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How Steel Mills Transform into Smart Mills: Digital Changes and Development Determinants in the Polish Steel Industry

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Abstract:

Purpose: *The research question is how do steel mills transform to smart mills. This is the purpose of this paper.*
Approach/Methodology/Design: *Dynamic technological development forces enterprises to introduce changes in production. Enterprises expect digital production to enable them to optimize production more than ever before. The changes concern especially the adaptation and integration of digital technologies. The article is about key areas and determinants of change in the steel industry in Poland on the way of steel mills to digital technologies. The article is a compilation of theory and practice. On the basis of statistical information, data on key areas of change in the steel industry in Poland was presented in the paper.*
Findings: *At the current stage of transformation of the steel industry in Poland to Industry 4.0, steel mills are investing in technologies to process data in real time and acquire IT systems along with computer services to compile solutions (installations), combining steel production technologies with IT applications. Steel production technologies are entwined with IC systems with access to IoT, Big Data and Cloud Computing solutions. Compact OT (operation tech) and IT (informatics) structures are emerging, which in the future will create a cyber-physical steel production system (CPSPS: Cyber-Physical Steel Production System).*
Practical Implications: *The analysis and evaluation carried out in the article shows that a key factor affecting the development of this sector is the way to Industry 4.0. Presented analysis in the paper can be used by companies in the steel sector to build a development strategy towards Industry 4.0.*
Originality/Value: *The topic of the article is very important because it focuses on changes and determinats in the Polish steel Industry unnder the conditions of the Fourth Industrial Revolution.*

Keywords: *Digital technologies, ICT, steel industry, Poland, Industry 4.0, steel mills and smart mills.*

JEL classification: *D25, L61, O33.*

Paper Type: *Research article.*

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1. Introduction

Dynamic technological development forces enterprises to introduce changes in production. The changes concern especially the adaptation and integration of digital technologies. Prahalad and Krishnan (2010) suggest that technological innovations are the essence of maintaining a competitive advantage. Producers want to optimize key processes through innovation. The transformation of industry in the fourth industrial revolution to Industry 4.0 relies on digital technologies (Kagermann, 2015; Kagermann *et al.*, 2011).

Digital technologies make it easier for enterprises to use the potential of digitization to improve business and production processes. Modern information and teleinformation technologies create conditions for the development of digital business around the world. Digitization integrates technologies in individual areas of economic activity on a global scale. Digital technologies connect processes inside enterprises and in business networks. Enterprises expect digital production to enable them to optimize production more than ever before (Davies, 2015; Stock and Seliger, 2016; Tihinen *et al.*, 2017).

Metallurgy is one of the industries transforming to digital industry, and the period of change has already begun. The title of the article posed the question: How do steel mills transform to smart mills? The answer to the question is the aim of the paper. The author presented the key fields of changes along with the factors that detriment them. The article is a compilation of theory and practice. Information on key areas of change in the steel industry has been linked to data on ICT in steel industry. The source of the data were tables of Statistics Office in Poland (in Polish: GUS) and Polish Steel Association (in Polish: HIPH). The author, on the basis of secondary information, developed her own charts and considered the changes in the Polish steel sector towards Industry 4.0.

The paper is organized as follows: a theoretical backgroud is presented in section 2; section 3 presents the key changes in the field of using ICT in steel industry in Poland, section 4 is about key determinants of the changes analized in section 3; the 5th section summarizes the paper.

