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Digitalisation and Innovation in the Steel Industry in Poland—Selected Tools of ICT in an Analysis of Statistical Data and a Case Study

Bożena Gajdzik [1,*] and Radosław Wolniak [2]

[1] Department of Industrial Informatics, Silesian University of Technology, 40-019 Katowice, Poland
[2] Department of Organization and Management, Silesian University of Technology, 41-800 Zabrze, Poland; radoslaw.wolniak@polsl.pl
* Correspondence: bozena.gajdzik@polsl.pl

Abstract: Digital technologies enable companies to build cyber-physical systems (CPS) in Industry 4.0. In the increasingly popular concept of Industry 4.0, an important research topic is the application of digital technology in industry, and in particular in specific industry sectors. The aim of this paper is to present the tools used in the steel industry in Poland on its way to the full digitalisation that is needed for the development of Industry 4.0. The paper consists of two parts: a literature review and a practical analysis. The paper provides the background information about digitalisation using digital tools in the steel industry in Poland. The paper was prepared based on secondary information and statistical data. The object of the research is the Polish steel sector. This study assumes that digitalisation is the main area of innovation in the steel industry. The digitalisation determines the creation of new or modified products, processes, techniques and expansion of the company's infrastructure; therefore, the data on digital technology were supplemented with data on the innovativeness of the Polish steel sector. The results of this study provide managers with valuable information to understand the importance of full digitalisation and the need to focus on digital strategies. Such insights can be used to improve companies' processing capabilities and produce better products, which is key to innovation.

Keywords: Industry 4.0; steel industry; digitalisation

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1. Introduction

Rapid changes in digital technology are revolutionising industries and societies [1]. Digitalisation is the technical achievements of the Third Industrial Revolution, also the so-called digital revolution. Digital technologies take a central place in Industry 4.0 [2].

The paper presents the research about the level of development of digitalisation. Note that, to improve readability of the paper, we listed all abbreviation used in the paper. Digital technology in steel production with communication systems is a prerequisite for the development of Industry 4.0. Digitalisation in industry already started several decades ago. By converting analogue data into a digital form using appropriate electronic devices, huge sets of data can be processed, stored and transmitted via digital circuits, hardware and networks. The digitisation of industry is an ongoing process and digital technology is evolving into Industry 4.0 Key Enabling Technologies (KETs) such as: Big Data, new generation of sensors, Artificial Intelligence (AI); Machine Learning (ML), Internet-of-Services; Internet-of-Things (IoT), Cloud Computing, Cybersecurity, Mechatronics and Advanced Robotics, Additive Manufacturing, Machine to Machine (M2M) communication and Digital Twin.

In the Third Industrial Revolution, Information Technology (IT) started booming and analogue technology was transformed to digital. Computers, microprocessors, cellular phones and the Internet transformed the traditional production and created a foundation for future digitisation [3]. Industry 3.0 allowed flexible production systems, a higher variety of products and programmable machines; however, flexible production in terms of quantity was still a limitation [3]. In recent years, the digitisation of production has become increasingly smarter. With the popularisation of the concept of Industry 4.0, the importance of digitalisation is increasing. The impact of digitalisation is major, and many companies believe it is vital to follow the digitisation trend in order to stay competitive in terms of effectiveness, growth and prosperity [4].

Although the term "Industry 4.0" was introduced in 2011 by Henning Kagermann [5–7], industrial digitalisation started much earlier [8,9]. Digitalisation is considered a prerequisite for Industry 4.0. In presenting the place of digitalisation in Industry 4.0, it is necessary to start with a basic definition of digitalisation and then point out how this definition has already been modified to be used in Industry 4.0. According to OED, (2016) "Digitalisation (digitisation) is the conversion of analogue data (esp. in later use images, video, and text) into digital form" [10].

Digitisation is narrower than digitalisation. According to Schumacher et al. [11] digitisation describes the conversion of continuous analogue, noisy and smoothly varying information into clear bits of 1 s and 0 s [12–15], and digitalisation describes the social implications of increased computer assistance, new media and communication platforms for the economy, society and culture [16–20]. Due to differences in the concepts, this publication uses the broader concept of digitalisation. Now, digital technologies together with automation are used by enterprises in order to change a business model and to provide new revenue and value producing opportunities [21]. Industrial digital technology is a component of production systems.

Modern digitalisation also concerns digital products and digital services. According to Stolterman and Fors (2004) [22] "the ability to turn existing products or services into digital variants, and thus offer advantages over tangible products". Digitalisation enables the transformation of communication links into business functions and models. Digital transforms affect the operational process and both internal and external stakeholders [21]. In a global economy, business activities require digital solutions. Without digital technology, it is no longer possible to do business in a global economy. Digitalisation is part of the framework for Industry 4.0 [23,24].

The key technologies of Industry 4.0 benefit from the level of digitalisation already achieved in enterprises. The information and computer systems used in companies are still key in the planning, implementation and optimisation of processes, e.g., ERP [25]. Data are transformed into information by many IT tools. For a long time now, managers have been making decisions using information and computer systems and mobile devices. The Internet has gained new value created by IoT and IIoT [26,27].

The aim of this publication is to analyse statistical data on digitalisation of enterprises of the metal (steel) industry in Poland on the basis of secondary data from Statistics Poland. The Polish steel industry employs over 24,000 people and produces over 9 million tonnes of steel a year. Polish industry was (before the economic transformation) classified as heavy (mining and metallurgy were the driving forces of the economy). After the transformation (1989), the steel sector was adapted to the requirements of a market economy. The largest steel plants are still important producers of steel and are owned by foreign capital. The largest group, ArcelorMittal, is one of the world's leading steel producers. Steel is a basic material for other industries: automotive, construction, machinery manufacturers, household appliances producers and others. Technological progress in the steel industry influences the functioning of supply chains and markets for steel customers. On the one hand, digitalisation enables steel mills to work better with steel customers' markets; on the other hand, steel production processes are improved and increasingly better finished products are offered to the market. The analysis of digitalisation was supplemented with data on innovativeness of the studied sector, according to the assumed assumption that creating better conditions for digitalisation is equivalent to building conditions for innovativeness. The following hypothesis was adopted in the study: during the transition of enterprises to Industry 4.0, digitalisation and innovation mutually reinforce each other, and the promoted technologies of Industry 4.0 (KETs) favour the pro-innovative impact of digitalisation. The results of the analysis were preceded by a review of literature on digitalisation in the steel industry. The case study was used for the practical review of digital investments. The included analysis of this organisation is a case study and was based on the company's social responsibility reports (SR).

2. Literature Review about Digitalisation in the Steel Industry

When we implement digitalisation in an organisation of the steel industry, we can achieve as a result a better level of optimisation in steel production processes. Using information technology with automation of processes and better connectivity leads to better digitalisation of the production in the steel industry. This process of digitalisation can go beyond typical, conventional automation of the industrial production. Especially in the steel production industry the increase of digitalisation can be obtained due to a combination of different tools, for example physical modelling, plant experiments or computational modelling [9,28,29].

The effect of the digitalisation of the steel industry can be better flexibility, quality and productivity of a product. Additionally, it can lead to better visibility due to the possibility of real-time operation, which can provide insights useful for better and faster process of decision-making [30,31].

Currently, the main demands for digitalisation of the steel industry are connected with the volatility of the market, intensification of the competition of the global market, shortened life cycles and innovations as well as an increase of the complexity of products [32,33].

Business requires information and companies are connected by electronic networks; as a result, nowadays, there is a transformation in business relationships and dependencies, as well as in the type and nature of business. Information systems are a formal part of communication systems in business. It consists of a group of people and machines that process information and use it or enter into communication links to achieve business or service process goals [33,34]. The awareness and interest for digitalisation have increased tremendously in recent years. Technology is advancing with the virtualisation of data, real-time animation and the development of cyber-physical systems.

