustainability practices in the surveyed printing companies are Environmental pollution and management (nine of 11 of the surveyed printing companies currently use these practices), Sustainable technology (nine of 11), and Green/sustainable product life-cycle analysis (eight of 11). Due to the fact stated above (Section 3.1), printing companies use sustainability practices to a much greater extent than I4.0 technologies, as shown in Figure 4. Due to the well-known high requirements of global FMCG companies, which require all their companies cooperating in the supply chains to manage natural resources responsibly, there is a higher interest in SD practices in printing companies at present.

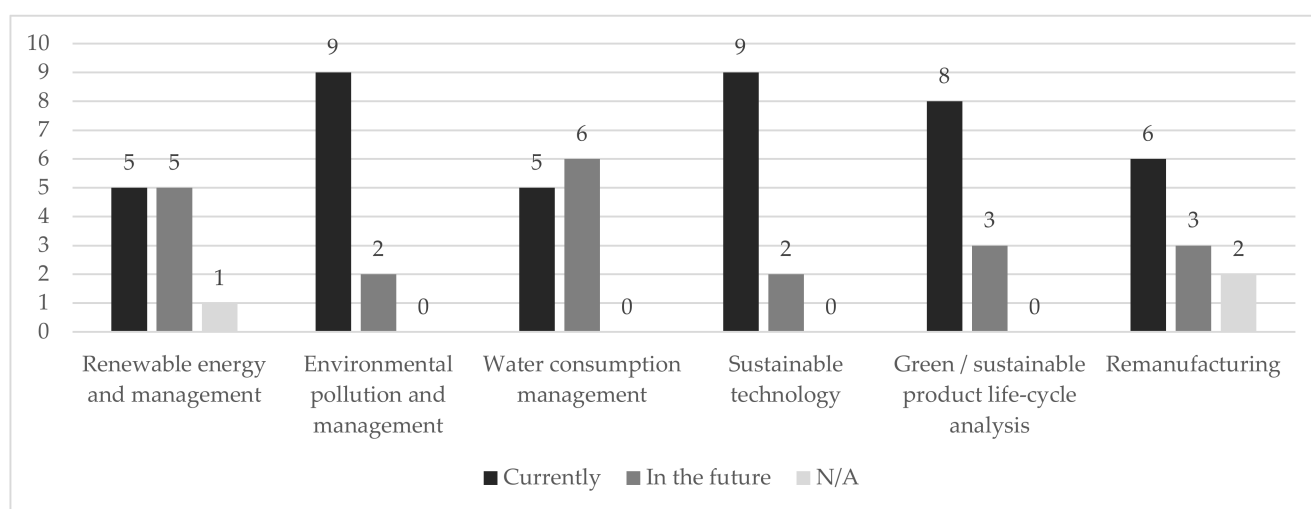


Figure 4. Sustainability practices currently used or planned to implement in the future.

To a slightly lesser extent, printing companies use the following practices: Remanufacturing (six of 11), Renewable energy and management (five of 11), and Water consumption management (five of 11). Remanufacturing practices arose in the automotive sector but nowadays more companies have stated that they are using remanufacturing parts. In the printing industry there are many parts that can be easily remanufactured and used many times. Two such examples are magnetic cylinder for the die-cutting process and anilox rollers or gravure cylinders. These parts could be remanufactured many times, which is a good example of sustainable practices being performed in the printing industry. For the future, six of 11 of the surveyed printing companies are interested in Water consumption management practices and five of 11 are interested in Renewable energy and management. Only one of the surveyed printing companies is not interested in Renewable energy man-

agement practices, while two are not interested in Remanufacturing practices. This could be tied to their knowledge or lack of knowledge of these practices.

3.4. In Which Areas of Your Company's Business Activities Do You Use Industry 4.0 Technologies and Sustainability Practices?

Analyzing the results of the interviews, it was found that currently 10 of 11 of the surveyed printing companies use I4.0 technologies in Processing and seven of 11 use I4.0 technologies in Operations planning and control. This result of the analysis shows that printing companies currently use I4.0 technologies in their manufacturing processes, collecting data from various sensors from machines. These data are becoming more and more available, so we can even consider the topic of big data implementation. These data are analyzed to optimize processes, mostly for large, global companies.

The CEO of a large, global printing company said:

Using IoT inside the company, data from sensors, machines, and devices are collected and processed.

Analyzing the results of this study, shown in Figure 5, when considering the future, printing companies are interested in using I4.0 technology in areas of their activity such as Smart and adaptable products (eight of 11) and Maintenance (seven of 11). To a lesser extent, printing companies are also interested in using I4.0 technology in such areas as Operations planning and control and Collaborative technologies, i.e., human–machine interface and Servitization and Ecosystemization. This is because printing companies use I4.0 technologies to a lesser extent than in other industries, such as automotive, which explains the less interest in using these technologies in their areas of activity. Moreover, this study shows that six of 11 of the printing companies are not at all interested in implementing I4.0 technology in the area of Servitization and Ecosystemization, and three of 11 of the companies are not interested in it in the area of Collaborative technologies.