2. The Theoretical Background

The digitization of industry is strongly supported by the European Union. In 2016, the European Commission launched initiatives supporting the digitization of European industry - the policy of Digitizing European Industry (DEI). Industry digitization aims to help enterprises improve processes, products and services. The following were established in the EU: Competence Centers, Digital Innovation Hubs (DIH), Incubators, Platforms 4.0 and other forms of support for the transformation of the European industry. The assumption of the European Commission in the digital transformation policy is the creation of ecosystems. Entities from various backgrounds (research organizations, incubators, government authorities, investors, scientists, etc.) support enterprises in digital transformation. Digital development is the goal of individual countries in the European Union. Governmental and regional authorities (in line with European Union policy) support the digitization of industrial sectors. Enterprises use the knowledge and experience of organizations that create various support structures for the development of Industry 4.0 (Santos *et al.*, 2017). Digital Innovation Hubs enable organizations to test technologies suitable for their products and business processes. Organizations also use financial instruments, e.g., lower taxes, loan guarantees (Branca *et al.*, 2020). The support environments created by politicians for the growth of digitization in industrial sectors are opportunities for the development of digitization.

Manufacturing companies have been introducing digital innovations for many years. In Industry 4.0, however, the point is for technological solutions to build cyber-physical production systems. Industry 4.0 is a set of technological solutions dominated by artificial intelligence and cyber-physical systems (Schwab, 2016). The technologies promoted at the European level are: Internet of Things (IoT) - i.e., a network of physical devices embedded in elements enabling connection with other devices, data collection and data exchange (Ashton, 2009). Artificial Intelligence (AI) with autonomous industrial robots (technologies have ability to learn and logical thinking) (Wang *et al.,* 2016), big data with open data and mega data, cloud computing and cloud computing with data storage and access to computer software, etc.), modeling and simulation (M&S) - a set of tools to solve problems based on the optimal scenario of process operations (Gubáni *et al.*, 2017), 3D printing technologies and many others. Each enterprise builds own path to Industry 4.0. Top management decides about changes towards Industry 4.0. New directions of changes are written in enterprise strategy. Some projects are small, others are big (Frank *et* al, 2019). Some of them are realized in production process, others in processes of storage, sale, distribution etc., (Gajdzik *et al.*, 2021a).

The steel industry is undergoing a massive digital transformation. Digitization in mills combines steelmaking technologies into cyber-physical systems (CPS) (more about architecture of the systems in Lee *et al.* (2015). The changes focus on two main, often overlapping directions:

- advanced tools for optimizing the production chain in the steel industry,
- the best technologies for low-carbon and sustainable steel production.

Steel is the basic material for other industries: automotive, construction, machinery and equipment manufacturers. The high demands of the steel-consuming markets force steel mills to innovate. The steel (metal) industry together with the machine industry are among the Top 10 innovative industries according to IFR. Technological and process changes in the steel industry intensified at the end of the 1990s and are still ongoing. Digital technological solutions are used, among others for monitoring the operation of devices, technological service, maintenance, control of production parameters, technology control, production tracking, etc. Maintenance by using new technologies is realized by operators of machines or by professional teams. Both autonomous and professional maintenance led to better machine efficiency (Gajdzik, 2014). Steel smelting technologies, e.g., blast furnace, are supervised and controlled using IT systems. AI is based on the creation of data between computers. This is also known as peer-to-peer computing technology.

In AI, some of this technology includes "blockchain", encrypted, decentralized, and time-stamped data history. Equipment in steel and rolling mills is equipped with sensors that provide real-time process data and assist equipment operators in controlling operations. Modern rolling and metallurgical processes require new forms of interaction between machines and people. In the future, people's work (physical activities) will be greatly reduced. Many activities in the smelters will be taken over by robots to reduce the risk of injury to people. Automation of activities will reduce the number of equipment operators in steel smelting and steel rolling processes.

Technological lines, called Continuous Steel Casting in steel mills, are a significant facilitation for the automation of steel smelting and rolling mill. Many technologies in the steel industry are monitored by information and computer systems. Popular IT systems in mills are ERP and CRM (Gajdzik and Wolniak, 2021). The first of the systems is used in procurement and resources of the investor, the second is used for customer service. Connecting physical objects with digital production support systems is the basis for digital steel production (Murri *et al.*, 2019; Neef *et al.*, 2018). Digital solutions in the steel industry are integrated into the material area of the steelworks' activity (Herzog, 2017). IC systems are integrated into both steel production technologies: the Furnace-Basic Oxygen Furnace (BF-BOF) and the Electric Arc Furnace route (EAF). The technologies are key steel smelting technologies used in steel mills around the world.

