Blueprint "New Skills Agenda Steel":

Industry-driven sustainable European Steel Skills Agenda and Strategy (ESSA)

Digital Transformation in European Steel Industry: State of Art and Future Scenario

Deliverable D2.1

Version 1

(Status: 30.09.2019)

Project acronym:	ESSA
Project title:	Blueprint "New Skills Agenda Steel": Industry-driven sustainable European Steel Skills Agenda and Strategy
Project number:	2018-3059 - 600886-EPP-1-2018-1-DE-EPPKA2-SSA-B
Coordinator:	
Funding Scheme:	Erasmus+
Due date of deliverable:	30.09.2019
Actual submission date:	30.09.2019
Project duration:	01.01.2019 – 31.12.2022 (48 months)
Work package:	WP 2 – Technological and Economic Development and Foresight
Work package leader:	CSM SpA
Authors:	M. Murri, E. Streppa (CSM SpA) V. Colla, B. Fornai, T. A. Branca (SSSA)
Dissemination level:	Public

Co-funded by the Erasmus+ Programme of the European Union

Summary

The current technological transformation in the European industry is driven by seven drivers of changes (as listed in ESSA project):

1. Advanced manufacturing (Industry 4.0)
2. Advanced materials development
3. Complex and global supply chains
4. Market competition and over-capacity
5. Life cycle design, pollution prevention and product recyclability
6. Decarbonisation and energy efficiency
7. Evolution of customer requirements. ESSA thus constitutes an industry driven European technologies for low-carbon production.

However, digitalization can be considered the main driver that directly impacts on the advanced manufacturing and transversally affects all the others. As consequence, it can be said that the technological transformation in the European Industry is driven by digitalization, aiming mainly to increase the production efficiency and sustainability in order to reduce the industrial environmental impact. That is particularly true for the energy-consuming industry, like the steel industry. The digital transformation of the steel production mainly concerns the application of the related technologies on the steel production processes, where the ongoing technological developments are focused on two fields: 1) advanced tools for the optimization of the whole production chain and 2) specific technologies for low-carbon production.

Starting with some necessary definitions, next paragraphs describe the current state of this technological transformation with an analysis of the main developments funded by EU Research Programs achieved in the above fields. In addition, the analysis of the Best Available Techniques (BAT) document provides information, mainly based on the application of digitalization systems, in particular in the Energy management, Water and Wastewater management and in some production processes. The application of BAT aims at achieving continuous improvements in the steel sector, in particular regarding quality, costs, energy consumption and environmental performance. In this context, digital technologies help to reach these objectives, adapting and integrating them with the traditional ones and with the new process. For this reason, the analysis of this document can be a good starting point to understand the innovative and emerging techniques for the steel production processes.

The effects of digitalization on the steel industry workforce as well as the future economic developments are also described in the following paragraphs.

Concerning the methodology, this deliverable has been prepared following an integrated research approach. It foresees to collect all the necessary information through desk research (European funded projects and literature) and a survey addressed to steel companies. To this aim, an explorative questionnaire has been launched to gather specific information directly from steel industry.

The current version of the deliverable is based exclusively on the desk research, waiting for a significant sample of answers from the questionnaire addressed to European steel companies. This survey was launched at the beginning of June 2019, and made online available (https://cardiff.qualtrics.com/jfe/form/SV_cOVWH19wfk28kdL). Data collected from the survey will be statistically analysed in order to integrate the content of this deliverable with data from the field.

Definitions

Digitization, digitalization and automation are the three distinct, but merging concepts. Digitization and digitalization are closely associated. According to the Oxford English Dictionary (OED), the term "digitization" is defined as "*the action or process of digitizing; the conversion of analogue data (esp. in later use images, video, and text) into digital form*". On the other hand, the term "digitalization" is "*the adoption or increase in use of digital or computer technology by an organization, industry, country, etc.*" (Oxford English Dictionnary, 2016). "Digitalization is the use of digital technologies in order to change a business model and to provide new revenue and value producing opportunities." (Bloomberg, 2018). By summarizing, the term "digitalization" indicates the transformation of interactions communications, business functions and business models into digital ones. It concerns the use of "digital technologies" and digitized and natively digital data to achieve revenue, improve business, replace/transform business processes and create an environment for digital business. In general terms, "digitalization" consists in the integration of digital technology into areas of a business (i-SCOOP, 2016). The term "automation", mainly used in the industrial context, is defined as "*the use or introduction of automatic equipment in a manufacturing or other process or facility*" (Oxford English Dictionnary, 2016). In addition, from a technological perspective, Groover defines automation as "*the technology by which a process or procedure is accomplished without human assistance*" (Groover, 2001) (Schumacher, 2016).

The term Industry 4.0, introduced in 2011, refers to the fourth industrial revolution and produces interoperability, decentralization of information, real-time data collection and heightened flexibility. In order to understand the difference between the I3.0 and I4.0 it is important to underline the changes introduced in the previous Industry revolutions (Chan, 2019). In particular, the 1st industrial revolution refers to the mechanization of production performed manually by hand. In this context, steam and water power were used for mechanization of work. The 2nd industrial revolution concerned the transformation by the introduction of electricity in the various processes, allowing for mass production with assembly lines. The first electric assembly line was built in 1870. As far as the steel sector is concerned, it was characterized by the invention of the production area, the improvement of transportation technologies and the electrification of industrial processes as well as by the production of cheap steel through the Bessmer process and the introduction of the open heart furnace (Steel Sector Careers, 2019) The 3rd industrial revolution consisted in the use of Information Technology (IT) and computer technology to automate processes. In Industry 3.0, the processes were automated by using logic processors and IT. In particular, these processes operate automatically without human interference, but there is still a human aspect behind it, which should make corrections. In this period of transformation robots were used into the processes to perform the tasks previously performed by humans, resulting in manual

work reduction and in industrial output increase. Furthermore, it was characterized by the development of the work in assembly lines and factories, focusing on optimisation and the removal of production inefficiencies (Steel Sector Careers, 2019). Finally, the 4th industrial revolution (Industry 4.0) consists in the presence of new interconnected technologies in plant operations. In particular, it is based on enhancing automation and connectivity with Cyber Physical Systems (CPS), that include smart machines, storage systems and production facilities capable of autonomously exchange information, triggering actions and control each other independently. The information exchange, through the Industrial Internet of things (IIOT), is done by sensors working in real time and transferring data to a local server or a cloud server, where the analysis of the data is carried out by developing predictive models. They help the organization to anticipate some irregularities in the processes (Predictive Maintenance), thanks to the data (Big Data) captured by the sensors. The data analysis helps to maintain the processes as well as to improve manufacturing processes, material usage, supply chain and life cycle management of the product.

The basic difference between Industry 3.0 and Industry 4.0 is that in the second one the machines work autonomously without the intervention of a human while in the industry 3.0 the machines are only automatized. Similarly, in the Industry 4.0 the tool changes are automatic but all parameters, important to carry out the process, are recorded by hundreds of sensors and the optimum settings are carried out on its own, based on the large amount of data to compare and optimize the process.

1 Determination of the current state of the digital transformation of the European Steel Industry

1.1 Current state of the digitalization transformation in the European Industry

Companies are committed to be more and more competitive about globalization and intensification of competitiveness, the volatility of market demands, shortened innovation and product lifecycles as well as the increasing complexity around products and processes. According to Eurostat (Eurostat, 2018), Information and Communications Technologies (ICTs) have quickly become an integral part of how enterprises function and its extensive use has had a profound impact on how businesses run (e.g. the organisation of the internal communications, the sharing of the information with business partners, or a communication with the customers).

The digitalization is a central topic in the European industry, revolutionizing the design, production and organization of the global value chain as well as the distribution and payment of goods. The digital technologies promote new processes implementation along the entire value chain, through manufacturing and sales to services, concerning the use of a product, performed by research and development activities. For this reason, digitalization should be considered a holistic approach that covers all areas and functions of a company in order to exploit digital potentials and analyze each stage of its value chain. Digitalization is not a simple transfer from analog to digital data and documents, but it is the stronger networking between the business processes, the creation of efficient interfaces and the integrated data exchange and management (Bogner,

Voelklein, Schroedel, & Franke, 2016). According to (Commission, 2017), the future of industry will be digital. Digital transformation is the core of the ongoing industrial revolution. Some new Key Enabling Technologies (KETs) are represented by new generation of sensors, Big Data, Machine Learning, Artificial Intelligence (AI), Internet-of-Things (IoT), Internet-of- Services, Mechatronics and Advanced Robotics, Cloud Computing, Cybersecurity, Additive Manufacturing, Digital Twin. Their application will lead to develop new skills and new competencies as well as new business models, with the aim of achieving the production optimization. This can allow the manufacturing industries improving their competitiveness and efficiency, thanks to a higher interconnection and cooperation, sharing resources belonging to the industries, such as plants, people and information. The digitalization could be *ex novo* applied to a new plant, but, on the other hand, new technologies can be adapted to existing plants (Beltramini, Guarnacci, Intini, & La Forgia, 2017).