The Internet age makes it possible to work at a distance and communicate without time and space constraints. Virtual teams, virtual work and virtual organisations are becoming more common in organisations. Networks are built out of organisations, which are fast and flexible thanks to ICT [35].

IC technologies enable companies to enter world markets and obtain world production standards (WCM). The popularisation of global production standards started with the automotive sector and now covers increasingly more industries (including the steel sector in Poland) [36]. Although digitalisation has started the journey of companies towards Industry 4.0, Industry 4.0 is much more than just digitalisation. Industry 4.0 creates a 'new world' that is a strong combination of the cyber and physical worlds. Peters (2017) [37] referred to this strong combination as a 'marriage' but in this marriage "Industry 4.0 is more a paradigm, it is rather a philosophy than a technology" [37].

The emphasis on paradigm is due to the fact that in Industry 4.0, there is a re-evaluation of previous views about production, business and development. There is an emerging belief in the need to build new ways of production and new ways of business activity. Industry 4.0, with its technologies, is an opportunity for new sources of value. The Industry 4.0 technologies are not fully homogeneous; rather, it is a set of technologies (KETs—Key Enabling Technologies). This set is made up of: Internet of Things (IoT), Internet of Services (IoS), Big Data with Big Data Analytics, advanced simulation, cloud computing, augmented reality, machine learning, cognitive computing, additive manufacturing, 3D printing, autonomous robots/cobots, digital twins etc. [38].

Digitalisation integrates technologies across business areas [39] and facilitates the construction of cyber-physical production systems [40,41]. With digital technologies and digital data, companies do business in many markets. IT has created the conditions for business without restrictions (beyond the barriers of place and time). Digital technologies help producers to be more sustainable, e.g., in the aspect of resources intensity and energy intensity [42,43]. Sustainability creates the background for Industry 4.0 [44,45]. Information systems, Internet, mobile application, Industrial Internet of Things (IIoT) and services (IIoS) are building a new business environment [26,27,46]. The era of the Internet of Things is an opportunity for automation networks [47]. The combination of internal and external sensors, sensors and device control systems gives factories access to real-time data [48].

Manufacturing environments are created by auto-ID technologies such as Barcode, QR code and RFID (Radio Frequency Identification) [34,49–53]. The results of this technological application are process optimisation (increasingly also device self-optimisation) and the improvement of production systems. The value for a business is 'smart', e.g., a smart production, smart product, smart service, smart solutions, smart innovations, smart analytics, smart factory and smart supply chain [54,55]. Digital technologies in Industry 4.0 also include smart maintenance. An essential application which is used in smart maintenance leads to improve the maintenance planning in the organization. This is also connected with better criticality assessment [56]. Using the aid of artificial intelligence, organization should consider that maintenance planning can provide better decision process which is also faster. The effect is the decision making process in maintenance management.

Autonomous data and predictive data are useful for self-learning production systems [57–62]. Smart machines in established areas improve themselves (machine learning). Employees follow the work of the machines. Visual systems for operating systems help them to coordinate machine performance. Increasingly, workers are using gestures, smart helmets and glasses instead of keyboards. Scenarios of machine operation and technology development are evolving from machine operators to autonomous machines [63].

New technologies are reducing human work [64], but new skills are needed to use these new technologies [65,66]. Digitalisation applied in Industry 4.0 is changing the relationship between machines and humans [2,67]. A new set of relationships based on the symbiosis of human and machine is being built. According to Romero et al. (2015, 2016) [65,66], symbiosis is a more efficient solution than a lack of humans in factories. In companies' pursuit of Industry 4.0, the already applied principles of low cost, high quality and quick response to customer needs apply to the industry (based on Keinänen and Inas-Kukkonen, 2000) [68]. When we think about digitalisation, we must use information systems (IS). The goal of these systems is to deliver information useful for decision making and business improvement [34]. In enterprises, those solutions are very popular.

The first system is ERP (Enterprise Resource Planning). The ERP system integrates all information and processes of the enterprise [69]. The ERP system is built from different components of computer software and hardware to enable information flow throughout the enterprise. The ERP system itself evolved from the MRP II (Manufacturing Resource Planning) concept, which followed the MRP (Material Requirements Planning) concept.

MRP was the system about material needs in the production of goods. MRP II represents the management of production resources and integrates them. Basic functions of the systems are monitoring, quality assurance, technical maintenance, logistics and distribution, service activities as well as human resource management.

The next step of expanding the system will be the ERP II version of the system [34]. The second most popular system is CRM (Customer Relationship Management). The CRM system collects information about customers to increase customer satisfaction and to have better, longer and more profitable relationships with customers [70].

The third system is the MES (Manufacturing Execution System) [71]. The system supports: scheduling, production reporting, product tracking, dispatching, performance analysis, maintenance operations, workforce tracking, resource allocation and similar. [3]. The most common activities in this area are the integration of information systems (e.g., integration of ERP and CRM systems) and integration of information systems with digital technologies, such as tracking technologies (barcode, QRCode and RFID) and mobile applications [34,49–53,72].

Digitisation in the enterprise is used in many ways. One of them is using digital technologies to protect an environment. According to Feerrari et al. (2021) [73], digitalisation can be applied in manufacturing companies to achieve environmental protection goals. Large datasets and the information derived from the data can form the basis for a life cycle analysis (LCA—Life Cycle Assessment). An ERP version of the system is available on the market with an adapted LCA tool by means of Business Intelligence (BI) software.

A special aspect of the analysis of new information system applications is the assessment of resource intensity. In the pursuit of sustainable economies, an important aspect of assessment is the analysis of electricity. This is also an important area of analysis in the steel sector due to its high electricity consumption in steel production. The digital transformation of industry is linked to an increase in innovation amount (new and improved products or new and improved processes, etc.).

The impact of digitalisation on process innovation was studied by Tajudeen et al. (2021) [74]. The authors applied the dynamic capability theory (DCT) to determine the impact of IT on process innovation in organisations. The result of the authors' research was the following conclusion: with the rise of Industry 4.0, underpinned by Digitisation, every organisation must adopt a strategic vision of digitalisation in order to strive to improve its process innovation capabilities. IT flexibility and IT integration have (in the authors' view) a significant positive relationship with process innovation in organisations.

Innovation management is a source of competitive breaks as long as firms know how to manage them [75]. Companies finance innovation from their own resources, bank loans, funds from public institutions and others. They are also supported on their way to digitisation by European projects [76]. Several projects (e.g., RFCS projects, FP7 projects, Horizon 2020) have received funding from steel companies (ArcelorMittal, Tata Steel, ThyssenKrupp).

A list of participants from the steel sector in European programmes is available in the EC Final Reports. Steel sector activity is also the subject of Branca et al. [76]. The steel industry is one of the most energy-intensive industries. This means that it is very important from an energetic balance point of view, and digitalisation can be one of the possible methods for decreasing its energy demands. The digitalisation processes of the European steel industry is used as a part of Industry 4.0 implementation in the steel industry organisations.

In Table 1, we put information about the digital technologies used in the steel industry in the best digitalised organisations in the world. Used digital technologies can be applied in order to increase the flexibility and reliability of industrial processes and improve the product quality. Digital technologies can also be used for monitoring and assessing the environmental performance of the steel industry organisation processes, improving the control level of the production and of the auxiliary processes that have a big environmental impact. Those technologies should also provide key performance indicators for resources efficiency [77]. The main challenges of the steel industry in the European Union are related with the following points [76]:

- Legacy equipment;
- Uncertainty about the impact of digitisation on jobs;
- Issues connected with data protection and safety.

The main difficulties of the digitalisation of steel production are connected with the following points [77]:

- Problems with the integration of new processes and technologies with site workers, which is especially important in the case of older employees;
- Big gaps between workers which are now employed and the prospective employees in the case of knowledge transfer;
- Lack of investment in education and training from steelmaking companies as well as an insufficient number of others types of training provided by companies.