ICTs are in supply and storage processes, and in distribution and sales processes. Companies cooperating with steel mills create an integrated IT and computer environment with them (Gajdzik and Wolniak, 2021a; 2012b). Integrated technologies (OT and IT) streamline the steel chain, from iron ore extraction, through steel production, to the distribution of steel products. Using the new technologies, steel mills want to improve the quality of steel products (Gajdzik and Sitko, 2014).

The implementation of digital solutions strengthens the effectiveness of devices, including in the areas of consumption of raw materials and resources in production processes, and in production logistics (Pichlak, 2020). Cooperation in value chain in realized according to model SECI. IC technologies improve the forms of cooperation between enterprises (Grzybowska, and Gajdzik, 2014). In the steel industry, besides simultaneous cooperation, competition between enterprises takes a form of network connections (Cygler *et al.*, 2014).

The use of cyber technology in steel mills is focused on comprehensive support for all related processes, including, material management, inventory level control, full synchronization of raw material supplies (semi-finished products and products) with production plans, control of production costs, etc., (Peters, 2017). Modern production equipment, equipped with a wide spectrum Wireless sensors, controllers and embedded software systems are "participants" in the improvement of processes. By dynamically configuring production processes, intelligent technologies are conducive to meeting the key principles of sustainable production, in accordance with the principles of 3R (Reduce, Recycle, Reuse) (Kiel *et al*., 2017). Changes in enterprises towards Industry 4.0 have to be realized according to sustainability (Gajdzik *et al.,* 2020).

In the future, the steel and metallurgical industries may change in three ways:

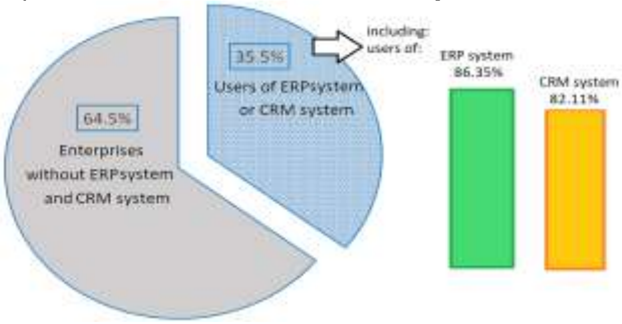
- machine learning can simplify manufacturing processes while improving steelmaking operations,
- virtual reality (VR) could enable virtual operations in plants, allowing for the creation of new business models,
- blockchain could make it possible to track verified materials when purchasing, such as recycled steel.

3. The Fields of Digital Changes in the Steel Industry in Poland

In the digital industrial environment described in section 2, steelworks in Poland operate. The Polish steel industry, in terms of the volume of steel production, ranks 5th on the European Union market (World Steel Association, 2020). The average annual steel production in Poland amounted to 9 million tonnes. The steel industry in Poland consists of steel producers and enterprises producing steel products. The presentation of the areas of changes in the steel industry in Poland towards Industry 4.0 was carried out on the basis of research in Polish steel Industry (section: metal production). In 2019, this section, according to the Polish Classification of Activities (abbreviation in Polish PKD), numbered 5,717 enterprises. The key technological trends on the Polish steel market are: computerization of processes using the following systems, ERP, CR, use of the electronic document exchange system with business partners (EDI), robotization of processes, use of Big Data, IoT and Cloud Computing services, additive production, e.g., printing 3D and other technological and digital solutions that cooperate with the technologies of steel smelting and rolling of steel products used in steel mills.