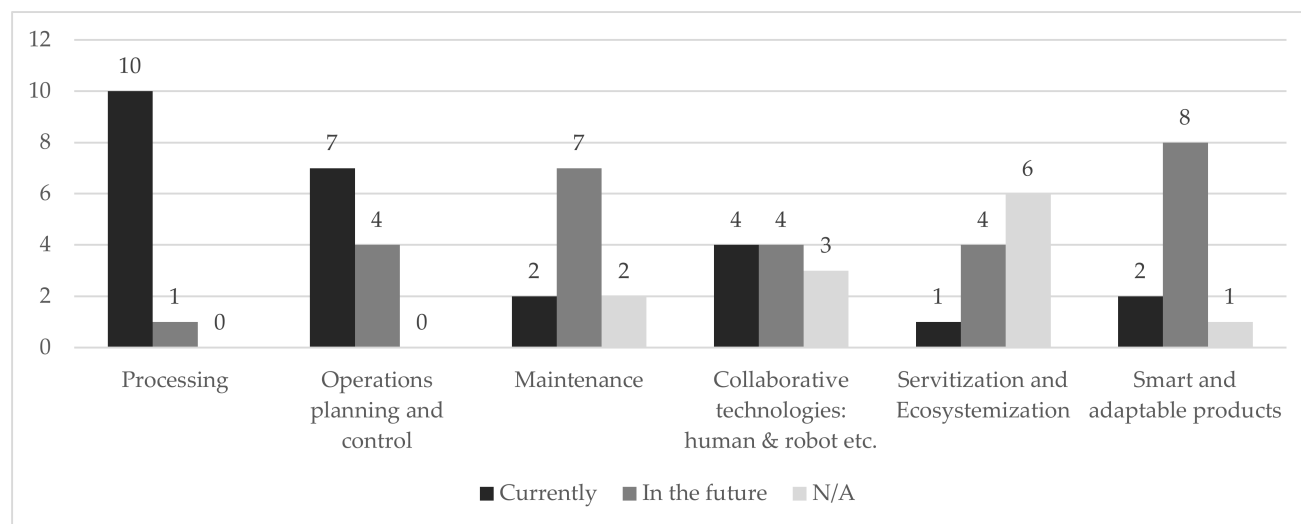


Figure 5. The companies' areas using Industry 4.0 technologies.

Sustainability practices are mostly used in four types of printing company activities: (1) product design, (2) industrial processes, (3) logistics, and (4) other processes. These outcomes are presented in Figure 6.



Figure 6. Areas of the used sustainability practices.

Printing companies use the best available technologies to reduce energy consumption through machines, processes, and products. Closed-loop material cycle systems have been implemented to optimize the consumption of raw materials (also known as the Circular Economy). Some companies have cooperated with key experts in using innovative technologies related to energy and/or material consumption and waste reduction. In the area of product design, seven of 11 of the surveyed printing companies stated that they use sustainability-oriented technologies. This is due to standards compliance, since printing companies are mostly in the supply chain of globally networked FMCG companies, which have implemented required global quality standards. The COO of a large international printing and packaging company said:

We follow Circular Economy trends and try to meet legal requirements, keeping up with the current trends.

As many as 10 of 11 of the surveyed printing companies stated that they use sustainability-oriented industrial processes. This comes from the designing and building of new factories; all new factories built are with the use of sustainable practices or technologies like renewable energy and energy saving, recuperation, gathering energy from the machines, and other techniques facilitating energy and water saving. The CEO of a medium-sized Polish printing company (operating throughout Europe) said:

Referring to the protection of the environment, it is worth mentioning the new, modern building of the company, equipped with advanced recuperation technologies, air purification, energy and water saving systems... etc. [...] After introducing innovative solutions and technologies in the newly built investment, based on the indications of the installed equipment, the company achieved significant savings. The period of 3 months of operation in the new premises was taken into account and compared with the corresponding period of operation in the previous location. Approximate results are presented:

- *CO₂ emissions decreased by approx. 25%,*
- *lower water consumption by approx. 18%,*
- *the amount of waste reduced by approx. 15%,*
- *improvement of work safety by approx. 20%.*

Eight of 11 of the printing companies surveyed stated that they use sustainability-oriented technologies in the area of logistics. Mostly closed-loop material cycle systems have been implemented to optimize the consumption of raw materials. Additionally, according to the research, six of 11 of the printing companies replied that they use sustainable technologies in other areas, where most indicated that closed-loop material cycle systems have been implemented to optimize the consumption of raw materials and that the companies use the best available technologies to reduce energy consumption through machines, processes, and products.

3.5. Which Obstacles Did You Encounter When Implementing/Using Industry 4.0 Technologies and Sustainability Practices in Your Company?