There are some challenges that industries are facing, such as:

- Ensuring continued responsiveness in order to fulfill the changing future demand and securing the market position;
- Preserving competitiveness through efficient process and cost structures, by also resources saving;
- Achieving a higher level of product quality;
- Maximizing plant performance, by also minimizing maintenance and low capital lock-up;
- Planning a flexible production by also guaranteeing timeliness of delivery (Reifferscheid, 2017).

These challenges can be achieved through the main features of the Industry 4.0, such as real-time capability, interoperability and the horizontal and vertical integration of production systems through ICT systems (Ibarra, Ganzarain, & Igartua, 2018). In addition, a flexible production is related to a flexible work and, consequently, to significant impacts on labour content and work organisation in the near future. In this regard, the workforce will need to have strong self-organisation and multi-tasking skills, according to education and lifelong learning initiatives in order to upgrade their existing skills.

The 4th industrial revolution is represented by the Industry 4.0, and both the European government and the individual Member States are promoting its policies. Such term, Industry 4.0, originally first appeared in Germany based on initiative of the German Government's High Tech 2020 Strategy (Commission, 2017). It is characterized by the spread of cyber-physical systems, AI, IoT, Big Data, Cloud Computing and M2M (Machine to Machine) communication. The complexity of the products manufactured is increasing, while their lifetime is becoming shorter, due to this complexity (Tokody, 2018). The bases for the development of "Industry 4.0" are an intelligent networking of machines, electrical equipment and modern Information Technology (IT) systems, with the main aim to optimise the processes and to increase the productivity of value creation chains (Stahl, 2016).

According to DIA (the European Digital Industry Alliance): "By 2025, Europe could see its manufacturing industry add gross value worth 1.25 trillion euros – or suffer the loss of 605 billion euros in foregone value added" (DIA, 2018).

The strategy of Industry 4.0 is based on the creation of intelligent factories, with upgraded manufacturing technologies and transformed by CPSs, the IoT and the cloud computing. In the Industry 4.0, the combination of embedded production system technologies with intelligent production processes aims at achieving a new technological age. In this context, Zhong, Xu, Klotz, and Newman (Zhong, Xu, Klotz, & Newman, 2017) carried out a study where three distinct manufacturing systems in Industry 4.0 have been highlighted and where each system is characterized by its proper challenges and opportunities. The first system is intelligent manufacturing system (IMS), also known as smart manufacturing: in this system, the employment of advanced manufacturing technologies and information permit to optimize the process of producing goods and services. The second manufacturing environment is viewed as IoT-enabled manufacturing, relying on the employment of smart manufacturing objects (SMOs) and the third major manufacturing is cloud manufacturing. The intelligent systems involve the development of competitive, sustainable, safe, economic, flexible manufacturing systems that can be organized into a functional network.

In different possible scenarios, manufacturers can generate revenue growth, as follows:

- Adopting more flexible production lines, robotics and 3D printing in order to manufacture products with higher customization;
- Implementing innovative business models, such as machines as a service;
- Deploying augmented reality to develop new services;
- Expanding their efforts to increase use for Industry 4.0 technologies, such as autonomous robots and plant-wide optimisation processes (in production and maintenance).

Nevertheless, according to an estimation performed by The Boston Consulting Group (BCG, 2015), the full shift to I4.0 could take 20 years. This can be due to the fact that the Small and Medium-sized Enterprises (SMEs) in the manufacturing companies do not frequently use the key enabling technologies, compared to the larger companies. The adoption of digital technologies strongly varies with company size. For instance, in Europe, only 36% of surveyed companies with 50-249 employees use industrial robots compared to 74% of companies with over 1000 employees (Jäger, Moll , & Dr. Lerch, 2015). Large enterprises have a scale advantage and more capacity to employ at least some IT/ICT specialists, i.e. data sharing infrastructure such as Enterprise Resource Planning (ERP) is much more common in large companies. However, SMEs are relatively active on social media (44 %) and the usage of mobile internet, allowing employees to exploit business application, is also becoming more common (European, 2017).

The new digital technologies, overall indicated as Industry 4.0, have been in depth affecting industries. Concerning the business processes, Industry 4.0 will have a positive effect, making them more efficient and productive. For instance, the product will extract greater value from data for usage-based design and mass customization, resulting in opening to new markets.

However, existing studies on the future manufacturing work identify also some negative aspects and risks. Pfeiffer (Pfeiffer, 2017) developed a new interpretation of Industry4.0, criticizing the facts that Industry4.0 arise in a new level of technological development and that Industry 4.0 will retain a competitive advantage in a global market. According to (Pfeiffer, 2016), it is not possible that Industry4.0 magically solve some societal problems that were once thought to be insoluble—not only in Germany but across the world, so Industry 4.0 should be considered as part of a newly

emerging global production regime. The diffusion of digital technologies will have also consequences for jobs and skills, especially for the low-skilled works and repetitive tasks (Botthof & Hartman, 2015) (Hirsch-Kreinsen & Ittermann, 2015). Typical low-skilled activities in industry include manual operation of specialized machine tools, shot-cycle machine feeding, repetitive packaging tasks, monotonous monitoring tasks and many warehousing and commissioning functions in logistics (Abel, Hirsch-Kreinsen, & Ittermann, 2014). Even if the digitalization may accelerate and, in some cases, further automate processes, the human experience is an aspect that cannot be substitute. For instance, in DROMOSPLAN project (DROMOSPLAN, 2016-2019), it is likely that the upskilling will occur and it seems that the low-skilled jobs that drones are designed to replace will actually remain. Therefore, there are some different scenarios and paths which will be depicted subsequently in the 3.1 paragraph. For instance, in the mining and metals industry, particularly in the emerging economies, the digitalization will potentially create skills and pay gap between the highly skilled digital workforce and the more traditional workforce (World Economic Forum, 2017). For this reason, significant changes in workforce skills, organizational structures, leadership mechanisms and corporate culture will be required.

Consequently, new digital skills are needed for workforce with competencies aligned to industry-specific requirements, in particular competences in science, technology, engineering, and mathematics. This involves both attracting and recruiting new talent as well as re-skilling current employees, by performing training programs. In addition, the workforce should get into the habit of continuous learning, not only simply based on their own professions but also on an interdisciplinary perspective. For this reason, it is not important to have a digital workforce for future, but a future workforce able to quickly adapt, and to innovatively think and work, in order to contribute to make the companies more competitive. In addition, the re-designing work processes will aim to reduce the skill mismatch between jobs and employees as well as secure their jobs in the coming years (Ustundag & Cevikcan, 2017). The new technologies could also improve the health and safety of workforce, due to the reduced human involvement in dangerous locations as well as the minimal and remote interactions in harsh environments. In addition, through the industrial digitalization, a greener production (increased energy efficiency and CO2 utilisation), new and safer jobs (by using robots for some hazardous work), innovative and more customised goods and services could be achieved (DIA, 2018). However, it is difficult to predict what will be the effect of the digital/digitized technologies, as, compared to the past, there is a high level of discontinuity in the implementation of the new technologies.

Furthermore, the European manufacturing industry is facing the global competition. For instance, China is progressively turning its attention to increase its industrial base and focusing on particular technologies and strategic value chains. The *Made in China 2025* (Liu, 2016) strategy is a ten-year plan, aiming to upgrade Chinese industrial base by focusing on 10 key industries. In the short and medium term this strategy can offer attractive opportunities for some European businesses, by providing critical components, technology and management skills. Nevertheless, in the long term, *Made in China 2025* can be an import substitution plan, particularly where Chinese companies can close the technology gap, compared to the European companies.

The challenge for some manufacturing companies is to evolve towards a new production system, increasingly flexible and tailored on the needs of customer. In this context, as the European steel

industry is competing on high value goods and high-quality products, integration and digitalization as well as speed, flexibility, quality, efficiency, security are the key features to maintain the competitiveness.