Based on the analysis of data from the Central Statistical Office (in Polish: GUS), it was found that almost all enterprises (97%) out of 5,717 enterprises entered in the register of steel sectors in Poland use the Internet for business purposes. More and more enterprises have access to broadband (87%). In 2019, 35.5% of enterprises out of 5,715 registered in the steel sector (production of metals and metal products) in Poland used either the ERP system or the CRM system (Figure 1). In the steel sector in Poland, there are more users of the ERP system than the CRM system. Among 2,029 enterprises with IT and computer systems, 86.35% of enterprises used ERP systems. The advantage of ERP system users over CRM system users was 4.2% (Figure 1).

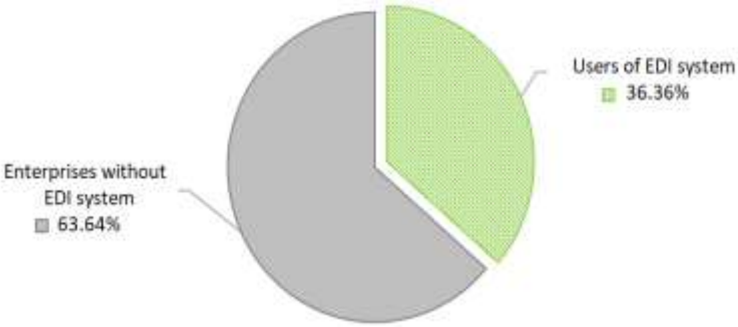
Figure 1. *Users of ERP and CRM in the steel industry in Poland*



Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

In business transactions, steel mills use EDI platforms that replace paper documents. EDI solutions ensure smooth and fast data transmission with business partners in the steel chain. Electronic exchange of EDI documents improves the cooperation of steel producers (steel products) with customers and suppliers. The purchasing and selling processes are taking a digital form. In Poland, over 36.4% of enterprises use the Infinite EDI solution. EDI platforms also archive electronic documents. The most commonly used functions are: transaction control, document transfer, electronic document handling: e-invoice, orders and many others. The number of EDI system users in the Polish metal sector is slightly greater than the number of ERP or CRM system users. In 2019, the advantage of EDI over ERP and CRM systems was 0.86% (Figure 2).

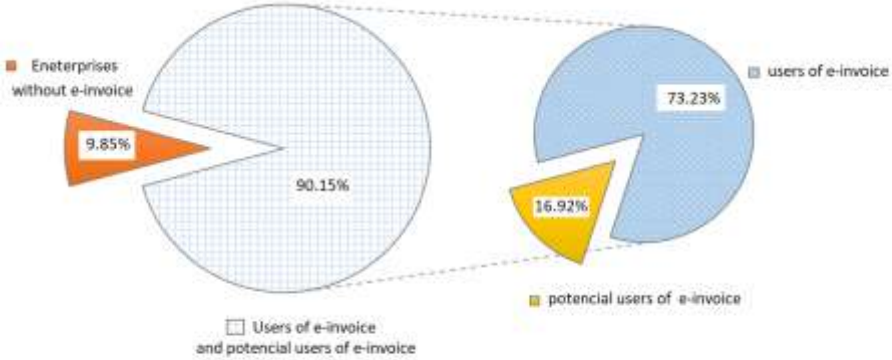
Figure 2. *Users of EDI in the steel industry in Poland*



Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

In the total number of enterprises in the metal sector (5,715), 73.23% of the steel industry enterprises use e-invoices. The research also found that another group of enterprises (16.92%) is already prepared for electronic invoice processing. In total, users of e-invoices together with enterprises starting electronic document processing constitute 90.15% of all enterprises (Figure 3).