Neef (2018) [78] found that technical barriers are normally considered less important than organisational ones. The crucial process of digitalisation in the steel industry is the engagement and knowledge of internal managers, which represent the driving force for the Industry 4.0 implementation process. Technology- and production-related issues are important but less crucial.

Organisations in the steel industry have problems with a lack of a suitable amount of good qualified personnel which can use the new digital technologies in the production environment. One of the main challenges connected with the increase of digitalisation of the European steel industry is connected with attracting and retaining enough qualified personnel (European, 2019) [79,80]. This is especially a problem when we want to integrate new, digital technology among older employers. In this industry, we can observe an age gap between workers currently employed by steel companies and prospective employees having very good knowledge in the field of digital technology. To minimalise this problem, steel industry organisations should invest in training programs to increase their employees' digital competence level.

Table 1. Digital technologies used in the steel industry.

Technology	Characteristic
Internet of Things	Internet of Things in the steel industry refers to the use of many electronic devices and an inter-networking work environment. Steel industry organisations use sensors, actuators and other types of digital devices, which are networked and connected between themselves with the main purpose of implementing a system based on an Internet of Things architecture. This type of system consists of four layers: network, sensing, application and service resource layers. This type of system was implemented in many real steel casting production lines [76,81].
Big data analysis	In the steel industry, the conventional way of managing the data can have nowadays some difficulties in the process of finishing the storage, capture, analysis and management of large volumes of structured and unstructured data. The new method of big data analysis is related to new algorithms based on historical data, which can be used to identify quality problems and for reducing the failure of products. In the steel industry sector, the big data solutions are used in many organisation for monitoring the quality of the products. The technology can enable new processing modes to obtain significant, new information from different data types. In this way, we can understand the data in-depth and make better decisions on the basis of them [76].
Cloud computing	Cloud computing use in the steel industry give on-demand computing services. Those type of services have a high level of reliability, scalability and availability in a steel industry environment. Using this technology, all data can be treated as a service [82].
Robotisation of production processes	The use of technology based on the use of humanoids in the steel industry in order to perform operations is especially important in the field of assembly and packaging. It is widespread due to the higher demand for better quality, faster delivery time and the reduction of cost in the steel industry. In many organisations with business activities in the steel industry, the use of robots leads to an increase of the surface quality of the steel products and minor improvements of the whole production process [76,83].
Simulations	Organisations in steel sectors can use new technology to try doing simulations to find a way to optimise the production processes. For example, decision support systems are used in the steel industry to investigate the potential changes in design operations. The simulations use many statistical and mathematical methods [84].
Augmented reality	Organisations in the steel industry are using the digital solution in augmented work, maintenance and service. In the steel industry, organisations are using remote guidance to apply the fourth dimension. This technology usage can enable steel industry companies to improve the level of the maintenance services. Those organisations use remote maintenance equipment based on a remote connection used by technicians virtually connected to the system. The usage of augmented reality can result in decreasing travel costs and operation times. Additionally, this technology solves problems more quickly [76,85].
Cyber security	Cyber security is an important problem for organisations in the steel industry. The technology is especially important for Internet-based services and in every situation when computers or equipment are connected to the Internet. With the increase of Internet of Things usage, almost all equipment can be connected to the Internet, which leads to an increased role of cyber security in organisations [86].

Table 1. *Cont.*

Technology	Characteristic
Customisation and personalisation of production	Among steel industry organisations, we can spot an increasing number of vertical integration usage. This leads to an improvement of communication between the supplier and the organisation and also the organisation and its customer. The online connection between them and the faster data transfer can enable an intelligent factory solution as well as personalised customer manufacturing [87].
Drones and others self-driving vehicles	The steel industry can also benefit from drone usage, especially in logistic processes. This type of technology is based on automated systems of transportation. Intelligent software is used to support the operation of drones and helps steel industry companies to improve processes and make them much faster. In the steel industry, the logistics (supply, disposal and transport of products and raw materials) are a very important part of the industrial processes. The usage of drones and others autonomous self-driving vehicles can lead to better planning and controlling of the internal transport orders. The result of this is an increase of the service and productivity level and a decrease of the costs of logistic processes [76,88].
Knowledge management system	In a competitive market, the knowledge management can also be digitalised in the steel industry. The knowledge and experience of the workers—especially technical staff—can represent the basis for improvement. In the steel industry, we spot problems in the distribution of this knowledge. Especially older workers do not have enough digital competencies and should learn from more experienced staff. On the other hand, older technical workers have excellent knowledge about production processes. This knowledge should be digitalised and handed over to younger workers. The digital system of knowledge management usage can enable a better distribution of knowledge between workers within the steel industry organisation as a whole [89,90].

Source: based on [76,81–90].

3. Materials and Methods

The subject of this research is the use (popularity) of information, computer, digital technology tools, network communication and other innovative solutions by steel sector enterprises in Poland. According to the Polish Classification of Economic Activities Polish (PKD), metallurgy is classified in the metal production department, which belongs to the top 10 largest industrial sectors. The analysis was based on secondary sources of information.

The practical section was divided into three parts. The first part is a background for the analysis. This part describes the steel sector in Poland. It focuses on basic data on the sector's share in GDP, steel production (the volume of crude steel production between 1989 and 2020), the structure of business activities in the sector, steel consuming sectors, resources intensity and using technological processes in crude steel manufacturing. Part two of the background consists of digitalisation of the steel industry in Poland. Both the first and the second part are based on literature and statistical data of the Polish Steel Industry (in Polish: Hutnicza Izba Przemysłowo-Handlowa, HIPH) and data from reports by Statistics Poland (in Polish: Główny Urząd Statystyczny, GUS). The third part is a case study based on the largest producer of steel in Poland—ArcelorMittal Poland (AMP). The topic of the case study is the digital investments. This part of the analysis was based on information from reports about the Social Responsibility (SR) presented by the company on its website [91,92].

The main stage of the research was an analysis based on statistical data. The part of the study entitled steel digitalisation in statistics presents data on the use of IC technologies and innovation activity of steelworks. This part consists of two areas of research: the use of selected information and communication technologies (ICT) in industrial enterprises and innovation expenditures and the types of innovations introduced within the sector.

Information on the use of selected information and communication technologies in industrial enterprises has been developed on the basis of generalised results of surveys carried out by the representative method according to the harmonised methodology used in the European Union countries. In 2018, the survey covered 7.2 thousand industrial enterprises (i.e., 37.4% of the total number of enterprises).

Terms used in the paper:

- Cloud computing refers to ICT services that are used over the Internet (Virtual Private Networks (VPN) connections are also included) to access software, use certain computing power and store data.
- A broadband connection is a type of connection characterised by a high speed of information flow, measured in Mb/s (megabits per second). Broadband access is enabled by, among others: DSL family technologies (ADSL, SDSL, etc.), cable TV networks (cable modem), satellite connections and wireless connections via a modem or a 3G phone.
- Mobile Internet connection is a type of connection of mobile devices connected to the Internet via mobile telecommunications networks for business purposes.
- Information systems—use of ERP and CRM.
- Innovativeness—enterprises innovating within the scope of product innovations and business processes in the industry for the last 3 years in the field of metal production, as well as enterprises which introduced new or improved products or business processes: in total, with 50–249 employees or with 250 and more employees, new or improved products and new or significantly improved business processes (in % of the total number of enterprises).
- Sources of financing of outlays (in PLN million): own; acquired from abroad; credits, loans and other financial liabilities from financial institutions; national, from institutions disposing of public funds.
- Share of the net revenue from sales of new or improved products of the net revenue from sales in industry in the division of metal production: products—in percentage—introduced to the market in the last 3 years.

In the analysis, annual data were used in the period from 2010 to 2018 with the possibility to update the data for 2019 (if published). Figures 1–5 show the average shares for the period from 2010 to 2018 calculated on the basis of annual shares.