1.2 Current state of the digitalization transformation in the European Steel Industry

The steel sector in Europe has an annual turnover of EUR 166 billion and it is responsible for 1.3% of EU GDP. In 2015 it provided 328 000 direct jobs with an even greater number of dependent jobs. Although the steel industry remains a highly energy intensive industry, in Europe this sector is characterised by modern, energy and CO_2 efficient plants producing high value added or niche products for the world market, based on an outstanding R&D network (Commission, 2018). There are several ways in which the European Steel industry deals with digitalization and Industry 4.0. The industry workforce is ageing across the European Union and there are relatively fewer younger workers. On one hand, experienced workers have deep industry knowledge, but, on the other hand, they are less comfortable with digital tools or collaborative work and more resistant to training and learning. As companies are encountering a skill gap, among other actions, they are adapting their employment policies and practices to this situation. In the South East of Asia at a Tata Steel site, for instance, a substantial progress in refocusing its internal culture has been made in order to ensure a culture of multigenerational digital innovation: the company attempted to connect the younger workers generation under 30 with the older leadership team (Forum, 2017). EUROFER has highlighted its aims in order to find an alignment among the commitment of the European steel industry, the EU institutions, member states and relevant stakeholders on an EU Masterplan for a competitive, low-carbon European steel value chain (EUROFER, 2018). Peters (2017) argues that the digitalisation in the steel industry is a pre-condition for Industry 4.0, since Industry 4.0 is much more than digitalisation, Industry 4.0 is more a paradigm/philosophy than a technology. The European Commission communicates to the industry, Member States and EU institutions that in the steel sector the Europe cannot compete on the basis of low wages or deteriorating working conditions and social standards. Innovation, technology, quality and highly skilled people are the basis for competitiveness (Commission, 2018). A modern and competitive steel industry can be built and maintained by a highly trained workforce and a robust industrial base is essential for Europe's economic growth. Preserving industrial knowledge and a skilled workforce, in particular regarding young employees, is an important asset of EU's base metal industry (Commission, 2016). For example, in Czech Republic, the steel industries lag behind with respect to Europe by 20% in adopting new technologies and a quarter of domestic businesses do not have any comprehensive concept for digital transformation, even if in these last few years investments in modernizing production and in reducing environmental impacts have been done (E15.CZ, 2018). The investment on modernization production is related to the decrease of risks. The risk of reducing jobs, due to implementation and use of new technologies (elimination of hard work, modern machines replacing the older technologies, etc..) leads not only to the decrease of risks for workers, but also to changes in working time (i.e. changes in length of shifts, changes in length of working week and time off) (OS'KOVO, 2019).

1.3 Digitalisation as a support for the steel production

The steel production is a very complex process and the application of new technologies can really support the optimization of the entire production. The intelligent combination of process automation, information technology and connectivity enable the digitalization of steel production that goes far beyond the conventional automation of industrial production. According to (Herzog, et al., 2018), the digitalization of steel production can be considered as the consequent application of the new technologies to fulfill steel producer's requirements. Quality, flexibility and productivity are the focus topics, but, in addition, a production system needs to ensure the visibility of the real-time operational data and provides insight for a better and faster decision-making along the value chain, from product design, sourcing, to supply, logistics, distribution, sales.
In the last few years, some new changes in the digitalization are becoming apparent also in the steel industry, even if there is a big difference, for instance, between the assembly process for producing automobiles and the continuous process for making steel. It is very difficult and expensive to apply a decentralized, unmanned autonomous system, which is useful in assembling components, to the continuous process of steel, which involves liquid steel at high temperatures moving at high speeds (Cheong, 2016).
Looking in more detail at the processes affected by the Industry 4.0 , it can be said that the "downstream" production areas like rolling and coating/finishing and the interaction with customers in the organizational domain are expected to be the most affected ones (Neef, Hirzel, & Arens, 2018). The main challenges facing the European iron and steel industry on the way towards Industry 4.0 are related to legacy equipment, uncertainty about the impact on jobs and issues of data protection/safety. Furthermore, concerning the main barriers and driving forces about the implementation of the Industry 4.0, results from the survey carried out by (Neef, Hirzel, & Arens, 2018) showed that the technical barriers are considered less important than organizational issues. On one hand, the survey results showed that internal management represents the driving force for implementing the Industry 4.0 projects. On the other hand, technology and production, although important, are less crucial. In addition, technological innovations resulted to be driven by external parties, according to the tendency of the steel manufacturers to depend on external expertise and to cooperate with external partners for implementing Industry 4.0 solutions.

The lack of qualified personnel was a recurring issue during the interviews and was also rated as a very relevant in the survey. The main possible explanations on the current skill gaps overall perception are: the increased use of digital technologies, the lack of suitable educational programs, and the delays in training provision after the introduction of a technological innovation. Nevertheless according to (Steel Sector Careers, 2019) another challenge for the European steel industry is to attract and retain qualified personnel. This is due especially for three general aspects:

- Difficulty in integrating new technologies and processes among site workers, especially when it comes to older employees.
- A strong age gap between the workers that are currently employed and prospective employees creates knowledge transfer issues: this passage of knowledge is at risk, as the mismatch between the individuals leaving the industry and those entering it is increasing.

- A lack of investment in training and education from steelmaking companies as well as an insufficient amount of in-house training provided by companies, coupled with a general lack of talent management strategies.

Another barrier is related to the short payback requirements, which might affect the implementation, since Industry 4.0 projects are often expected to yield both economic benefits and contribute to company strategy. This is in line with results showing that steel manufacturers tend to rely on external expertise and cooperating with external partners when implementing Industry 4.0 solutions.

1.4 The Best Available Techniques (BAT)

The "Best Available Techniques (BAT) Reference Document for Iron and Steel Production" (Roudier, Sancho, Remus, & Aguado-Monsonet, 2013), according to the Directive 2010/75/EU of the European Parliament and Council on Industrial Emissions (Integrated Pollution Prevention and Control) (Directive, 2010), presents the results of an exchange of information between EU Member States, the industries concerned, non-governmental organizations promoting environmental protection and the European Commission. The main four routes for the production of steel are analysed in the document. The BAT Conclusions concern the processes involved in traditional routes of the iron and steelmaking and they are generally applicable.

The topics presented in the document have been analysed and the information, mainly based on the application of digitalization systems, have been extracted. A summary, focused on the main topics (such as Energy Management and Water and Wastewater management) as well as the iron and steel production processes where digital technologies are applicable, has been carried out.

ENERGY MANAGEMENT - In order to improve the energy efficiency in integrated steelworks, there are some important items. In particular, the online monitoring is focused on the digitalization. It is used for the energy flows and combustion processes. The stored data can be analysed and the online monitoring is used in order to avoid energy losses in the flares and combustion processes.

The continuous monitoring systems for all energy-related process parameters can be used to optimize process control and enable instant maintenance. On the other hand, reporting tools are useful in order to check the average energy consumption of each process. In addition, controlling energy aims at optimising energy consumption and cost savings. An energy controlling system is useful for comparing actual data with historical data.

In integrated steelworks, potential process-integrated techniques are used to improve energy efficiency through the optimization of process gas utilization. These techniques include the use of a computer-controlled calorific value control system.

Currently, in iron and steelmaking processes, monitoring and control computer-based systems aim to optimize the processes, to increase energy efficiency and maximize the yield, by also continuously adjusting online relevant parameters. Furthermore, the continuous monitoring of emissions, coming from relevant sources, can allow quantifying emissions and can control the abatement systems.

Concerning the Energy management**, BAT is focused on the reduction of thermal energy consumption by using a combination of the techniques,** such as process control optimization including computer-based automatic control systems, online monitoring for the most important energy flows and combustion processes.

In addition, **BAT is to reduce primary energy consumption by the optimization of energy flows and of utilisation of the extracted process gases such as coke oven gas, blast furnace gas and basic oxygen furnace gas.** On this subject, the optimization of the off-gases management in an integrated steelwork represents also a key aspect of industrial symbiosis. Although off-gases are currently used outside the steel production, such as in power plants, heat and steam production, the new developed approaches (e.g. Decision Support System) could be exploited for the application in other industrial sectors.

WATER AND WASTEWATER MANAGEMENT - As far as the **Water And Wastewater Management** is concerned, **BAT consists in the measurement or assessment of all relevant parameters necessary to steer the processes from control rooms through modern computer-based systems, that are focused on the continuous adjustment and on the optimization of the processes online, in order to increase the energy efficiency and to maximize the yield and to improve maintenance practices.**

BAT CONCLUSIONS FOR BLAST FURNACES - **BAT is focused on preheating the hot blast stove fuel gases or combustion air using the waste gas of the hot blast stove and on the optimising the hot blast stove combustion process.**

On this subject, the optimization of the energy efficiency of the hot stove, different techniques or a combination of them can be applied. Some of them are focused on the digitalization, such as the use of a computer-aided hot stove operation. In order to maximize benefits through the implementation of the computer-aided control a fourth stove, in the case of blast furnaces with three stoves, could be built.

BAT CONCLUSIONS FOR BASIC OXYGEN STEELMAKING AND CASTING - BAT is based on minimizing dust emissions through process integrated techniques, such as general techniques to prevent or control diffuse or fugitive emissions, and through the appropriate enclosures and hoods with efficient extraction and a subsequent off-gas cleaning, using a bag filter or an ESP. In order to prevent diffuse and fugitive emissions from the relevant BOF process secondary sources, among different processes management technologies, computer control and optimisation of the steelmaking process are included (e.g. preventing or reducing slag slopping).