To provide further analyses for the pilot diagnostic survey “Sustainable printing 4.0”, Pareto–Lorenz charts are used to present the main obstacles and/or hurdles from two perspectives:

- the I4.0 transformation itself (Figure 7),
- I4.0 transformation in the context of sustainability (Figure 8).

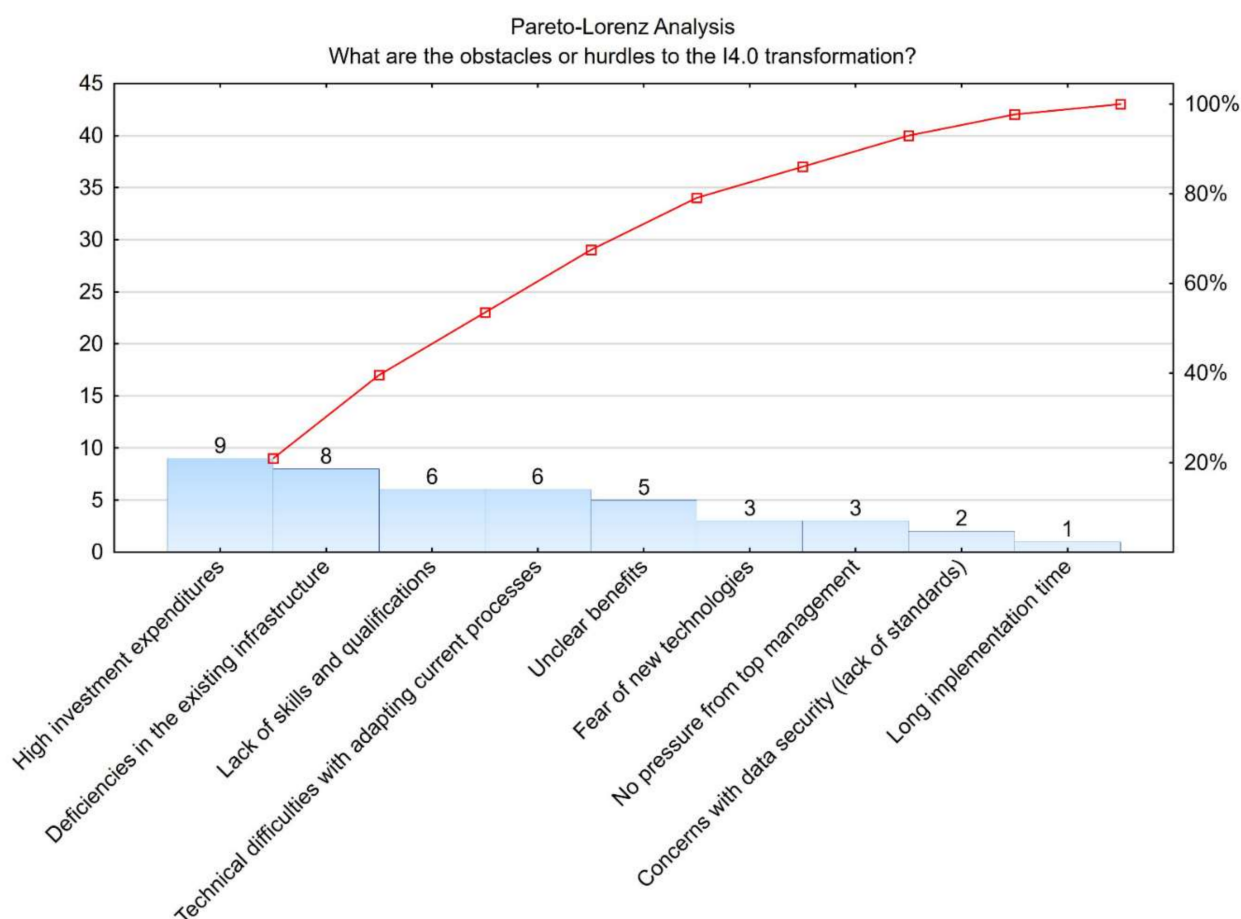


Figure 7. The obstacles or hurdles to the I4.0 transformation.

A total of 80% of the obstacles referred to the five hurdles (out of nine) such as high investment expenditures (nine), deficiencies in the existing infrastructure (eight), lack of skills (six), technical difficulties with adapting current processes (six), and unclear benefits (six). The highest values showed that the most impacted hurdles in implementation of I4.0 related to the high investment cost and infrastructure deficiencies. Following the Pareto rule, those are the problems where attention should be concentrated in order to improve them (to prioritize them), strengthening, in turn, the companies’ operations.