The aim of the research is to present and analyse the development of digital technologies in the Polish steel industry. The use of ICT has been linked to innovation. The hypothesis cited in the introduction of this publication was adopted in the study. The reason for the formulated hypothesis is that companies strive to increase innovation through technological development. The topic of digitalisation of the steel industry in Poland is part of one of the current authors' own research (other studies are in the process of being published) [93,94].

However, previous studies have not considered the impact of digitalisation on product and process innovation opportunities, nor have they captured the role of digitalisation vision, strategic IT components and its impact on the development of the steel sector (based on average volumes over the analysed period from 2010 to 2018). The current study filled the gap and the results of this study provide valuable information to understand the importance of digitalisation in the steel industry. Data can be used to plan the enterprises' development.

4. Background for the Analysis

4.1. The Steel Industry in Poland

The Polish steel industry has come a long way from the time of state-owned enterprises to private ones. In the industry restructuring, a wide range of changes were conducted: ownership, products, assets, employment and management to an innovative industry. Radical changes in the metallurgical industry took place during the transformation of the Polish economy (the highest intensity of changes was in the 1990s) [95]. Innovation (in statistical statements) of the sector is assessed by new or modified products, new or modified processes, technological investments and R&D activities. The steel sector in Poland directly generates 3% of the value of the industrial production in the country and about 0.3% of the total GDP (HIPH based on GUS) [96,97]. In broad terms ('economic footprint'), as an element in the supply chain, it is responsible for generating about 2% of the GDP [98,99].

The value of sold production of the steel sector in 2019 was PLN 35.7 billion. The average annual steel production in Poland between 1989 and 2019 was 9.8 million tonnes. After taking into account the pandemic year, the average annual production for the period from 1989 to 2020 was 9.7 million tonnes, and thus, it decreased by 0.1 million tonnes (100 thousand tonnes) [99]. The sector of steel producers in Poland consists of 9 steel mills, 5 rolling mills for flat products, 12 rolling mills for long products and 10 rolling mills for pipes and sections (Polish Steel Association—HIPH) [96]. Statistics in Poland (GUS) give the following numbers of entities: 16 in the sections: production of pig iron, steel and products; 24 companies in the sections: production of tubes and sections, 27 companies in the section: production of other pre-treated products (2018) [97]. The sector of finished metal products consists of 1266 companies.

The steel products distribution sector, according to the PUDS, counts 35 companies (the largest companies). Steel is sold to the following: construction sector, automotive sector, manufacturers of metal products, manufacturers of machinery, manufacturers of household appliances and manufacturers of means of transport. The largest domestic customer for steel is the construction sector (over 40%). In the period from 1989 to 2019, investment expenditures in the sector of steel producers amounted to PLN 23 billion [90,91]. The features of steel production are resources and energy intensity (about 0.2 toe/tonne of produced steel) [100,101].

In 2002, Polish steelworks switched off uneconomic steelmaking technologies (Marten's technology) [95]. Steel mills are currently introducing energy-saving technologies and diversifying their sources. The direction of changes is in line with the "green" policy, i.e., a reduction of the consumption of solid fuels (mainly coke) and electricity generated from coal while increasing the share of process gases (i.e., blast furnace gas and coke oven gas) [102]. The lower energy intensity in steel mills is influenced by improved energy efficiency of steel production processes. The pursuit of steel mills to reduce the consumption of electricity and natural resources (iron ore, coal) can be counted among the challenges in the implementation of investments to ensure steel mills are brought closer to Industry 4.0 [42,43,103].

The analysis of resource intensity in steel companies has been supported by information (computer) systems such as MRP, ERP and more recently by access to IoT—Internet of Things (more information in the analysis) [46]. Foreign capital has a strong influence on the development of the steel sector in Poland (the largest Polish steel mills belong to foreign groups). During the privatising process, IC technologies have been used to build (create) new internal and external dependency structures in the Polish steel industry. Now, the technologies help to build competitiveness of the sector in the world steel market.

4.2. Digitalisation in the Steel industry in Poland

Since the early 1990s, intensive digital investments have been made in many industries around the world [8]. In Poland at that time, steel mills were reorganised and restructured. The economic transformation and the postponed privatisation of steel mills delayed the digitalisation of the steel sector in Poland.

It can be assumed that it was only after privatisation and restructuring were completed that steel mills could plan their own new technological investments. This stage occurred at the end of the first decade of this century. In 2007, the European Commission considered the restructuring of the Polish steel mills to be completed. The assets of the largest Polish steel mills were sold to foreign investors. Foreign groups entered the Polish market: in 2003, LNM Holdings N. V. (Mittal), in 2006, Arcelor Mittal (formal presentation of AMP brand was in 2007), in 2003, the American capital group CMC and in 2003, Celsa—a Spanish investor [104]. New owners invested in new production technologies (BAT) and IC technologies. Now, the intensity of digitalisation of the steel industry in Poland is increasing.

The Polish steel industry is implementing digital technologies, which, together with the development concepts of Industry 4.0, bring it closer to the requirements of advanced and high technologies [103]. Digital technologies in the Polish metallurgical plants monitor the work in selected sections of production and operate basic technological equipment (monitor the parameters of equipment operation and control the work of equipment). The blast furnace is supervised and controlled by IT systems. Equipment in steel mills and rolling mills is equipped with sensors, which provide data on the processes and facilitate their control. In integrated steel mills (with BF + BOF technology), equipment with sensors forms network structures, called the Blast Furnace Network (BFN).

The BFN forms a network of sensors installed on blast furnaces together with algorithms to identify furnace conditions. The data provided from the sensors and sensors allow the BF technology load and maintenance work to be planned accordingly. This technology is used at the Dąbrowa Górnicza smelter, which is a branch of ArcelorMittal Poland [105]. Big data in real-time allow optimising processes with model predictive control. A huge progress in the application of digital technologies in steel mills has been made in Total Productive Maintenance [106,107].

The pursuit of failure-free machineries is realised in World Class Manufacturing (WCM) [36]. Many years of investment in this area on the ballast production line at ArcelorMittal Poland in Swietochlowice have made, from a failing machine park, a more modern production line [106]. The large number of installed sensors (thousands on the production line) provides the operators with data (KPI—key performance indicator). KPI analysis and optimisation processes in real-time increase the production capacity of the steel mills. Digital technologies have reduced unplanned downtime to an absolute minimum.

For long-term resilience, process optimisation systems are based on maintenance schedules and on maximising resource availability and efficiency. Information systems used for resource intensity analysis are proactively oriented, i.e., they enable anticipation of upcoming problems [108,109]. IC technologies also enhance collaboration between end users and original equipment manufacturers (OEM). In resource management, steel mills use IC systems with multiple modules. Systems, such as ERP, MES and CRM, provide data on resources, production, machine operation, products and customers. Expanded IC systems (ERP, CAx) are equipped with applications for documentation management, project management, production planning and scheduling and Business Intelligence (data analysis and reporting).

The full IT package consists of SAP systems. In large steel mills in Poland belonging to foreign capital groups, the systems create an integrated IT and computer environment, connecting enterprises, corporations, capital groups and entire supply chains. The interconnected information systems come from collaborative networks [110]. Google Cloud and Microsoft Azure are some solutions facilitating the exchange of information. In addition to information exchange, data analysis (including comparative comparisons of resource rationality) is realised. IoT and smart technologies through dynamic configuration of production processes foster the fulfilment of key principles of sustainable production [111].

On the path to steelworks 4.0, IC technologies assist steelmakers in their roles. The examples of those roles are connected with for example fully and semi-autonomous robots, increased use of artificial intelligence, drones, augmented and mixed reality, virtual, 3D and 4D printing, digital twins and ever more innovative methods to transform organization towards Industry 4.0. This described intelligent combination of sensor technologies combined with quality and production planning and control systems as well as digital models lead to possibility of creating new dimensions in product quality and production processes, and also it leads to cost reduction in the process of steel production. Many of the mentioned problems are the challenges of ICT in Industry 4.0 [112].