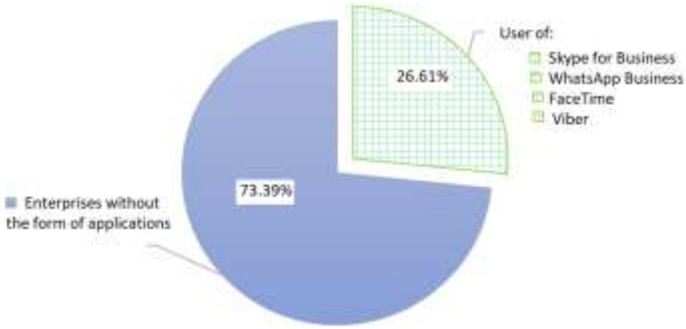
Figure 3. *Users of e-invoice in the steel industry in Poland*



Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

In 2019, in the Polish steel sector, 26.61% of enterprises used applications for conducting audio or video calls over the Internet, such as: Skype for Business, WhatsApp Business, Facebook, Viber (Figure 4).

Figure 4*. Users of Internet communicators in the steel industry in Poland*

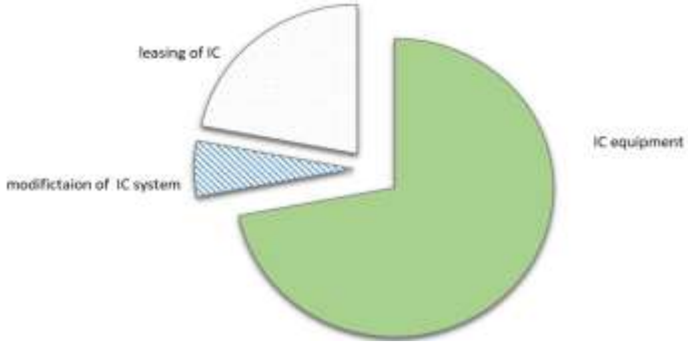


Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

IT systems in the metal sector are constantly being expanded and improved. The steel mills have either their own development of modifications to the systems in use or the acquired software modules for the system in use. The steel mills are either the owners of the IC equipment or the lessee.

In 2019, the share of leasing in the total gross value of expenditure on information and communication technologies incurred by financial steel enterprises was 6.47%. The share of the value of IT or ICT equipment in the total gross value of expenditure on information and communication technologies incurred by enterprises in 2019 was 72.40%. The structure of the remaining shares is shown in Figure 5.

Figure 5. *Value of ICT in the steel industry in Poland*

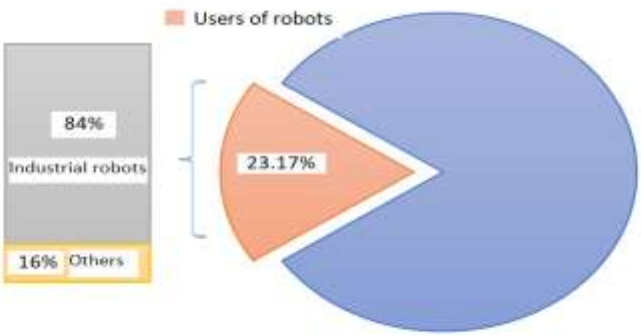


Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

In 2019, out of the total number of enterprises in the steel sector, the share of enterprises using industrial robots amounted to 19.46% (Figure 6). Industrial robots in the total number of enterprises using robots for business purposes accounted for 83.99%. The robots are used for:

- protection, observation, supervision, e.g., with the use of autonomous drones,
- transport of people or objects, e.g., with the use of autonomous vehicles,
- cleaning or garbage collection,
- work in the warehouse, e.g., stacking pallets,
- assembly work,
- customer service,
- assembling the structure or repairing damage.

Figure 6. *Users of robots in the steel industry in Poland*



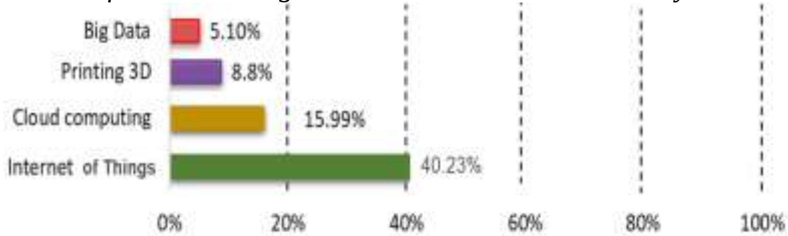
Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