Finally, in the "Best Available Techniques (BAT) Reference Document for Iron and Steel Production" **EMERGING TECHNIQUES** are defined as innovative techniques that have not yet been applied in the industrial sector on a commercial basis. On this subject, these techniques may be applied to the iron and steel sector. For instance, they include: novel pollution prevention and control techniques under development, that can provide future economic or environmental benefits; techniques to address environmental issues, having only recently gained interest to the sector.

1.5 Digitalization and RFCS Projects

The RFCS (Research Fund for Coal and Steel) represents the most important program for developing technologies in the European steel sector. Consequently, this program concerns the innovation in the digitalization of the steel industry as well. In a recent study 145 RFCS-projects have been identified, with the total budget of 250.1 Mio. Euro (Arens, Neef, Beckert, & Hirzel, 2018) resulting in an average budget per project of 1.7 million euros (Neef, Hirzel, & Arens, 2018). These projects concern some aspects of digitization and industry 4.0 (e.g. adaptive online control, through-process optimization, through-process synchronization of data, zero-defect manufacturing, traceability, intelligent and integrated manufacturing). In the RFCS program, within the Technical Group- Steel 9 (TGS9), *Factory-wide control, social and environmental issues,* digitalization and industry 4.0 projects are included. However, also other TGSs, such as *Steelmaking processes* (TGS 2) and *Casting* (TGS 3) include high rates of digitalization projects, while the others, such as (*Ore agglomeration and ironmaking*, TGS 1, *Hot and cold rolling processes*, TGS 4, *Finishing and coating*, TGS 5) include one third of the projects with elements of digitalization. The main research institutions are participating in the RFCS program are: the German VDEh-Betriebsforschungsinstitut (BFI), followed the Swedish R&D institution Swerea MEFOS/KIMAB, the Italian based institutions RINA Consulting-Centro Sviluppo Materiali and the Scuola Superiore Sant'Anna as well as the Belgian Centre de Recherches Metallurgiques. The most active companies among the RFCS-projects are: ArcelorMittal, ThyssenKrupp and Tata Steel and to some extend also Gerdau and Voestalpine. The plant manufacturers rarely are involved in R&D projects, but that they are key players to patents, such as Primetals and SMS Siemag, followed by Danieli.

Some Use Cases of KETs (BCG, 2015) in the steel industry, with particular focus on the RFCS projects have been identified, as follows:

Internet of Things (IoT) system: The IoT is referred to an inter-networking world in which various objects are embedded with electronic sensors, actuators, or other digital devices, so that they can be networked and connected with the purpose of collecting and exchanging data (Xia, Yang, Wang, & Vinel, September, 2012). An online monitoring system based on an IoT system architecture is composed of four layers: 1) sensing, 2) network, 3) service resource, and 4) application layers. The proposed system has been implemented and demonstrated through a real continuous steel casting production line and integrated with the Team Center platform (Zhang, Liu, Zhou, & Shen, 2016). An example is provided also by TRACKOPT (2017-2020) (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021), an ongoing project, which aims to implement automatic ladle tracking systems, in order to ensure the tracking of the product from steelmaking via casting to delivery.

Big data Analytics and Cloud Computing: big data analytics concern the algorithms based on historical data that identify quality problems and reduce product failures. In the manufacturing industries, including the steel industry, conventional database technology presents some difficulties in completing the capture, storage, management and analysis of the large amounts of structured and unstructured data. Big-data technology uses new processing modes in order to achieve valuable information from various data types, and, consequently, to in-depth understand, gain insight and make discoveries for accurate decision making. In particular, the Big-Data solutions are currently used for quality monitoring and improvement on steel products. For instance, in

order to reduce the crack or scratch defects on steel slabs, the prediction or the detection of them in the production earlier stage is necessary. The prediction of the surface defects on steel slabs can be based on the online collected data from the production line. An accurate prediction of surface defects is important for online adjusting the process and for reducing their occurrence. The main problem is that the samples for normal cases and defects are usually unbalanced. In particular, the number of defective samples is usually much fewer than that of normal cases. On this subject a one-class SVM (Support Vector Machine) classifier based on online collected process data and environmental factors for only normal cases was proposed in order to predict the occurrence of defects for steel slabs (Hsu, Kang, & Weng, June 20–21, 2016). On the other hand, the main aim of the cloud computing is to give on-demand computing services with high reliability, scalability and availability in a distributed environment. Moreover, in the cloud computing, everything is treated as a service (i.e. XaaS), e.g. SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service) (Xun, 2012). Some examples of RFCS projects in such issues are:

- **TRACKOPT** (2017-2020) (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021) Multi-Objective Optimization (MOO) Framework and data analytics, as well as acoustic sensors are used in order to increase factory output (avoided hold-ups or downgrading of products, due to mix-up of ladles) and improve safety in steelworks.
- **Quality4.0** (2018-2021) (Quality4.0, Ct N° 788552, 01/06/2018-30/11/ 2021): in this running project, advanced AI and Machine Learning-based analytics also suitable to big data processing are exploited with the aim to the quality management. Within this project, an adaptive platform will be developed allowing online analytics of large data streams to realize decisions on product quality and provide tailored information of high reliability.
- **PRESED** (2014-2017) (PRESED, Ct. No. RFSR-CT-2014-00031, 01/07/2014-31/12/2017) such project proposed a solution built around Big data, Feature Extraction, Machine Learning, Analytics Server and Knowledge Management in order to analyse automatically the sensorial time series data.
- **NewTech4Steel** (2018-2021) (NewTech4Steel, Ct No 800677, 01/06/2018-30/11/ 2021) this ongoing project focuses on dedicated use cases in steel industry developing and implementing methodologies, meeting the requirements of examined steel processes and exploiting all the technological and scientific possibilities offered by latest technologies, concerning data handling and data analysis. Exploitation of advanced AI and Machine Learning-based analytics also suitable to big data processing are used in order to process performance monitoring.
- **CyberMan4.0** (2018-2021) (CyberMan4.0, 2018-2021) where big-data tools and techniques are applied to merge process and product data in order to forecast quality downgrading, faults, anomalies, residual life of critical components in order to timely plan suitable and cost-effective maintenance interventions.
- **DROMOSPLAN (2016-2019)** (DROMOSPLAN, 2016-2019) a project still running where new sensors data will be produced in order to prove and evaluate the benefits deriving from Unmanned Aerial Vehicles (UAV) technology in two steelworks (TKSE Duisburg, ILVA Taranto). The implementation of real use cases with autonomous flight and the experimental feasibility for indoor applications will be demonstrated and proven (CSM, 2019).

Robot-assisted production: it is based on the use of humanoid robots that perform operations, for instance, assembly and packaging. In the last few decades, automation and robotics have achieved more importance for the manufacturing industry, due to demands for higher quality, faster delivery time and reduction of cost. For instance, if existing technologies are enhanced with part of automation and the use of robots in the steelmaking, the improvement of surface quality of steel products can be achieved. An example is provided by the ongoing RFCS project **ROBOHARSH** (ROBOHARSH, 2016-2019), which firstly introduces some concepts of human-robot symbiotic cooperation in the steel industry for the development of a complex maintenance procedure (Colla, et al., 2017). In this project, one of the main results is that the operator role is changing, becoming a supervisor and, therefore, there is no replacement of the worker but a safer and heavy weight operation reduction. Another example is **DROMOSPLAN** (DROMOSPLAN, 2016-2019), which aim is to use in steel plants the UAVs in order to substitute men in all those operations related to the monitoring, maintenance and safety. In particular, it makes robust autonomous flying UAVs tailored for steel industry through: the improvement of general robustness of UAV in harsh environment, by integrating sensor and protections; the development of dedicated software (algorithms for autonomous flight and cooperative strategy, integrated system for data acquisition); the implementation of management strategy (analysis of legal and company constraints, training system for operators). As in the ROBOHARSH project, the results of the research suggest that the substitution of men is premature to envisage at this stage. In this project, chemical, attitude and positions sensors have been used as well as Video transmission device, MAVlink protocol and algorithms for autonomous and robust flight. **DESDEDMONA** (DESDEMONA, 2018-2021) is another example where procedures for steel defect detection by robotic and automatic systems such as UAVs and ground mobile robots will be developed.

Production line simulation: the software, based on a novel approach, allows assembling line simulation and optimization. The simulation optimization solution approaches in the analysis of complex systems have been developed in the steel sector. In particular, the development of decision support systems aims at investigating potential changes to the designs and operations. Some RFCS projects examples are, as follows:

- **GASNET** (2015-2018) (GASNET, Ct No. RFSR-CT-2015-00029, 01/07/2015-30/06/2019) (Colla, et al., 2019) (Matino, Dettori, Colla, Weber, & Salame, 2019) (Matino, Dettori, Colla, Weber, & Salame, 2019) (Dettori, Matino, Colla, Weber, & Salame, 2018) where Machine Learning tools and technologies such as Hammerstein Wiener (HW) models, Neural Networks and predictive modelling are used in order to improve energy efficiency and environmental sustainability of the steelmaking processes.
- **SOPROD** (2014-2017) (SOPROD, Ct No. RFSR-CT-2014-00028, 01/07/2014-31/12/2017) (Iannino, Vannocci, Vannucci, Colla, & Neuer, 2018): this project used and implemented several key enabling technologies for the vision of Industry 4.0. A combination of real-time and de-centralized optimizations for scheduling, an automatic process self-optimization and autonomous communication among the processes have been used in order to improve product intelligence and autonomous communication. Objected-Oriented Programming (OOP), Python language, LabView, MongoDB and Optical character recognition are some of the used technologies.