The digitalisation of steel production we can define as the consequent application of new technologies which is needed to fulfil steel producers' requirements in quality, productivity and flexibility [9]. The IC technologies used in steel mills are being developed in the following directions: achieving full connectivity between devices, increasing the computing power of computers and creating intelligent advanced software, which in the long term takes the form of ubiquitous applications with ever-increasing levels of intelligence and "networking".

The growth of software intelligence in steel mills is manifested in the development of software, often called 'self-learning', 'adaptive' and 'self-modifying'. In the future, steelworks from level 3.0 (steelworks 3.0) want to reach level 4.0 and become steelworks 4.0 (the levels of steelworks correspond to the levels of industrial revolutions) [37].

Digitalisation and cyber-physical systems are used in many steel industry companies in Poland. For example, Miśkiewicz [113] has written about the ReAlloys company, which has implemented active monitoring devices based on the Raspberry Pi + Arduino architecture named Vizum Box to increase the online digitalisation of production data. Additionally, they used server software with the use of NETcore technology. This technology can allow to embed server software and also use of cloud computing [113].

The visual system used in ReAlloys consist of three modules we described in Table 2. In this system, the process of communication between cloud computing and Internet of Things devices is realised by an Internet connection and the use of an MQ Telemetry transport protocol. To ensure maximum reliability of communication the Vizum Opitrack system is integrated with another system—Orange Live Objects service, which can enable communication of cloud computing and Internet of Things devices via the used protocol directly in the software layer of the Orange operator infrastructure worldwide [114].

Table 2. Modules of the Vizum system used for digitalisation in ReAlloys.

Modules	Characteristic
Vizum Workforce	The system is used for vehicle monitoring. The Optitrack system allows for the fully automatic recording of every entry and exit, monitoring of attendance and time spent in them and checking the employee's reaction to random tests. At the end of the day, an automatic report will show any irregularities identified (e.g., lateness, too long breaks or absenteeism). The Opitrack system is used to detect any potentially dangerous situations, such as falls, fainting, changes in environmental conditions (temperature) or staying too long in certain areas of the site. The Optitrack system allows for a continuous survey of the safety status of people present on site and their knowledge of health and safety. Employees walk around equipped with unattended Vizum ID cards and/or a mobile app on a smartphone. Vizum ID cards are automatically detected by checkpoints. Employees can also reflect and assign themselves to projects on touchscreens. Mobile applications on smartphones send data non-stop from any location. In one panel, you can see the current situation of the entire workforce in individual plants. Summaries and detailed periodical reports of individual employees are updated every hour.
Vizum Vehicles	The system is used for vehicle monitoring. The Opitrack system enables continuous tracking of location and work of vehicles both in open spaces (field trips) and in closed spaces (warehouses, garages). The Optitrack Vehicles system, besides recording the location and working time, also collects information about the vehicle operator and passengers [114]. The vehicles are equipped with VizumBox devices, whose sensors continuously monitor the immediate surroundings. Maintenance-free and non-invasive so-called position markers are installed in confined spaces. VizumBox devices collect data from motion sensors, GPS data and information about detected position markers in confined spaces and detected Vizum ID cards worn by employees. All data are sent to the cloud. The current status of the entire fleet can be viewed in a single administration panel. Summaries of periodical reports and detailed reports of all vehicles are updated every hour [115].

Source: based on [114,115].

In Poland, ArcelorMittal uses drones which fly over commodity stores to measure their condition. ArcelorMittal also uses 3D printers to print spare parts from devices in the steel mills. ArcelorMittal sells steel by using online platforms and mobile applications to contact customers and to monitoring the process of orders. Another digital technology used in AccelorMittal is blockchain (five application, 2018). According to the research conducted by the EU Commision Directoriate-General for Economic Financial Affairs in 2019 [116,117], it is estimated that over 2 million industrial robots work in the world. The leaders in this matter are China, which by 2021 will have over 1/3rd of all industrial robots in the world.

In Poland, so far, over 11,000 units have appeared and have been implemented in the country. Compared to the density of employees, there are 36 robots per 10,000 employees in Poland, and 106 robots per 10,000 employees in Europe. The demand for intelligent machines is growing year by year, which is due to not only the general trend, but also the growing awareness of business owners about the advantages of robotisation.

The automotive industry shows the greatest demand. This may explain why the western neighbours of Poland are in the lead in Europe in this respect. However, the electrical and electronics sectors are responsible for the overall increase in robot sales. The third place is shared by the metallurgical, metal and machine industries [118]. The high position of the steel industry makes it an industry where in the coming years there will be a significant increase in the use of industrial robots, and thus, the level of digitisation of this industry.

Despite the low level of robotisation in Poland, an upward trend is noticeable. The robotisation density index is growing (the robotisation density index is an index prepared by the International Federation of Robotics to measure the level of implementation of robots in production), but it remains too slowly compared to other regions and countries, even for those with a similar level of development, such as the Czech Republic or Slovakia, which have already reached the European level [119,120]. The steel industry has shown to have one of the highest demands for industrial robots in Poland in recent years.

The current low level of robotisation in some steel companies results from the following reasons, depending on the particular company [121]:

- Low production scale, which translates into no need to introduce processes related to robotisation;
- A specific production profile where robots are not needed;
- Not taking into account robotisation in the company's development plans;
- Financial barriers;
- No need to develop production processes.

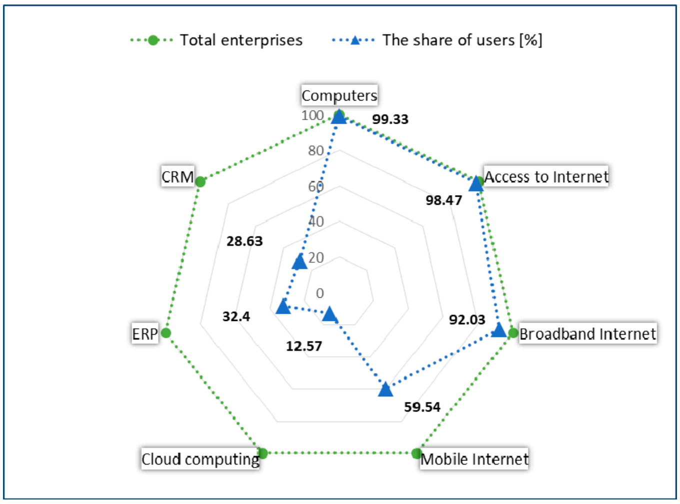

Figure 1. ICT in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

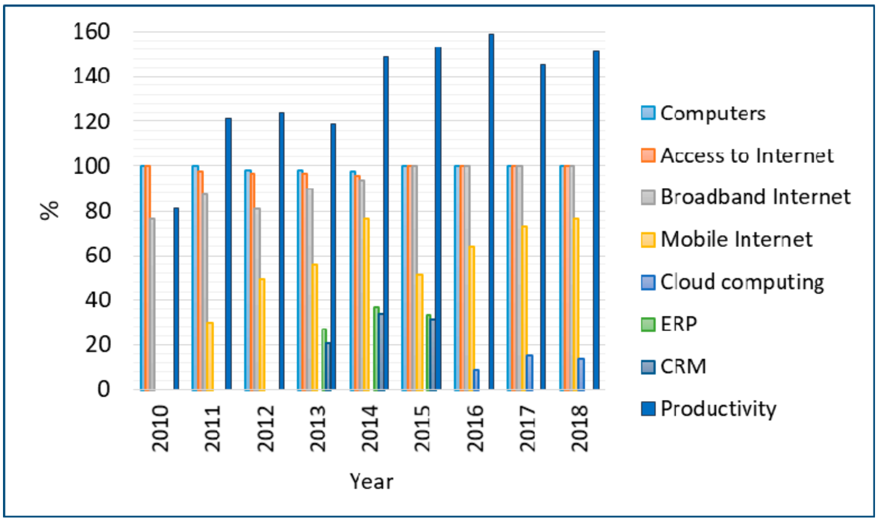

Figure 2. ICT and labour productivity in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