In 2019, steel sector enterprises used IoT (40%), cloud computing (16%), 3D printing (8.8%), Big Data (5%) - Figure 7. Examples of the use of new technologies:

- 3D printing - prototype printing, machine parts, construction elements for own purposes or for other enterprises (commercial offers);

- Big Data - communication M2M, using of digital sensors and RFID tags, machine learning and transfer data (service of open data) etc;
- cloud computing - office software is purchased through the cloud and storing files (documents) in the cloud, IoT - communication M2M, machine learning.

Figure 7. *Users of new technological solutions in the steel industry in Poland*



Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

4. Key Determinants of the Steel Industry Development in Poland towards Industry 4.0

Many factors influence the transformation of steel mills to smart steel mills. There are factors that depend on and are independent of enterprises in the business environment. In the last two decades, three main groups of determinants of change have developed in the vicinity of steel mills. The first group consists of technologies of the future, setting the directions of changes in steel smelting processes, e.g., DRI (Direct Reduced Iron) technology. The second group consists of economic and ecological determinants. This group is made up of factors that mills are able to classify in terms of costs or benefits resulting from the introduced technological innovations.

In green economy, the group of economic factors is strongly related to environmental conditions, including legal restrictions that reduce the negative impact of the steel industry on the environment. The Community's sustainability policy defines sustainable business strategies. In line with the assumptions of Green economy, steel mills strive for sustainable steel production. The law in force forces steel mills to abandon coal in favor of renewable energy. Considering the depletion of natural resources, steel mills must also replace iron ore with steel scrap. In the future, in Poland, the share of steel obtained in the BOF technology (steel smelting from iron ores) will decrease and the share of steel production in electrical processes (steel obtained from steel scrap) will increase.

Currently, in Poland, the production of steel according to technological processes is in the ratio of 1:1. Micro-mills with EAF technology will displace mega-mills with BOF technology. The third determinant is the human factor. Along with technological progress, the labor market changes, some jobs are disappearing, others are emerging. Industry 4.0 will create new jobs for ICT operators. The selection of three key groups of determinants of the transformation stell mills towards smart steel factories was created on the basis of four criteria forming the acronym PEST (Political, Economic, Social, Technological).

4.1 Technologies of the Future

The transformation of the steel industry to Industry 4.0 requires enormous investment outlays and is associated with higher operating costs. Technological change from traditional metallurgy towards metallurgy based on electricity and hydrogen is inevitable. Traditional blast furnace technology / oxygen converters / will be changed by Electric Arc Furnace (EAF) technology. EAF technology will work in combination with DRI installation. In the future, DRI technology will be based on the use of green hydrogen produced from renewable energy sources.

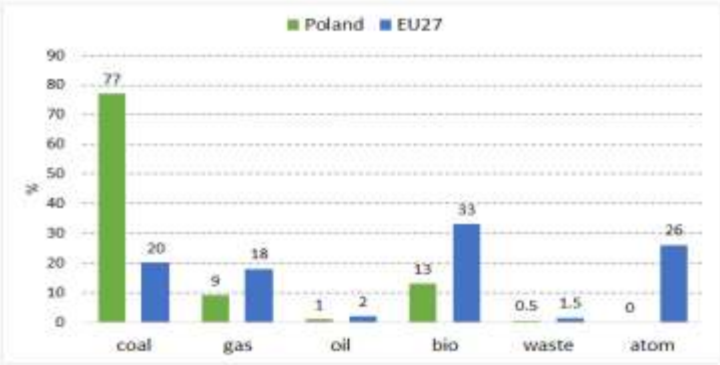
During the transitional period under DRI, it will be necessary to use solutions based on natural gas and coke oven gas. Investments planned by steel mills in Poland will require investment in billions. The largest company on the Polish steel market - ArcelorMittal Dąbrowa Górnicza - plans to build EAF and DRI installations by 2028. The transition to the DRI technology in the case of half of the steel production in Poland (on average, Poland produces about 9 million tonnes of crude steel) will involve the need to provide 4.5 billion Nm3 of hydrogen per year. With the current technology, about 20 TWh of electricity is needed to produce such volumes of hydrogen in the electrolysis process (HIPH, 2021). In the world, the DRI installation is used (on a larger scale) in steel mills on the Asian continent. In 2017, the global metallurgy produced 75 million tons of steel (top 20) in DRI technology (World Stseel Association, 2019).