- **AdaptEAF** (2014-2017) (AdaptEAF, Ct. N° RFSP-CT-2014-00004, 01/07/2014-30/06/2017): the aim of this project was to set up an adaptive online control for the electric arc furnace considering the properties of the charged materials, optimizing the efficiency of the chemical energy input by reducing the total energy consumption and improving the metallic yield.
- **TRACKOPT** (2018-2020) (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021) includes also the review of the transferability of the tracking system to other parts of the steel production in order to improve plant wide monitoring of products and processes.
- **Cyber-POS** (2016-2019) (CyberPos, Ct No. 709669, 01/07/2016-31/12/2019) is a project where simulation and verification tools as well as a new IT framework for establishing the feasibility, safety and benefits of CPPS (Cyber Physical Production System) in the framework of "Steel Industry 4.0 Automation" are being introduced.
- **OptiScrapManage** (2014-2017) (OptiScrapManage, Ct. N° RFSR-CT-2014-00007, 01/07/2014-30/06/2017): the modern techniques of process monitoring and control through multi-criteria approach of performances indicators, together with the optimization activity have been used. Acoustic and hyperspectral sensors as well as laser scanner are some of the used technologies.

Self-Organizing Production: it concerns the automatic coordination of machines, leading the optimization of their utilization and output. The self-organizing product concerns the decentral instead of central solutions. It includes the new combination of resources, equipment and personnel, based on a close interaction within them with a master computer. The Self-Organizing Production increases automation and leads to the real time control of production networks. Some examples of RFCS projects are:

- **Cyber-POS** (2016-2019) (CyberPos, Ct No. 709669, 01/07/2016-31/12/2019): in this ongoing project, process (thermal, rolling, transport) models, material-quality models, logistics/scheduling models and communication (computers, software, networks) models are merged and used for production optimization, enabling fast dynamic and flexible reaction on changes in set-points, production routes, process disturbances or interruptions.
- **TRACKOPT** (2018-2021) (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021): thanks to this project, an automated system, that reliably monitors the movement of the ladle, is developing. Innovative sensors and instrumentations are applied. Optimization of ladle logistics, production planning and safety are developing.
- **Quality4.0** (2018-2021) (Quality4.0, Ct N° 788552, 01/06/2018-30/11/ 2021): a customer/supplier exchange of quality relevant information is expected in this running project, enabling lower production costs, increased yield and improved identification of quality problems in steel production processes.
- **DYNERGYSteel (**2014-2017) (DYNERGYSTEEL, Ct. No. RFSR-CT-2014-00029, 01/07/2014-31/12/2017) (Marchiori, et al., 2018) (Marchiori, et al., 2017) : simulation, decision support procedures, control tools have been implemented in this project at several steelmaking plants to improve power management capability and the power engagement forecast.
- **AdaptEAF** (2014-2017) (AdaptEAF, Ct. N° RFSP-CT-2014-00004, 01/07/2014-30/06/2017) : in this project, on-line information on bath level, steel and slag amount, scrap melting progress and energetic behavior have been used for model based on-line control of scrap charging as well as chemical energy input via burners and oxygen injectors.

- **PRESED** (2014-2017) (PRESED, Ct. No. RFSR-CT-2014-00031, 01/07/2014-31/12/2017) : its aim was to develop new methodologies and tools to help plants in order to improve the quality of their products and reduce their manufacturing costs by tools which allow: 1. Optimize the manufacturing process by identifying the main causes of bad quality. 2. Predict the quality of the product in order to better characterize it and reduce the costs.
- **SOPROD** (2014-2017) (SOPROD, Ct No. RFSR-CT-2014-00028, 01/07/2014-31/12/2017) (Iannino, Vannocci, Vannucci, Colla, & Neuer, 2018): in this project, a de-centrally optimization considering a detailed product and process knowledge facilitates a process self-optimization by using individual product properties and processing information of neighboring processes.
- **DESDEMONA** (2018-2021) (DESDEMONA, 2018-2021): by the use of advanced tools, in this project, novel design methods, systems, procedure and technical solution will be developed and sensing and automation technologies for the purpose of self-inspection and self-monitoring of steel structures will be integrated.
- **PlantTemp** (2015–2018) (PLANTTEMP, Ct. N° RFSP-CT-2015-00026, 01/07/2015-30/06/2018), : the project developed an operator advisory system covering the electric arc furnace and casting processes, meeting the target casting temperature, by saving energy and material consumption.
- **AUTOADAPT** (2015-2018) (AUTOADAPT, Ct. N° RFSR-CT-2015-00030, 01/07/2015-31/12/2018): the proposed expandable system in this project aims to apply self-learning methods for adapting such automations to new products and plants. Genetic Algorithms, polynomial models, iterative learning control methods and feed-forward control are some of the used technologies.
- **INFOMAP** (2015-2018) (INFOMAP, Ct. N° RFSR-CT-2015-00008, 01/07/2015-31/12/2018): this project developed a tool for objective interpretation of maps from different devices along the process route, generating concise data suitable for use within automatic control/advisory systems.

Cyber Physical Systems (CPS): CPS are integrations of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa (Systems, s.d.). The representation and transformation of traditional rolling mills into Cyber-Physical-Systems is addressed in the ongoing projects Cyber-POS and CyberMan4.0, respectively:

- **CYBER-POS** (2016-2019) (CyberPos, Ct No. 709669, 01/07/2016-31/12/2019) whose aim is to develop a virtual simulation platform for the design of cyber-physical production optimization systems (CPPS).
- **CyberMan4.0** (2018-2022) (CyberMan4.0, 2018-2021): investigations on new methods and experimental tools will validate approach and expected benefits like flexibility, machine uptime and costs. In this ongoing project, four use cases will be developed considering flat products, an innovative rolling mill for long products, the hot and cold rolling roll shop management for flat products connecting product quality and machine status as a valuable indicator of health awareness.

Smart supply network: the monitoring of an entire supply network enables better supply decisions. In the steel industry, the supply chain requires the consideration of numerous factors and objectives. The smart supply networks optimize the steelworks production processes from the raw materials to the final products by using models as part of the integrated supply chain. Some RFCS projects examples can be provided by:

- **GASNET** (2015-2018) (GASNET, Ct No. RFSR-CT-2015-00029, 01/07/2015-30/06/2019) (Colla, et al., 2019) (Matino, Dettori, Colla, Weber, & Salame, 2019) (Matino, Dettori, Colla, Weber, & Salame, 2019) (Dettori, Matino, Colla, Weber, & Salame, 2018): a simulation tool of the network of process gas and steam including their generation and flows as well as a multi-level strategy for optimization of gas and steam networks have been developed.
- **Quality4.0** (2018-2021) (Quality4.0, Ct N° 788552, 01/06/2018-30/11/ 2021) whose aim is to reach a new level of customer-supplier collaboration over the complete supply chain.

Vertical/Horizontal Integration: horizontal integration refers to integration between a resource and an information network within the value chain while vertical integration is related to networked manufacturing systems within the intelligent factories of the future and personalized custom manufacturing (Zhou , Liu, & Lifeng , 15-17 August 2015). Some examples of RFCS projects in this context are **DYNERGYSteel** (2014-2017) (DYNERGYSTEEL, Ct. No. RFSR-CT-2014-00029, 01/07/2014-31/12/2017) (Marchiori, et al., 2018) (Marchiori, et al., 2017), **SOPROD** (2014-2017) (SOPROD, Ct No. RFSR-CT-2014-00028, 01/07/2014-31/12/2017) (Iannino, Vannocci, Vannucci, Colla, & Neuer, 2018) and also **Quality4.0** (2018-2021) (Quality4.0, Ct N° 788552, 01/06/2018-30/11/ 2021) where the new level of customer-supplier collaboration will be established by means of the horizontal integration of quality information over the complete supply chain comprising the full exploitation of all available quality information and knowledge from the measurement up to the final product at downstream industries.