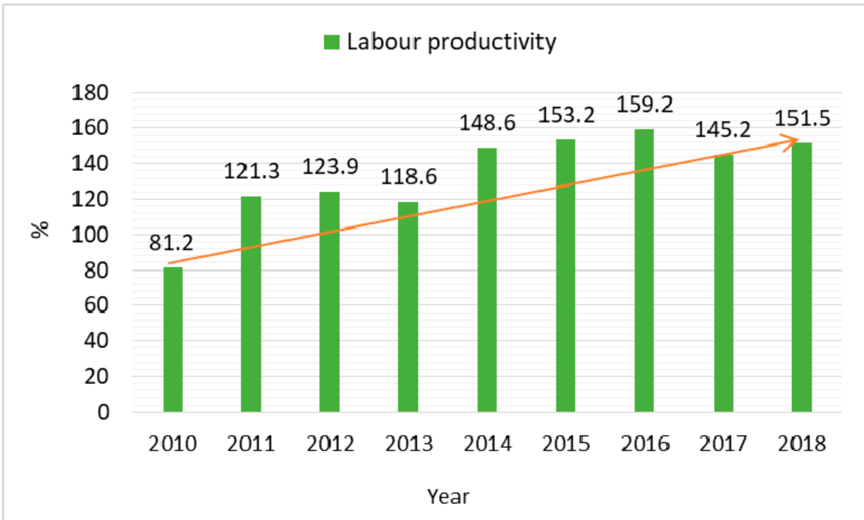

Figure 3. Labour productivity in industry measured by the gross value added in Poland. Description: line in red colour—increase of labour productivity. Source: Data from GUS [122].

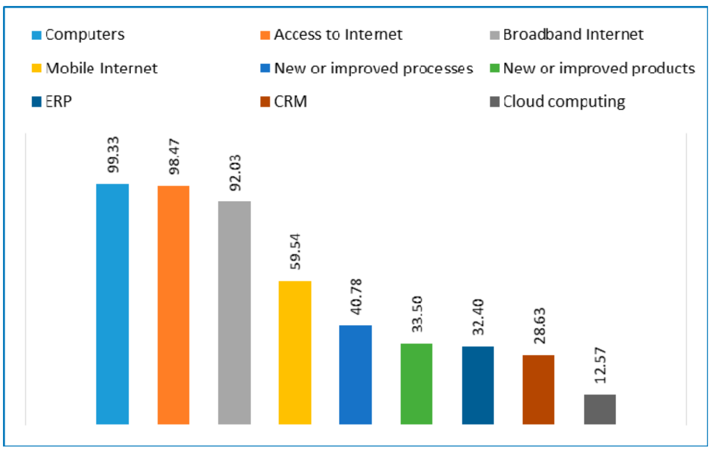

Figure 4. ICT and innovation in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

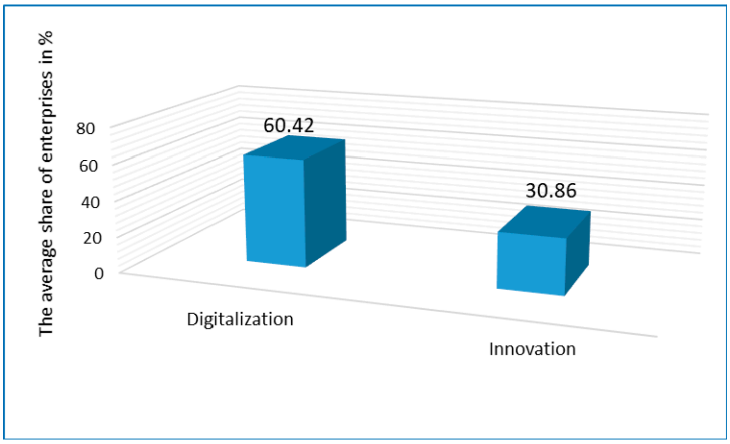

Figure 5. Average analysis of ICT and innovation in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

4.3. Digitisation in Steelworks—A Case Study of the Corporation ArcelorMittal Poland

The case study presented in this paper is based on the SR reports (Social Responsibility) realised in the corporation ArcelorMittal Poland in 2018 and in 2019. ArcelorMittal Poland (AMP) is the largest steel producer in Poland. It employs nearly 11,000 people. The average annual steel production (in the last 5 years) was about 5 million tonnes. The corporation has six production divisions located in: Dąbrowa Górnicza, Kraków, Chorzów, Sosnowiec and Świętochłowice. The corporation also has a coke plant in Zdzieszowice.

The share of AMP's production capacity in the whole market of steel producers in Poland amounts to 70%. The group was formed by the merger of Mittal and Arcelor in 2006. Since the beginning of its activity in Poland, AM has invested over PLN 7 billion in the modernisation of its steel mills and plants. Now, AM has started working on the adoption of new platforms and algorithms based on artificial intelligence in many business areas [76].

This case study gives examples of digital investments made in 2018–2019. In 2018, video-based image processing was introduced at the Dabrowa Gornicza steel plant to analyse converter vibrations in the production line. In 2018, 3D visualisation of the hall was applied at the Sosnowiec plant for work planning and optimisation of the production area layout [91,92].

In 2019, drones were used at the AM Poland sites to observe areas around the steelworks and belonging to the steelworks [92], p. 50. Moreover, an IT system for digital product location was used in warehouses (Krakow branch). The process of the identification of metallurgical products was carried out remotely, without the need for employees to move around the storage area.

Ultimately, the system will cover all the steelworks warehouses. The system tracks the entire path of the coils from the rolling mill to the dispatch to the customer. A logistics system was also installed at the Krakow branch to monitor the movement of cars on the roads and in the car parks of the mill. The system restarts, identifies and controls the movement of vehicles from the entrance gate to the relevant loading gates and halls (in the steel product warehouses).

Employees in the steel mills are equipped with mobile devices. The operators of the devices carry out mobile inspections in the rolling mills in Kraków, using an application installed on their phones. The employee scans the QR code and, upon completion of the inspection, confirms that the task has been completed [28,29]. The information is sent directly to the SAP system. A rail production tracking system was installed at the rolling mill in Dąbrowa Górnicza, which allows for the precise identification and monitoring of the products. The IT system makes it possible to view the current status of production, control the throughput in the rail finishing plant, speed up the quality acceptance of the products and reduce the risk of human error.

The Krakow coking plant has a system for measuring the filling of the coking chamber after backfilling with a coal mixture and its levelling—the data obtained are used to optimise chamber backfilling operations, resulting in a reduction of the negative environmental impact of the process. At the cold rolling mill in Kraków, in closed or confined spaces where employees are not allowed to be or which are associated with greater danger (risk to the health or life of employees), drones operate, which carry out technical inspections and inspections of the structural condition of machinery, equipment and facilities (LED lighting installed in the drone makes it possible to also monitor plant operation in the dark) (Report AMP, 2019, p. 55) [92].

At AMP, IT systems, for years, have been used to detect defects in steel products, e.g., defects in rollers installed in a grinding machine (Kraków branch). The system installed at this plant identifies both surface and sub-surface cracks in products. Thousands of sensors have been installed in steel mills, e.g., in the Krakow metallurgical plant. The installed sensors improve the band guidance on the roll shear in the pickling line of the cold rolling mill. The solution used there enables very precise cutting of the edge of the pickled sheet to the required size, reducing the number of jams.