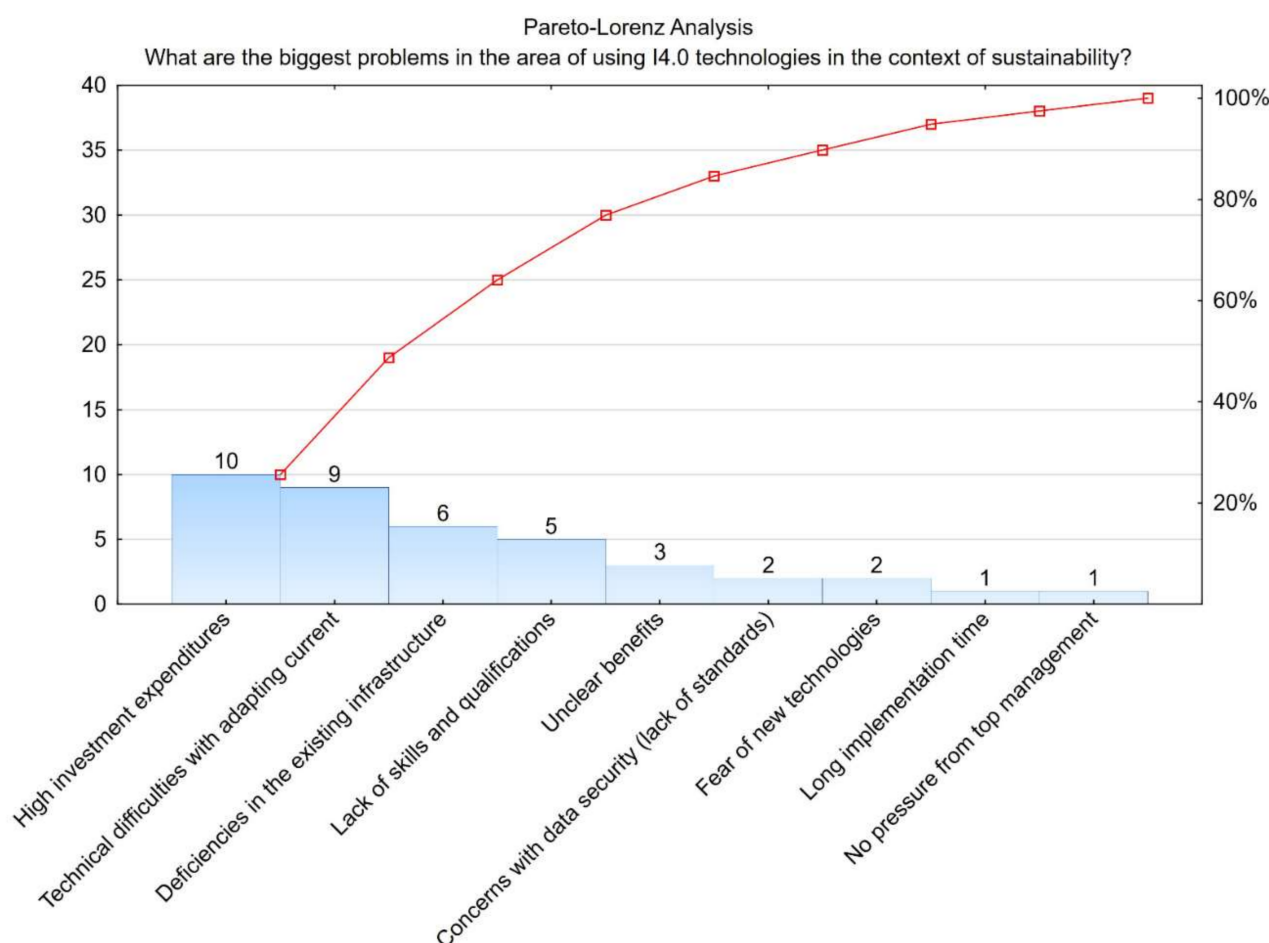


Figure 8. The biggest problems in the area of using I4.0 technologies in the context of sustainability.

By comparing the charts, the distribution of obstacles to using I4.0 transformation in terms of sustainability follow a similar shape with the same overlapping number of hurdles (nine, eight, six, six) accounting for the biggest share of the obstacles. The graph below (Figure 8) shows that companies perceive I4.0 technologies to be a trigger for the implementation of the sustainability concept in the printing companies.

3.6. Do Industry 4.0 Technologies and Sustainability Practices Currently Contribute to Your Company or Will They in the Future?

The research conducted on selected printing companies shows that currently five of 11 of the respondents agree that solutions in the field of I4.0 contribute to the implementation of sustainability practices, and 18% strongly agree with this statement, as shown in Figure 9. Furthermore, it is significant that six of 11 of the respondents stated that in the future they agreed with the above statement with respect to the future and five of 11 of them strongly agreed with this statement. This shows that the awareness is at a high level for people managing printing companies in the area of I4.0 technology and sustainability practices. These companies also see the importance of I4.0 technology for the future, as the analysis below shows precisely; respondents said that in the future even more I4.0 technologies will be important in the context of sustainability practices. Only one of the respondents from the printing companies disagreed with the above statement and three of the respondents are currently neutral with respect to the statement on the contribution of I4.0 technologies to Sustainability Development practices.