Predictive Maintenance: based on remote monitoring of equipment, it allows to repair prior to breakdown. Predictive maintenance techniques can be implemented by equipment monitoring combined with intelligent decision methods. Machine Learning and Data Mining techniques can be used to draw insights from the data and accurately predict results in order to support decision-making and, consequently, to help steel companies to improve their operations and competitiveness. An RFCS example is the on-going **Cyberman4.0** (2018-2022) (CyberMan4.0, 2018-2021) which aims at turning maintenance strategy in steel industry from preventive to optimize predictive maintenance by experimental systems and tools built upon the Industry 4.0 enabling technologies proposing the Integrated Maintenance Model 4.0 (IMM4.0) applied into the rolling area.

Cyber Security: the cybersecurity should be considered, particularly for the Internet-based services. In (Flatt, Schriegel, Jasperneite, Trsek, & Adamczyk, 2016) the procedural model for a Cyber-Security analysis based on reference architecture model Industry 4.0 and the VDI/VDE guideline 2182 is shown for the use case of a Cloud-based monitoring of the production.

Augmented Work, Maintenance and Service: by applying the fourth dimension, which means the use of the augment reality, the operating guidance, the remote assistance and the documentation are favored. Augmented Reality represents one of the most interesting technologies for companies, particularly for improving the maintenance services. For instance, remote maintenance

based on remote connection can be carried out by a service technician who is virtually connected. This results in travel costs and time saving, and with a quick problem solving. An example in the steel industry is provided by the RFCS project **TeleRescuer** (2014-2017) (TeleRescuer, Ct. N° RFCR-CT-2014-00002, 01/07/2014-30/06/2017) where a system for virtual teleportation of rescuers to subterranean areas of coal mine has been developed by using special unmanned vehicle (UV) capable of moving within the area.

Self-driving logistics vehicles: it is based on fully automated transportation systems that are used within the factory. The use of intelligent software to support intralogistics operations helps companies to improve processes and to make faster them. In a steelworks it is important to supply and dispose raw materials in the plant, to transport intermediate products and to removal finished as well as to handle by-products, such as bulk material or slag. The use of an intelligent transport control system can allow to plan and control the internal transport orders, although there is a high level of complexity. This can result in increasing productivity and service levels and cutting costs. Through the intelligent systems, transportation can be intelligently controlled. An example is the ongoing RFCS project **TRACKOPT** (2018-2021) (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021).

Some further RFCS projects started in 2012 related to the enabling technologies are: **IConSys** , (IConSys, 01/07/2012-31/12/2015) (Colla, et al., 2016), developing an Intelligent Control Station, supporting decision making in rolling and finishing, **I2MSteel** (I2MSteel, 01/07/2012-31/12/2015), developing a factory and company-wide automation and information technology for the intelligent and integrated manufacture steel and **EvalHD** (EVALHD, 01/07/2012-31/12/2015) (Brandenburger, et al., 2016), which investigates aspects related to the implementation of Industry4.0-related concepts, tools and technologies (Commission, 2016).

Digitalization of knowledge management. Due to an increasing competitive market, the steel sector has been committed to face significant challenges in the digitalization. Although this process has already started, further improvement can be achieved. On this subject, the knowledge and experience of the technical staff represents the basis of this improvements. The main barriers about the usage of this knowledge and experience are represented by their heterogeneous distribution over the individual staff members, human obliviousness, and knowledge erosion by leaving staff members. The RFCS project "**KnowDec**" (KnowDec, RFSR-CT-2009-00031, 01/07/2009-31/12/2012) aimed at investigating and implementing a method for the collection, representation, storage and utilisation of the human knowledge to exploit it in computer based applications. The new developed approach was based on the methodology knowledge-based decision support system. This can allow the operators of the quality department to capture their experiences concerning to the approval of slabs. The experiences collected are stored in the knowledge base and can be used for decision support to give advices in similar cases.

Initiatives on digitalization and Industry 4.0 include also the Integrated Intelligent Manufacturing (I2M) Working Group of the ESTEP Platform, founded in 2008, which has published the first edition of I2M Roadmap for European Steel Manufacturing in 2009 with a vision up to 2020, when this was an emergent concept in Steel Manufacturing. This ESTEP Working Group covers a broader range of stakeholders and it consists of plant manufactures and several European Universities

and R &D Institutions. Recently, a workshop on the concept and operational benefits of the Digital Twins in the steel sector has been held in Brussels (ESTEP, 2018). In addition, the Working Group Planet, among different areas, covers also the Digital technologies for environmental impact assessment. Digital technologies are usually applied in order to improve the flexibility and the reliability of process and to improve the product quality. In addition, they can be applied for monitoring and assessing the environmental performance of processes, improving control of production and auxiliary processes that have an environmental impact, providing key performance indicators for resources efficiency (ESTEP, 2017).

1.6 Digitalization and other Projects

According to (Nils Naujok, 2017), the European steel industry faces important challenges due to cost pressure (e.g. lower demand from Russia and increasing over capacity), regulatory requirements (e.g. efficient use of resources and energy), product and service requirements (e.g. shorter product life cycle and shift from commodity steel towards heterogeneous product portfolio). Industry4.0 is moving by combining vertical and horizontal integration with customer access and business models, since one of its main goals is to optimize a process, to make the best or most effective use of it, minimizing cost and maximizing throughput and/or efficiency.

In order to achieve these important challenges, over the last few decades, the European steel industry has been involved in several policy activities, R&D projects and patents in the field of digitalization. In addition to the European RFCS program , the European Union research and the innovation-funding program has included the 7th Framework Program (FP7) (2007–2013) and its successor Horizon 2020 (2014–2020) (Commission, 2018).

Furthermore, projects focused on the steel industry digitalization are funded by other European programs, i.e., Eureka and SPIRE. EUREKA is a pan European network for market-oriented, industrial R&D (Eureka, 2018), while SPIRE, which stands for Sustainable Process Industry through Resource and Energy Efficiency (Commission, Sustainable Process Industry, 2018), is a public private partnership under the Horizon 2020 program for the most important European process industries, including the steel industry. Most of these projects started between 2014 and 2017. Nevertheless, digitalizing the steel industry started before calling these activities Industry 4.0 (Hecht, 2017). On this subject, some projects, starting in the early 1990s and covering some aspect of digitalization of the steel industry, have been identified.

Among the EUREKA projects, **BRICK** (1990–1993) aimed at reducing downtimes at steel converters by predicting failures. In addition, other 32 activities in the field of digitizing the European steel industry have been identified. They cover, for instance, proper research projects funded by national ministries or innovation agencies. **OREXPRESS** (1990-1993) is another EUREKA project whose aim was to produce a logistical information and a scheduling system for the transportation of bulk materials on the European inland waterways. The targets of a subsequent project, called **TAM** (1993-1997), were to integrate advanced techniques for measurement analysis and diagnosis of industrial equipment and installations for maintenance purposes as well as to develop tools

(modelling, data collection and treatment) helpful for the interpretation of measurements and establishing inspection methodologies applicable to industrial systems' maintenance. A more recent project, called **H2PREDICTOR** (2000-2004), developed a new standard product to be used at any tank or RH-type of vacuum degassing plant for steel where the main output from the processing is color video images. A neural computing model analyses the information, both image and key process input variables. It started in 2014 and ended in 2017, having as main objective to design and develop a new advanced technology to optimize and improve the productivity of rolling mills and skin pass, improving process efficiency, quality of material produced and reducing their operating costs.

As far as the H2020 projects are concerned, in **WaterWatt** the mission is to remove market barriers for energy efficient solutions, in particular the lack of expertise and information on energy management and saving potential in industrial water circuits (WaterWatt, Grant Agreement No 695820). The project outputs include digital products aimed at managers and workers to improve efficiency. **FACTS4WORKERS**, Worker-Centric Workplaces for Smart Factories, is another H2020 project, which is integrating already available IT enablers into a seamless & flexible Smart Factory infrastructure based on worker-centric and data-driven technology building blocks (FACTS4WORKERS, 01/12/2014-30/11/2018).
In through cross-sectorial digital solutions with specific demo in steel industry, other SPIRE projects face this issue are:

- **DISIRE** (DISIRE, 01/01/2015-31/12/2017) introduces novel concepts on modelling, control and big data processing in production processes to improve product quality and reduce energy consumption;
- **CoPro** (CoPro, 01/11/2016- 30/04/2020) aims to develop process monitoring and optimal dynamic planning, scheduling and control;
- **FUDIPO** (FUDIPO, 01/10/2016- 30/06/2020) develops a future process optimization system, using adaptive modes in a machine learning approach;
- **MORSE** (MORSE, 1/10/2017-30/9/2021) develops model-based, predictive raw material and energy optimization tools for the whole process route in steel industry;
- **RECOBA** (RECOBA, 1/1/2015-31/12/2017) aims to maximise and optimize efficiency in the process industry for the management of batch processes;
- **COCOP** (COCOP, 2016-2020) enables the plant-wide monitoring and control by using the model-based, predictive, coordinating optimisation concept by integrating with local control systems.