Modern IT systems installed in the mills collect data in real time and computer control of the equipment is carried out with the use of mobile devices (remote systems for measurement and control of equipment operation). AMP also uses incremental (additive) technology, such as 3D printing. The investments cited in this case study are examples of innovation in the field of digitalisation in the steel industry. The scope of innovations implemented at AMP in the area of digitalisation of processes is much broader.

The presented case study uses examples that the company provides in its SR reports. On the basis of the case study, it can be concluded that a new generation of digital technology is being introduced in steel mills in a wide range: from production preparation, production control and steering to processes of storing final products and their transport. In addition to the basic processes, digital technologies are used for additional functions, e.g., building administration, document management, maintenance and servicing. The effects of digitalisation in the company are presented in Table 3.

Table 3. Investments in digitalisation in ArcelorMittal Poland and its effects.

Investments in Digitalisation	Effects
Introduction of a video-based image processing system to analyse converter vibration in the production line [91].	Better analysis of the vibration—improvement of the production process [91].
3D visualisation of the hall [91].	Better work planning and optimisation of the production area layout [92].
The use of drones to observe the areas around the steelworks and belonging to the steelworks [92].	Better and faster identification of problems in the production line. Improvement of production processes [93]. Allows monitoring of observation areas that are too dangerous to be inspected by humans [91].
An IT system for digital product location in warehouses [92].	Faster identification of products in the warehouse. Faster delivery of the products to production or to the customer [92].
The logistic system to monitor the movement of cars on the road and in the car parks of the mill [92].	Better control over the usage of vehicles. The reduction of the downtime of vehicles [92].
The usage of mobile equipment by employees in the steel mill [91].	Possibility of doing inspections and many others activities remotely. The automatic integration of the scanned information with the organisation's SAP system [91].
Rail production tracking system in the Dabrowa Gornicza mill [91].	The system allows better identification and monitoring of products. Optimisation of logistic and production processes [91].
The system for measuring the filling of the coking chamber after backfilling with a coal mixture [91].	The optimisation chamber backfilling operations. Reduction of the negative environmental impact of the production process [92].
The AMP IT system used for the detection of defects [91].	Decrease in the number of defects. Better product quality and better customer satisfaction [86].

Source: own analysis based on: [91,92].

5. Steel Digitalisation in Statistics

Results of Analysis

The analysis of the use of digital technology tools in steel mills (metal production sector) started from a basic device—the computer. In the last two decades, the steel sector (almost all participating companies) has embraced the use of computers. From 2010 to 2018, the average share of enterprises was 99.33%. There was also a high share of internet users (98.47%), of which broadband internet users accounted for 92.03%. Moreover, mobile Internet was used in 59.54% of the companies. Of the many IT systems, ERP and CRM software packages were used in every third company. The new IT technology of cloud computing was first reported in research conducted by Statistics Poland (GUS) in 2016. In that year, 8.5% of the surveyed sector were cloud computing users [122]. The average share in 2018 was 12.57%—see Figure 1.

The industry productivity is growing (Figure 2; thus, it can be assumed that productivity growth is linked to digitalisation. Digitalisation applied in steel mills is used to optimise certain processes, which increases productivity. Enterprises which incurred expenditure on information and communication technologies accounted for 41.5% [101]. The use of ICT was compared with labour productivity (Figure 3). The labour productivity in industry was measured by the gross value added [122].

According to the research hypothesis, the next step of the analysis was steel innovation. In 2018, the innovative activity of steel enterprises (manufacturers of basic metals) was 36.20%. Among the innovative activities are new products, modified or new processes or modified processes. In 2018, in the segment of surveyed enterprises (CSO research), 33.5% of companies were introducing new products systematically (in the last three years). In 2018, 40.78% of enterprises had new or improved business processes. Companies that implemented both categories of innovation accounted for about 20% [122] (Figure 4). The innovation activity of companies in the metal sector (steel sector in Poland) was compared with the average participation level in activities included in the category of digitalisation of the industry (the average participation was calculated on the basis of data presented in Figure 1), and the results of the comparisons are presented in Figure 5.

Innovation in Figure 5 means average innovation based on a share of enterprises with new or improved products and new or improved processes and both innovation products and processes in the analysed period. Digitalisation refers to the average digitalisation based on a share of enterprises with computers, ERP and CRM, and enterprises with access to Internet, broadband Internet, mobile Internet and users of cloud computing.

On the basis of comparisons made between digitalisation and innovative activities (in relation to two categories: innovative products and innovative business processes), a 2:1 relation was obtained. In the steel sector in Poland, digital investments are twice as frequent as innovative investments (in the sense of innovation as new or improved products or new or improved business processes). The source of financing for new investments is (primarily) equity. In 2018, the share of own funds in investment expenditures accounted for 88%. The share of other sources of financing (loans, loans subsidising investments from public projects, funds approached from foreign support institutions and other sources) did not exceed 15% in total (Figure 6).

In recent years, the steel sector has been investing in Industry 4.0 technology. By comparison, in 2014, innovations such as using 3D printing and using industrial or service robots were not recorded in the Statistical Compilations in Statistics Poland. In 2019, the share of enterprises indicating the use of 3D printing in their activities was 7.5%, and the share of enterprises using industrial or service robots was 23.2%. In 2019, the share of enterprises using ERP or CRM software packages also increased—the share was 35.5% compared to 32.4% for ERP and 28.6% for CRM in 2018. In the period from 2010 to 2017, the average expenditures were PLN 82.2 million (Figure 7) [122]. In 2018, steel mills and steel product manufacturers' own spending on innovation, digitalisation, automation increased (according to the forecast based on a few points).

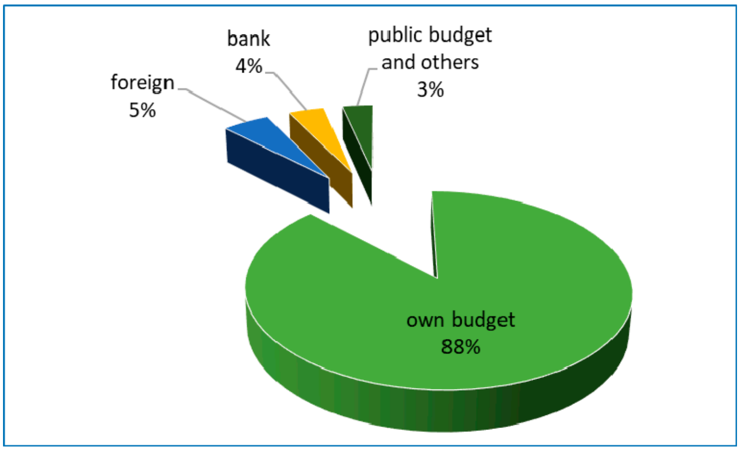

Figure 6. Sources of expenditures on ICT and innovation in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

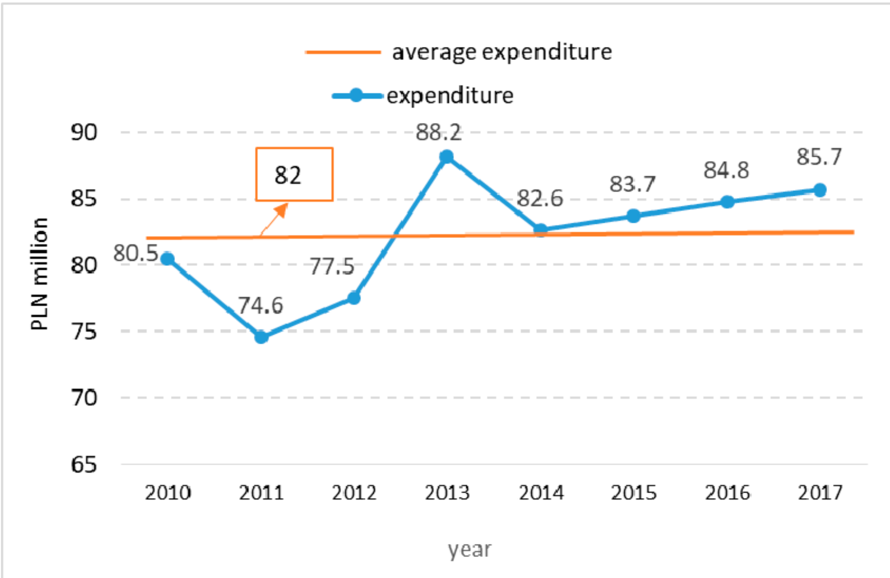

Figure 7. Expenditures on ICT, innovation and automatisation in the steel industry (manufacturers of basic metals) in Poland. Source: Data from GUS [122].