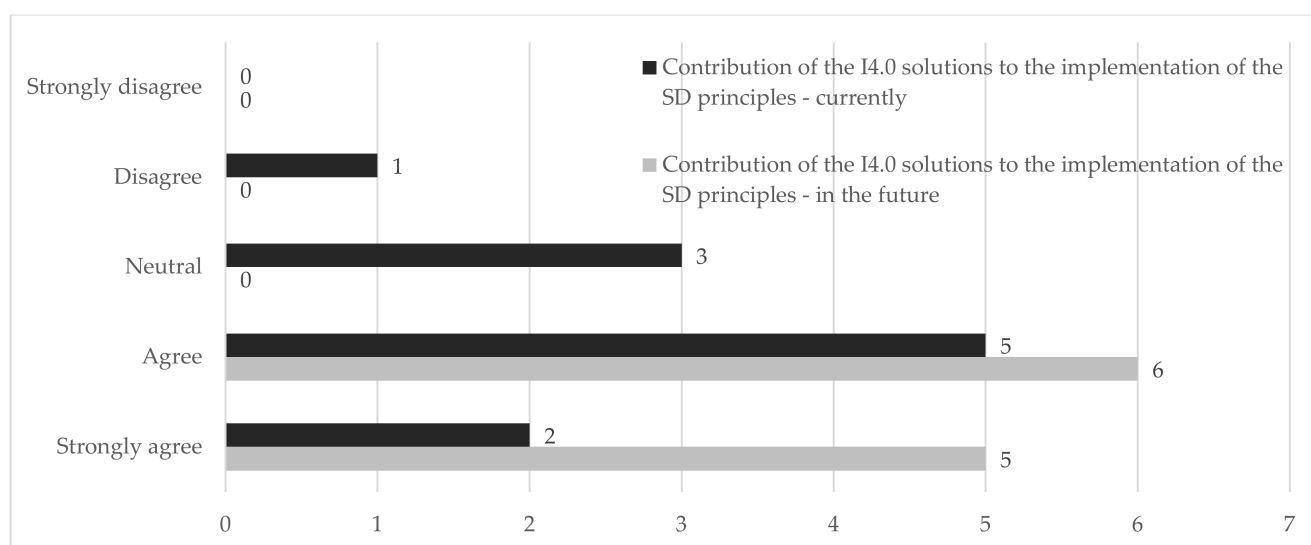


Figure 9. Contribution of the I4.0 solutions to the implementation of the SD principles.

The above analysis was confirmed by the statements of respondents to the survey conducted for the printing companies. The chief executive officer (CEO) of a large global company said:

I4.0 should enable the balance and optimization of the supply chain, lead to less waste of energy, labor, and material; I4.0 could also contribute to the optimization of stock levels, as currently many products are wasted due to the expiry date.

The R&D Manager of a medium-sized European company said:

I4 and SD are strongly related. I4 delivers instruments to achieve sustainable development goals (SDG). Decisions on I4 implementation are strongly related to achievement of SDG. Electro waste is risky, unemployment is risky. New technologies' decisions have to consider SDG.

The chief operating officer (COO) of a large international company stated:

Recyclable products, re-manufactured with 100% rPET, loss management, to reduce material losses.

The CEO of a medium-sized European company said:

Industry 4.0 forces a modification of the traditional perception of production. The ongoing transformation is inextricably linked with digital information technologies. This is an opportunity for the environment. Modern technologies offer many benefits by increasing the use of renewable energy in production, reducing CO₂ emissions, increasing energy efficiency in industry, or increasing the productivity of enterprises. The Industry 4.0 concept is based on eco-innovation, including eco-efficiency and cleaner (green) production. It is closely related to the idea of sustainability. Technological solutions of Industry 4.0, created thanks to individual and collective knowledge resources, can provide many highly functional products and services to their users and suppliers with much lower negative impact on the environment and society in a turbulent environment. A company operating in line with Industry 4.0 and adhering to the principles of sustainability can thrive in times of less and less predictable events and quickly adapt to the changing conditions in its environment.

The above representative quotes from the diagnostic survey conducted in the printing industry confirm that the printing industry in Poland is on the right track to implement I4.0 technology, which has a significant impact on the implementation and maintenance of sustainability practices. However, the printing industry is not currently at an equal level with other industries—e.g., automotive—but the management level knows the rules and

is familiar with the assets; so, in the future a higher impact from I4.0 technologies in the printing companies can be expected.