Among FP7 (2007–2013), **AREUS** (AREUS, 1/9/2013-31/8/2016) concerns of integrated technologies for robotic production system and robotic manufacturing processes optimization environment.

Concerning other activities, a project on industry 4.0 has been developed at Dillinger. It is a real-time forecasting project for a BOF supposed to be adaptive (i.e. it learns and therefore fine-tunes a production process based on the data from the manufacturing process) (Group, 2014). Another project, leading by SSAB, aimed at making available information and instructions relating to any

steel item, regardless of where it is produced: each link in the chain can use and accumulate information, creating a basis for both the circular and platform economy (SSAB, 2017). In addition, concerning patents, no significant increase of patenting activities has been carried out over time.

1.7 Technologies for low-carbon steel industry in EU funded project

A competitive and low-carbon European steel industry is a fundamental objective as defined in EU Masterplan (EUROFER, 2018).

In the path of sustainability, the resource-intensive sectors will suffer of substantial changes (ILO, 2012). In this context, the circular economy keeps products and materials at a high level of utility, maximizing the product life and promoting the reuse, refurbishment and the recycling (Foundation, 2013). The biggest change, however, could be the re-allocation of production: the extraction of primary resources and the production of metals will be replaced by the recycling and reprocessing of secondary metals, causing important employment losses in the mining and manufacturing. (ILO, 2018).

Although, in a first analysis, competitiveness seems strongly linked to digitalization, with special regard to the increased efficiency, both in process and quality, environmental issues (e.g. CO_2 reduction) can benefit from the KETs application. Advanced process monitoring and increased quality lead to a major efficiency. However, low-carbon steel production also requires the development of dedicated technologies. Concerning the digitalization, the RFCS and H2020 (2014-2020) programs represent the most important instruments for the EU funded research projects in the field of CO_2 mitigation technologies.

The project **LOWCARBONFUTURE** (LOWCARBONFUTURE, Ct No 800643, 01/04/2018-31/03/2020.) summarizes, evaluates and promotes research projects and knowledge dealing with CO_2 mitigation in iron and steelmaking. The list of applicable technologies for CO_2 mitigation, developed in EU funded projects, are grouped in three pathways: Carbon Direct Avoidance (CDA), Process Integration (PI) and Carbon Capture, Storage and Usage (CCU).

CDA technologies mainly consist in iron ore reduction by hydrogen (produced by H_2O electrolysis) and syngas from biomass and Fe reduction by electrolysis through ULCOWIN (iron ore particles suspended in alkaline solution) and ULCOLYSIS (iron ore dissolved in molten slag). The last two technologies were developed in **ULCOS** (2004–2010) (ULCOS, Ct No 515960, 1/9/2004 – 31/8/2010), a major RTD program, coordinated by ArcelorMittal, aiming at find innovative and breakthrough solutions to decrease the CO2 emissions of the steel industry. In this context one of the main project is **HYBRIT** (HYBRIT, 2016-2024) which is an initiative of three companies, SSAB, LKAB and Vattenfall, co-financed by Swedish Energy Agency, aiming to develop the world's first fossil-free ore based steel making technology using hydrogen to replace carbon as reductant. This project is a multi-phase project started in 2016 with a pre-feasibility study with the objective to gain knowledge and to create a basis for further studies and experiments in pilot scale. It also defined the prerequisites for establishing a pilot-plant including the basic design, location and major technologies to be used in the next step.

CDA technologies are also to produce a green industrial hydrogen via reversible high-temperature electrolysis designing, manufacturing and operation of a high-temperature electrolyser as a reversible generator based on the solid oxide cell technology in an industrial environment **GrInHy** (GrInHy, Ct No 700300, 1/3/2016- 28/2/2019.). To make hydrogen meet future needs of low carbon manufacturing value chains, fully scale demonstration of an electrolyser unit for H2 production and grid balancing services with next generation electrolysis technology has been done in **H2Future** (H2Future, Ct No 735503, 01/01/2017-30/06/2021).

Other CDA technologies concern iron production by electrochemical reduction of its oxide for high CO2 mitigation, **IERO** (IERO, Ct No RFSR-CT-2010-00002, 1/07/2010-30/06/2014) and to obtain a stepwise transformation of carbon-based steelmaking into hydrogen-based steelmaking, as in **SALCOS** project (SALCOS, Ct No 768788, 1/10/2017-30/09/2022) where the transition from Blast Furnace (BF) route to the direct reduction route was implemented.

Within the CDA technologies also falls the projects dealing with renewable energies as **SIDERWIN** (SIDERWIN, 1/10/2017-1/09/2022) project, which focuses on electrolysis process using renewable energies to transform iron oxides into steel plate offering a CO2-free steel production.

Process Integration (PI) includes technologies with reduced use of carbon. Several EU projects in this field have been funded for the development of specific technologies for:

- Reduction of coke utilisation in BF operations through, i.e., optimisation of the flow rate at the wall, **IDEOGAS** (IDEOGAS, 1/3/2006 – 28/2/2009)
- Organic sludges in steelmaking, as **OSMet S2** (S2, Ct No 2017-01327) project that aims at using sludge from pulp and paper, which contains valuable components (coal and lime), in various metallurgical applications to reduce climate impact while, at the same time, sustainably reducing waste to landfill for the pulp and paper industry.
- Smelting reduction, that is the reduction of ore in liquid phase, as the advanced smelting reduction experimental campaign in **HISARNA B, C & D** project (HISARNA, 1/07/2011-31/12/2014).
- Biomass utilization in sinter plant, i.e. the alternative carbon sources (incl. biomass) for sintering of iron ore are analysed, pre-treated and evaluated in **ACASOS** (ACASOS, Ct No RFSR-CT-2007-0003, 1/07/2007-31/12/2017.).
- Better use of steel plant gases (in BF):**CO2RED** (CO2RED, Ct No 745604, 1/03/2018-29/02/2020) which focused on reheating furnaces, or **REGTGF** (REGTGF, Ct No RFSR-CT-2003-00036, 1/09/2003-31/12/2006.) that focused on the improvement of top gas fired reheating, and direct reduction furnaces for high temperature using innovative regenerative burners. **RenewableSteelGases** (RenewableSteelGases, 01/03/2017-29/02/2020) aims to develop a complete process chains for the energy efficient use of steel gases by integrating renewable energy.
- Alternative fuels for electric arc furnace (EAF) (incl. biomass), as in **SHOCOM** (SHOCOM, Ct No RFSR-CT-2005-00001, 1/07/2005-30/06/2008), **Torero** (TORERO, Ct No 745810, 1/05/2017-30/04/2020) also including syngas production from biomass to be used in reheating furnaces as in **GREENEAF** (GREENEAF, Ct No RFSR-CT-2009-00004, 1/7/2009-30/06/2012) and **GREENEAF2** (GREENEAF2, Ct n° RFSP-CT-2014-00003, 01/07/2014-30/06/2016).

- Energy recovery from off-gases
- Utilization of waste low temperature heat from production processes.
- Process optimization in terms on energy register, CO2-monitoring and waste heat power generation. Several projects deal with this optimisation, as **ENCOP** (ENCOP, Ct No RFSR-CT-2009-00032, 1/07/2009 - 31/12/2013), dealing with the overall energetic optimisation of steel plants, **IDEOGAS** (IDEOGAS, 1/3/2006 – 28/2/2009), focusing on injection of reducing gas in BF and top gas recycling, **LoCO2Fe** (LoCO2Fe, 1/05/2015-31/10/2018), developing a low CO_2 iron and steelmaking integrated process route and **STEPWISE** (STEPWISE, 1/05/2015-30/04/2019), dealing with a novel technology for capturing CO_2 from blast furnace gas emitted by the iron and steel industry, based on the so-called sorption enhanced water gas shift process (SEWGS).

Moreover, within the technologies to reduce the carbon use, Destiny (DESTINY, 1/10/2018-31/03/2022) aims at developing and demonstrating a new concept of firing granular feedstock for materials transformation using full microwave heating as an alternative and complement to the existing conventional production.

CCU technologies concern the different methods for carbon capture based on chemical/biological processes of CO_2 conversion and CO_2 capturing by mineral raw materials.

Within the CCU technologies, conversion of industrial CO2 into biofuels is the focus of several projects, as **BIOCON-CO2** (BIOCONCO2, 1/01/2018-31/12/2021) dealing with the transformation of CO2 resulting from the iron, steel, cement and electric power industries into value-added chemicals and plastics using anaerobic microorganisms, aerobic microorganisms and enzymes. The use of carbon from metallurgic gases as raw material for chemical products as well as use of surplus energy from renewable sources were the focuses of **CarbonNext** (CarbonNext, 1/09/2016-31/08/2018.) project, which evaluates the potential use of CO2/CO and non-conventional fossil natural resources as feedstock for the process industry in Europe.