The final stage of the analysis was the research about results of innovation, which were presented as the share of new or improved products in sales revenues (a category in the report: revenues of industrial enterprises from sales of new or improved products as the share of total revenues from sales metals). In 2018, the share was 4% (PLN 1.5 billion) compared to the value of the sold production of the steel sector in 2018, which amounted to PLN 37.5 billion [122].

6. Discussion and Conclusions

IC technologies collect data and process and control physical production processes via unlimited internet access, including broadband and mobile internet. Cyber technology in Industry 4.0 is part of cyber-physical production systems (CPPS). CPPS is the integration of computers and physical processes. The bond between cyber technology and physical processes is getting stronger and stronger. Steel sector companies in Poland are now investing in digitalisation.

There used to be a time lag (two decades) compared to industries in other highly developed countries. Currently, in Poland, the steel sector is investing more strongly in IC systems and digital technologies (which in most developed countries were made in the 1990s) only after the privatisation of enterprises and restructuring of the industry, which contractually occurred after the publication of the EC final report (2007).

The Polish steel mills entered the second decade of the modern century with ambitious investment plans. Currently, the Polish mills are considered steelworks 3.0, similar to many European mills (Peters, 20016), but strategies towards steelworks 4.0 are being adopted and implemented in the mills. The steel sector, similar to other process industries, is gradually implementing changes. The change strategies towards Industry 4.0 are long-term plans [23]. The performed analysis of the digitalisation of metallurgy in the period from 2020 to 2018 indicates that users of the new IC technologies are in the minority (except for the use of computers and Internet access). The development of Industry 4.0 technology in the metallurgy in Poland, in terms of the share of companies using it, is at the initial stage (the proposed colloquial name "crawling").

For comparison, we refer to research carried out on the German market—a report by PwC about the Stahlmarkt [123]. This report states that companies in the steel and metal sector (on the German market) considered innovation as the basis for building a competitive advantage. As many as 79% of surveyed decision-makers from the metal sector stated that their company pursues a specific innovation strategy (the comparative value in other industries was 63%).

The steel sector is also distinguished by the high effectiveness of implemented innovation strategies, as confirmed by the participation of 82% of metalworking companies compared to 64% of industrial companies in other sectors. The number of patent applications at the German, European and global patent offices has been increasing in recent years (doubled). In 2014, there were 4300 steel patents, compared to 1800 patents granted for the steel area in terms of the community market in the early 1990s. In 2010, the annual increase of patent applications doubled, with growth ranging from three to six per cent per year [123].

The reports of the countries are difficult to compare because the ranges of data are different (and cannot be compared), but a significant difference can be seen in a very mature market economy such as Germany as compared to Central and Eastern European countries, which only started their journey to a market economy in the 1990s [124]. There is a need to study the steel sector, because steel innovation is important for steel-consuming sectors (construction, automotive, machinery industry, metal goods and others).

Steel producers are strongly linked to other industrial sectors. The mentioned sectors are among the key sectors that are indispensable for the development of economies (share of value added in GDP). The entry of digitalisation into the new technology environment of Industry 4.0 requires a cautious approach [125]. It is no longer the traditional digitalisation that accompanied the third industrial revolution. This new digitalisation is more smart and intelligent; however, as cited by Darvishi et al. (2021) [126], currently, many technical aspects have not yet been explored in terms of usability, e.g., sensor defect detection.

Research into the architecture of IT control systems is ongoing. The already-cited team of Darvishi et al. [126], who researched sensor validation, proposed a model built upon a series of neural-network estimators and a classifier. The cascade neural network used to identify sensor reading faults was also applied by Napolitano et al. 2000, Campa et al. 2002 and Hussain et al. 2015 [127–129]. The issue of sensor data quality and related technologies is a research topic in specific sensor application areas. The following are a few examples of these research areas: marine [130], wastewater infrastructures [131] and nuclear power [132].

In addition to the researched areas of technology, the study of faulty data readings by sensors is also the subject of research for specific machines or installations, e.g., the gas turbine engine [133]. The cost of information obtained from external sensors is also an important aspect (sensors can either be internal company sensors or more informative external sensors); this issue was considered by van Staden et al. (2021) [134]. Nowadays, legislative fit and data security is also an issue of the analysis of cyber security. In the times of Internet of Things, when all machines are connected between themselves using the Internet [134–138], cyber security is a very important issue for the continued assurance of the development of production processes.

On the basis of the analysis made in this paper, the following conclusions can be formulated:

- The level of digitalisation of the steel sector in Poland is differentiated in terms of the use of particular ICT tools in enterprises and is as follows: the share of enterprises having computers is almost 100%, while 98.5% of the Polish steel enterprises are Internet users, of which 92% are broadband Internet users and 59.5% of the researched enterprises are mobile Internet users;
- Cloud computing—the purchase of this service by steel companies is small because it is a new ICT tool; 12.6% of metallurgical users have been reported to use it so far;
- ERP and CRM are popular information systems; these systems are installed in every third company (metallurgical companies also use SAP systems);
- The relation of digitalisation to innovation is 2 to 1;
- Investments in the steel industry in Poland are financed mainly from the companies' own resources (86% share of the total financial sources).

On the basis of the results obtained in the analysis, an attempt was made to confirm the hypothesis on the relation between digitalisation and innovations. However, a limitation was the limited scope of the static data, which made it impossible to examine the correlation between digitalisation and innovations in the examined sector, where innovativeness referred to new and improved products and new or improved processes.

The data support our hypothesis because we have found the existence of the relationship between digitalisation and innovation, which is 2 to 1 in favour of digitalisation. Statistical data on Industry 4.0 technologies are reported residually (narrow data range). Industry 4.0 technologies are new technologies that are gradually entering the steel sector, and the number of users of, e.g., users of cloud computing and 3D printing remains small (12% for cloud computing and 7.5% for 3D printing), though it is growing.

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Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AI	Artificial Intelligence
AMP	ArcelorMittal Poland
BF	Blast Furnace
BFN	Blast Furnace Network
BOF	Basic Oxygen Furnace
CAx	Computer Aided
CMC	Commercial Metals Company
CPPS	Cyber Physical Production Systems
CRM	Customer Relationship Management
DSL	Digital Subscriber Line
DTC	Dynamic Capability Theory
EC	European Commission
ERP	Enterprise Resource Planning
FP7	Seventh Framework Programme
GDP	Gross Domestic Product
GUS	Głowny Urząd Statystyczny—Statistics Poland
HIPH	Hutnicza Izba Przemysłowo-Handlowa—Polish steel Industry
IC	Information and Communication
ICT	Information and Communication Technologies
ID	Identification number
IoT	Internet of things
IT	Information Technology
KET	Key Enabling Technologies
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LED	Light-emitting diode
M2M	Machine to Machine
MES	Manufacturing Execution System
ML	Machine Learning
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
PLN	Polish Zloty
PUDS	Polska Unia Dystrybutorów Stali—Polish Union of Steel Distributors
QR	Quick Response
RFCS	Research Fund for Coal and Steel
RFID	Radio Frequency Identification
SAP	Systems, Applications and Products in Data Processing
SDSL	Symmetric Digital Subscriber Line
SR	Social Responsibility
VPN	Virtual private network
WCM	World Class Manufacturing

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