4. Discussion

4.1. Impacts of Industry 4.0 on the Printing Industry

In recent years, the following question is more and more often asked: “What impact has the advent of Industry 4.0 had on the printing companies?”. There are still large gaps in the scientific literature in this field, and the answers to the question posed above should be sought in white papers [48–50] or at large trade fairs such as LabelExpo [51]. Businesses are aware of the existence of intelligent printing/labeling machines, as well as of the possibility of collecting and evaluating data from sensors, which allow them, for example, to improve process transparency and efficiency when it comes to printing lines. This is supported by the answers given in the interviews, the results of which are presented in this article. According to them, printing companies use sustainability practices such as Environmental pollution and management and Sustainable technology, with equal values of 9 of 11, to a much higher degree than I4.0 technologies. Unfortunately, a half-hearted interest in Renewable energy and management (five of 11) and Water consumption management (also five of 11) was identified. Considering the use of I4.0 technologies in the industry, currently 10 of 11 of the interviewed printing companies implement I4.0 in processing; significantly less, seven of 11 of the companies, apply their digital solutions in operations planning and control. Further research revealed that eight of 11 of the printing companies declared their intention to implement I4.0 in the future in Smart and adaptable products, and seven of 11 of them have intention for Maintenance (7 of 11). A negative outlook was observed for Collaborative technologies, seeing that three of companies are not willing to adopt this technology. Therefore, based on the presented findings, one may assume that the development of printing will coincide with the development of Industry 4.0. This assumption will be a starting point for further, more in-depth research.

In the printing industry, as in other industries, the size of the enterprise determines the level of its technological advancement [52,53]. The answers obtained during interviews indicated that large enterprises use more I4.0 technologies than SMEs. This should not come as a surprise, as printing machines are often very expensive and require appropriate technical infrastructure or personnel, which SMEs cannot always afford. Additionally, I4.0 technologies could be more helpful in large companies, which are usually faced with more complex processes and operate a bigger amount of information.

4.2. Awareness of Sustainability and Achieving It through Industry 4.0 in the Printing Industry in Poland

Taking another factor into consideration, the awareness of sustainability and SDG among on all hierarchical levels of printing companies is greater than that of Industry 4.0 (Figures 1 and 2). This might be due to the following factors:

- The concepts of SDG and sustainability are much older and more mature than Industry 4.0;
- For printing companies and their customers, the importance of achieving SDG and sustainability goals is more important and less costly than applying Industry 4.0;
- National and EU legal regulations already require the implementation of certain activities related to SDG;
- It is much easier to implement some SDG- or TBL-related recommendations or guidelines than to implement Industry 4.0 technologies.

This research reveals that the main barriers to the transformation of I4.0 (Figure 7) or using I4.0 technologies to achieve the goals of sustainability (Figure 8) are very similar compared to two perspectives: the I4.0 transformation vs. I4.0 transformation in the context of sustainability and consistent with the hurdles in implementation of smart technologies, presented in [54]. The most important respondents considered as most significant high investment expenditures, deficiencies in the existing infrastructure, technical difficulties

in adapting I4.0 to implemented processes, and the lack of adequately qualified staff. Further examples include, inter alia, the unclear benefits of implementing I4.0, a fear of new technologies, concerns about data security, or the long implementation time of I4.0. High cost as a barrier to the adoption of I4.0 technologies was indicated in [51]. This may result partly from some element of “short-term” perspective when it comes to investments. The two most important barriers are price and the awareness that automation and Industry 4.0 are the only things that will keep the company competitive.

Therefore, it can be concluded that the concerns of printing companies related to the transformation of I4.0 are similar to those described in the literature on implementing new technologies [55]. The confirmation of the significance of I4.0 technologies for the development and competitiveness of printing enterprises (not only in the area of sustainability) is the fact that companies that currently use I4.0 technologies see the importance of placing the development of the I4.0 concept in strategic objectives for the future. This may mean that they are satisfied with using I4.0 technologies and believe that the potential benefits outweigh any concerns/barriers. Interestingly, the companies that have placed I4.0 in their strategic objectives (current and future) have also included their sustainability goals. They have considered the development of both concepts (the alignment of the I4.0 concept with company’s strategic objectives and the alignment of the sustainability concept with company’s strategic objectives) to be simultaneously justified, and they also see the potential of I4.0 support for sustainability. This assumption was confirmed by the fact that the respondents agreed that the I4.0 technologies support the implementation of the SD principles (currently and in the future).

4.3. Challenges to the Adoption of Industry 4.0 and Achieving Sustainability

Considering the research results obtained, it should be noted that the transformation into a printing house using I4.0 technologies requires intelligent, comprehensive solutions at both operational and strategic levels. One of the challenges for printing companies is the enormous amount of data that they must process, analyze, and respond to—all while ensuring that they keep up with customer requirements. Manufacturing processes based on I4.0 technologies can provide point-by-point insight into production data, making it easier for users to find the information they are looking for. It will also involve the increased use of artificial intelligence and robotics to push the printing industry forward and extract even more value from production data. This will reduce waste and increase efficiency. All the advantages presented are directly or indirectly related to the achievement of SDG. Regarding the implications of I4.0 technologies for the future of the printing industry, it seems clear that the further development of Industry 4.0 can only accelerate the growth in value of the printing services’ market (Figure 9). It will also allow for the support and expansion of the implementation of practices consistent with the principles of sustainability.