4.2 Green Economy with Green Energy and Recycling

The implementation of climate goals results in an increase in electricity costs and additional regulatory and tax burdens for steel enterprises. Steel mills need to increase energy efficiency (Arens *et al.*, 2016). The Polish steel industry competes on the global market with steel mills from countries that are not burdened with additional environmental costs. The steel industry is the most exposed to the phenomenon of carbon leakage (among other industrial sectors). High prices of CO_2 emission allowances translate into high dynamics of electricity prices.

Distribution costs also affect the costs of providing energy. The energy mix in Poland is still not adjusted to the European climate policy (Figure 8). Coal is still the primary source of energy. Coal as an energy carrier and reducing factor in steel mills must be replaced with natural gas, coke oven gas and electricity, and ultimately with green hydrogen. The Polish policy until 2040 (PEP2040) assumes the replacement of coal with another fossil emission fuel – natural gas. In Poland, renewable energy sources are insufficiently developed.

Figure 8. *Mix of energy sources in Poland compared EU27 (2018)*



Source: *Own study based HIPH, 2021.*

Technological investments (BAT) implemented for years in steel mills improve the energy efficiency of steel mills in Poland (Gajdzik and Sroka, 2021; Gajdzik *et al.*, 2021b; Wolniak *et al.*, 2020). The technologies already used in steel mills lead to a reduction in direct CO_2 emissions. Planned technological changes may reduce pollutant emissions by up to 95%. The Polish Steel Association predicts that the decarbonisation of the steel industry is associated with a significant increase in electricity consumption (in the initial period of transformation of the steel industry), according to estimates - up to approx. 28 TWh per year. The promoted micro steel mills with EAF technology will increase the electricity consumption of the metallurgy industry from today's 6 TWh to 8 TWh per year (estimates of the Polish Steel Association, Katowice, Poland).

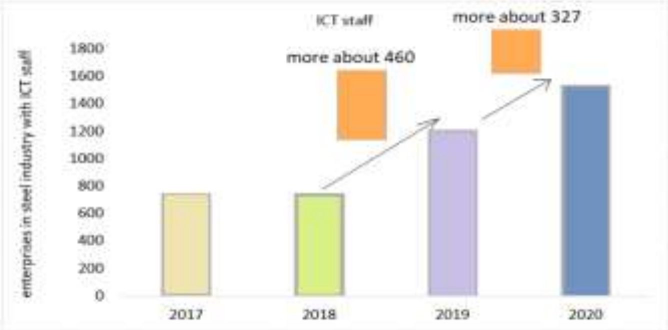
In order to make the necessary technological transformation of the integrated process (the primary one based on iron ore) ensuring the reduction of CO_2 emissions to a level that gives a chance to maintain international competitiveness, investments worth several dozen billion zlotys are necessary. Otherwise, the crude steel production capacity in Poland may decrease in the next few years. In steel industry there a lot of environmental aspects that will be improved to be more sustainable steel mills (Gajdzik, 2009). Steel mills expect Industry 4.0 technologies to improve the steel production process so that production becomes both sustainable and smart.

4.3 IC Staff

The development of technology results in changes in the competences of employees. Current and future employees must adapt to digital transformations and changes in production processes (Industrial Revolution 4.0), as well as to new working methods and ways of organizing work 4.0. In Industry 4.0, there is a need to strengthen employee specialization and horizontal skills. The employee competency profile 4.0 is modular and multi-tasking. Changes in employee qualifications are a challenge for many metallurgical professions. At smart steel mills, almost all employees will move away from difficult activities in favor of ITC service.