The issues raised during the interviews have not been investigated before now in the context of printing companies. In addition, they have not contained very detailed questions concerning, for example, the specifics of a given industry. However, it should be emphasized that many questions were closed, the reason for which was mainly due to a desire to carry out statistical analyses. Although the developed questionnaire (Appendix A) contained ca. 33 questions, many fields should be developed more extensively (e.g., linking individual I4.0 technologies with selected areas of sustainability, percentage impact of individual I4.0 technologies on the implementation of sustainability practices). It would also be advisable to explore some issues in a qualitative form (e.g., I4.0 initiatives that can support workers in implementing SDG). Another disadvantage was that questions on qualitative data were included in the questionnaires to a very limited extent. Interview questionnaires consisted mainly of closed questions, which, in the case of a larger-scale study, would make it very difficult to conduct a qualitative analysis of the results.

5. Implication for Research

5.1. Theoretical Implications

The theoretical contribution of this study to the literature on sustainable Industry 4.0 in printing is twofold. First, the research contributes to understanding the dependencies of the adoption levels of Industry 4.0 and sustainability practices in the Polish printing industry. To date, the literature suffers from a lack of studies diagnosing the relationship between the adoption of sustainability and the implementation of the Industry 4.0 concept for the printing sector. Product-service systems as a concept seems to be an emerging trend that might strengthen sustainability in this industry [14,15]. The empirical evidence reinforces the dynamics of digital transition towards sustainability by showing its positive impact. In this way, the research presented in this paper contributes to the closure of this research gap.

Second, the theoretical perspective was utilized not only to share research among academics but also to study the subject from another perspective beyond that associated with the usual sustainability awareness of the printing industry.

An additional contribution is the systematization of this knowledge, as well as the presentation of an original questionnaire that may facilitate research in other industries. Hence, the Industry 4.0—SD relationship is still under investigation.

Finally, the results of the qualitative research presented in this paper constitute a base for further quantitative research. The proposed research agenda for quantitative analysis is based on a set of hypotheses that have emerged from the interviews performed:

- H1: Company size determines the scope of I4.0 implementation in the printing company.
- H2: Company size determines the scope of sustainability-oriented actions of the printing company.
- H3: The scope of I4.0 implementation determines the scope of sustainability-oriented actions in the printing company.
- H4: The better the alignment of the I4.0 concept with the company's strategic objectives is, the better the alignment of the sustainability concept with company's strategic objectives is, both currently and in the future in the printing company.

Moreover, there is very scarce literature evidence on whether companies devoted to I4.0 initiatives are also devoted to sustainability issues. What little evidence that exists is not focused on the printing industry; it is focused, rather, on environmental aspects, than on full sustainability dimensions [56], or the assessments are conceptual rather than based on quantitative data from industry [57]. For this reason, there is a lack of quantitative evidence on full sustainability dimensions. It should be important, then, to understand if there are any such relationships or links, and to possibly promote them; as I4.0 initiatives in their nature could be either seriously harmful or seriously beneficial to sustainability. Therefore, understanding this problem could allow one to better address possible synergies (like less resources' usage, such as due to artificial intelligence) or diminish existing anergies (such as more electro waste due to implemented sensors).

5.2. Managerial Implications

From the managerial point of view, the paper explored the implementation of Industry 4.0 technologies as well as sustainability initiatives in the printing practice by:

- proposing the diagnosis questionnaire facilitating research on the I4.0—SD relationship;
- providing the inclusion of qualitative analyses of obtained results;
- providing the validation of the questionnaire, and the attempt to indicate the future direction of business in terms of the integration of I4.0 technologies and SD objectives for the printing industry;
- sharing knowledge on the Industry 4.0—SD relationship in printing for other industries. This has been possible due to the literature review giving opportunities to

distinguish the most important categories of questions for which answers are sought in the literature.

One of the managerial implications of this paper is to increase managers' awareness of the fact that technologies I4.0 can support sustainability practices. It is clear, based on the interviews, that most printing companies apply sustainability practices and have managers who are interested in their strengthening/enlargement along with the improvement of the company's operating activities; it is also clear that they know which I4.0 technologies are useful now and which can be important in the future. It is also crucial to notice that most respondents implement Industry 4.0 postulates and SDG in their strategic objectives. This shows how important, from the management point of view, it can be for printing companies to develop an appropriate strategy that considers I4.0 and SD.

Since knowledge about Industry 4.0 technologies is not enough (especially for middle management), it is worth organizing courses and training to help employees understand how these technologies can help carry out company processes, including those related to sustainability. Many decisions are made by testing a hypothesis instead of making a generalization from deduction. Therefore, the skillful management of I4.0 technologies seems to be an essential part of making rational decisions to take full advantage of their potential (technologies).

Based on the results obtained, managers may develop strategies assuming I4.0 and SD implementation programs. It is also possible to develop training programs for improving the skills and qualifications of employees related to the implementation of SDG using I4.0 technologies. Printing companies can also follow the trend in which the operation of the organization changes in the era of Industry 4.0 and how they can prepare for this change from the point of view of sustainability practices.

6. Conclusions

6.1. *Diagnosis of Sustainable Industry 4.0 in the Printing Industry in Poland*

Industry 4.0 and sustainability are currently very popular research topics. Most of the available papers describe these concepts separately and do not sufficiently consider their relationship to each other. In addition, some papers have not presented a complete diagnosis of sustainable Industry 4.0. Therefore, this research was necessary to fill in the current research gap. This article can be seen as a good starting point for further research to determine a holistic I4.0—SD relationship and then build a model of sustainable Industry 4.0.

The research interviews conducted to collect data explored unknown areas across sustainability and Industry 4.0 within the 11 companies in the printing industry. The qualitative data allowed for finding the analytical path between Industry 4.0 companies' sustainability performances that might be analyzed in further detail. The main challenge of the qualitative research used was to ensure the credibility or 'trustworthiness' of the results based on how general ability is applied because qualitative research is, by its own nature, an explorative approach. To avoid a lack of reliability, the authors formulated research questions in a proper way to carefully identify what they really want to explore in this research (explanation or prediction of links between SD and I4.0). An appropriate chosen methodology was provided to understand the phenomenon under study. The authors are aware that some bias may appear in the answers of the interviewed representatives. The answers given by them were confronted and double-checked to provide a greater degree of reliability.

The results obtained allowed for a preliminary diagnosis of the I4.0—SD relationship in the printing companies. Using qualitative research interviews, the research revealed that advanced technology has a positive impact on sustainability in the analyzed printing companies. The greater awareness of sustainability at all companies' levels and the size of companies influenced the achieved results. These are companies that will begin to recognize that the faster they transform their operational activities toward digitalization, the more they notice a positive effect on their sustainable businesses.

6.2. Directions of Further Research Agenda

The study also indicated what actions should be taken by the scientific community to make more in-depth research in the considered area.

Based on the obtained results, it can be concluded that there is still no clear understanding of the impact of I4.0 on sustainability in the context of printing companies in many operational areas. Although the results obtained do not differ significantly from those found in the literature regarding other industries, they may encourage scientists and practitioners to conduct further, more in-depth research and work aimed at preparing companies and their human resources for sustainable Industry 4.0. Therefore, the pilot study contributes to further research on the impact of Industry 4.0 on sustainability in terms of appropriate operational areas that might be applied in other industrial sectors across various geographic locations to support a greater impact on sustainability.

Future digitalization for sustainability in the printing sector is inevitable. The current technology development delivers efficient solutions, but does not fully maintain a focus on sustainability, especially in companies' operational areas. On the other hand, the COVID-19 situation encourages the growth of digital technologies with a decreasing performance impact on business activities, considering sustainable technological features in terms of flexibility, productivity, and reliability. This potential of Industry 4.0 to contribute positively to sustainability requires that each separate technology should be carefully analyzed and assessed; otherwise, these technologies will variably influence the industry and sustainability dimensions. It might be also interpreted that companies expect suitable I4.0 solutions dedicated to their sectors that have a positive impact on the natural environment and are economically sound (due to implementation costs) but balanced with social equality. Finally, more emphasis is required for the analysis of I4.0 initiatives that can support workers in the implementation of sustainability goals.

The main limitation of this research is the number of conducted interviews (11). In addition, this study was limited to the Polish printing sector. Due to the small sample size, the obtained results cannot be extrapolated to the entire population. Additionally, it cannot be necessarily concluded from the study that the results obtained during the interviews will be similar in other countries/sectors. Nonetheless, it seems that printing companies interested in the I4.0—SD relationship may benefit from the results presented in the article.

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Appendix A

Questionnaire and interviewees' metrics. Direct link to duplicate the questionnaire used in the survey: <https://forms.office.com/Pages/ShareFormPage.aspx?id=nCJQO3jNiEWbz5e3Yp4vDzy2pk17CeRNrkrwk2VspfhUMTJGUFI5R1FMV1kzM1FaUEIWSVRaMjFDNy4u&sharetoken=XudYm2MoxhqKbUjQ3gk1> (Accessed on 27 September 2021)

Table A1. Interviewees' metrics.

Company	Size	Range of Operations	Interviewee's Position
A	Medium	European	R&D Manager
B	Large	Global	Chief Executive Officer
C	Medium	European	Chief Technology Officer
D	Large	European	R&D Engineer
E	Medium	European	Technology Manager
F	Medium	International	Lean Manager
G	Large	International	Chief Operation Officer
H	Medium	European	Chief Executive Officer
I	Small	European	Vice Chief Executive Officer
J	Small	National	Deputy Production Manager
K	Large	European	Prepress Manager

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