Currently, the steel industry in Poland employs 24,000 people. Employment is changing the number of steel workers is decreasing and the number of ICT workers is increasing. According to GUS data, in the steel sector in Poland, the number of enterprises employing ICT pearsons has increased significantly in the last 3 years (Figure 9).

Figure 9. *Enterprises with ICT staff in the steel industry in Poland*



Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

More enterprises need employees to operate ICT devices, approximately 2% annually of enterprises from the steel sector in Poland recruit employees with ICT qualifications. In the Polish personnel market, the problem is the lack of formal education or certificates in the field of ICT / IT, and the lack of candidates with candidates of relevant work experience. In such a situation, almost 80% of enterprises use the services of external companies from the IT industries (details in Figure 10).

Figure 10. *Enterprises with indoor or outdoor ICT staff in the steel industry in Poland*

Source: *Compiled by the author based on Central Statistical Office (GUS), 2020.*

5. Conclusions

At the current stage of transformation of the steel industry in Poland to Industry 4.0, steel mills are investing in sensors mounted on production machines to process data in real time and acquire IT systems along with computer services to compile solutions (installations), combining steel production technologies with IT applications. Steel production technologies are entwined with IC systems with access to IoT, Big Data and Cloud Computing services. Compact OT and IT structures are emerging, which in the future will create a cyber-physical steel production system (CPSPS - Cyber-Physical Steel Production System).

Conclusion 1: More than 1/3 of enterprises in the steel market in Poland use or ERP system or CRM system. This share can be considered significant. ERP and CRM systems are popular systems on the Polish steel market. IC systems support the control, monitoring, process control and management of key customers in accordance with the pull strategy (production to order).

Conclusion 2: More than 1/3 of enterprises in the Polish steel industry use EDI. The number of EDI users is comparable to the number of ERP and CRM system users. Both ERP and CRM systems as well as EDI are crucial for the digitization of processes in the steel industry. The primary electronic document in the steel industry is e-invoice: 73.23% of enterprises use electronic document processing and 17% of enterprises are about to start using e-invoice in commercial transactions.

Conclusion 3: The share of steel mills using modern forms of communication (analyzed in Fig. 3), although it does not exceed 30%, can be considered significant due to the various forms of instant messaging used in steel mills.

Conclusion 4: The share of enterprises using industrial robots is 19.46%. The steel mills use industrial and service robots. The scope of tasks assigned to industrial robots in steel mills varies greatly from property protection to steel production and work in warehouses.

Conclusion 5: Enterprises in the Polish steel sector use the increasingly popular Industry 4.0 solutions:

- 40% of enterprises use IoT
- 16% of enterprises use cloud computing
- 8.8% of enterprises use 3D printing
- 5% of enterprises use Big Data.

Conclusion 6: The determinants of the transformation of steel mills into smart steel factories are new steel production technologies: DRI (or EAF with DIR) and the need to replace coal with renewable energy. Environmental restrictions force steel mills to change technology. New technologies are expensive. Steel mills have to factor in high investment costs in their development strategies. The steel mills (ArcelorMittal Poland) plan to achieve sustainable production using DRI technology by 2030.

Conclusion 7: The steel industry is the most (among other industrial sectors) exposed to the phenomenon of carbon leakage. High prices of CO_2 emission allowances translate into high dynamics of electricity prices. Distribution costs also affect the costs of providing energy. The energy mix in Poland is still not adjusted to the European climate policy.

Conclusion 8: Along with the development of IC technology, enterprises in the Polish steel industry report a need for IT and IC employees. The number of enterprises looking for new staff is growing every year. The demand for IC / IT staff is greater than the supply, which is why steel mills use the services of IT companies.

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