By means of the so-called carbonation, products, which, for instance, can be used in the construction sector, are to be formed from CO2-containing industrial waste gases and mineral feedstocks. The project **I3UPGRADE** (I3UPGRADE, 01/06/2018-31/12/2021) aims at the intelligent and integrated upgrade of carbon sources in steel industries through hydrogen intensified synthesis processes and advanced process control technologies.

Other projects dealing with a more efficient CO2 capture are: **FresMe** (FreSMe, 1/11/2016-31/10/2020) demonstrating how the CO2 captured from the steel process can produce methanol fuel that will be used as fuel in the ship transportation sector, **M4CO2** (M4CO2, 1/01/2014-31/12/2017) aiming to efficiently capture CO2 from a variety of sources, including biogas plants, power stations and the iron & steel and cement industries and synthesize the gas into methane or other chemical building blocks, such as formic acid, methanol, higher oxygenates and hydrocarbons (conversion).

It was demonstrated that it is possible to turn industrial waste gases (mixed CO/CO2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings, as in **Carbon4PUR** (Carbon4PUR, 1/10/2017-30/09/2020).

It is also possible to recycle carbon into sustainable, advanced bio-ethanol as in **Steelanol** (STEELANOL, 1/05/2015-31/10/2018). In fact, carbon-rich industrial waste gases can be captured and transformed into advanced bio-ethanol for use in the transport sector by way of a novel gas-fermentation technology.

1.8 Additive manufacturing

Additive Manufacturing is the most disruptive technology, as it twists traditional production paradigms. In the steel sector this technology opens up the possibility to develop innovative alloys with similar (or better) outstanding material properties as the already available high-performance alloy, but as a cost-effective alternative. In this topic, European funded projects deal with the design and development of innovative alloys in different production sector, as **AlForAMA** (ALFORAMA, 1/07/2017 – 30/06/2020) and **AMATHO** (AMATHO, 1/12/2016 - 30/11/2021) in the sector of aerospace or **RUN2Rail** (RUN2Rail, 1/9/2017- 31/8/2019) for railway sector. More precisely, AlforAMA deals with the development of an innovative High Strength Al alloy, feasible by powder metallurgy and suitable for Selective Laser Melting (SLM), while AMATHO aims to design, assess and manufacture a novel tiltrotor drive system housing exploiting the features of additive manufacturing techniques using powder from the recycle Al scraps to produce new powder for the different AM technologies (Direct Laser Deposition – DLD, Selective Laser Melting - SLM and Electron Beam Meelting – EBM). In railway sector, RUN2Rail aims to develop new high-strength alloys for railways industry for efficient fabrication processes for the running gear by 3D metal printing. Other projects focus on the application of new technologies in the industrial context, such as the application of Laser Metal Deposition (LMD) to hot forming sector, in order to develop high-performance barrels with innovative gradient coatings, as in **DEBACOAT** (DEBACOAT, 1/1/2013 - 31/12/2014). **CerAMfacturing** (CerAMfacturing, 1/10/2015 – 3/09/2018) deals with the development of a new approach concerning the AM techniques applications for multi-material, i.e. ceramic/metal material combinations. Also, funded projects deal with the integration of different technologies to obtain maximum efficiency, like the combination of available cutting-edge Laser-Based Additive Manufacturing (LBAM) machines and ICT innovations within an integrated multi-process production cell, which will include at least Additive Manufacturing and subtractive manufacturing machines, in order to ensure a fully finished product from the incoming raw material, as in **HyProCell** (HYPROCELL, 1/11/2016–31/10/2019), or establish Cloud based Toolboxes, Workflows and a One Stop-Shop for CAx-technologies supporting the design, simulation and process planning for additive manufacturing as in **CAxMan** (CAxMan, Ct No 680448). Lastly, the project **AMable** (AMABLE, 1/09/2017 – 31/08/2021) aims to support SMEs/midcaps in overcoming barriers like lack of skilled human resources, lack of access to know- how, equipment, infrastructure and markets to make available and enable the uptake of AM technologies by leading to the development of innovative business and service models and new value- chain models in a fully digital environment.

2 Current and upcoming developments in digital transformation and Industry 4.0

Based on research on key sectors of the German and European economies, the four levers of digital transformation, which is already underway, are: Digital Data, Automation, Connectivity And Digital Customer Access (Berger, 2015).

DIGITAL DATA. The digital data capture, process and analysis can allow better predictions and decisions to be made. In this context, the access to data and the ability to analyse them are the most important aspects. Starting from the IoT, the new applications of sensors are increasing. In particular, the IoT are connections between devices equipped with sensors, software and wireless capabilities, coupled with a growing capacity to collect and store data. Consequently, new data sources are available to modern analytical technologies, that allow companies to pre-processing data faster and in more detailed way than ever before.

In the steel sector, real-time data helps in monitoring processes and products. By using sensors, every single piece can be checked along the production chain and errors can then be easily traced back and amended. Consequently, a more efficient production can be achieved. In addition, in the maintenance of equipments significant improvements can be reached, thanks to the data availability and machine learning, enabling maintenance work to be anticipated and done before something goes wrong. Furthermore, equipments may even be able to schedule their own maintenance and many checks can be made remotely.

AUTOMATION. The combination of traditional technologies with artificial intelligence is increasing, producing systems that work autonomously and organize themselves. This leads to error rates reduction, speed increase as well as to operating costs cut. In particular, the steel sector is continuing the process to adapt itself to the automation of production and consumption.

CONNECTIVITY. Interconnecting the entire value chain via mobile or fixed-line high-bandwidth telecom networks is useful for synchronizing supply chains and reducing production lead times as well as innovation cycles. The increasing connectivity of what used to be separate systems will overcome the lack of transparency and, consequently, will improve the process efficiency. For instance, smart factories are based on the interconnection of production systems facilitated by machine-to-machine (M2M) communications. Nevertheless, this is possible only if the application of an interoperable, universal communications standard is carried out.

In the steel sector, greater connectivity and data sharing can reduce some issues due to remote locations and widespread supply chains as well as to markets fluctuation and to potentially hazardous working environments. For instance, M2M communication also allows for automated stock management, namely materials that are running low can immediately be re-ordered.

DIGITAL CUSTOMER ACCESS. The (mobile) Internet gives new intermediaries direct access to customers, in order to offer them transparency and new kinds of services. Due to the availability of digital data, the automation of production processes, the interconnection of value chains and the creation of digital customer interfaces, the business models are transforming and entire industries are reorganizing. On this subject, steel companies are now looking at ways in which they interact with suppliers and customers. In the near future, the customer demand will push towards change,

as companies become increasingly able to compete on delivering exactly what is required by customers.

Some ongoing European projects will provide significant results in the near future. In particular, COCOP (COCOP, 2016-2020), COPRO (CoPro, 01/11/2016- 30/04/2020), FUDIPO (FUDIPO, 01/10/2016- 30/06/2020), MORSE (MORSE, 1/10/2017-30/9/2021), HYBRIT (HYBRIT, 2016-2024), thanks to the specific demo, will develop cross-sectorial digital solutions. In addition, TRACKOPT (TRACKOPT, Ct. N° 753592, 01/01/2018-30/06/2021), QUALITY4.0 (Quality4.0, Ct N° 788552, 01/06/2018-30/11/ 2021), NEWTECH4STEEL (NewTech4Steel, Ct No 800677, 01/06/2018-30/11/ 2021), DESDEMONA (DESDEMONA, 2018-2021), CYBERMAN4.0 (CyberMan4.0, 2018-2021) are some RFCS Projects that can provide further results on the real implementation of the digitalization in the steel sector.

In order to explore the current activities and expectations of Industry 4.0 in the European steel industry, a review of the publicly funded projects, patent analysis, expert interviews and a qualitative survey of academics and practitioners related to Industry 4.0 in iron and steel making, has recently carried out (Neef, Hirzel, & Arens, 2018).

Concerning the current status of Industry 4.0 implementation in the European iron and steel industry, as previously discussed, a lot of research projects are focused on the digitalization. Results showed that about 30 to 50 R&D projects are “strongly” focused on Industry 4.0 beyond digitalization. In addition, among them, the implemented projects are mainly prototype applications and demonstrations.

The interviews and survey results showed that the main issues concern the transformation of the organizational structure of a company. This represents the main challenge and they are related to updating legacy equipment, to the collected data exploitation and to the economic situation of some European steel producers. Further results also showed that Industry 4.0 implementations are required to provide economic benefits to the company development.

The expected role for Industry 4.0 in the future mainly concerns improvements in process efficiency and in the development of new business models. In addition, Industry 4.0 is seen as a mean to improve effectiveness by providing intelligent support systems for the workforce. In the future the Industry 4.0 will mainly affect “downstream” production areas like rolling and coating/finishing in the technical domain and the interaction with customers in the organizational domain.

3 Development of a future scenario of a digitized Steel factory inclusive of economic evaluation and impact on the personnel

The future SPIRE 2050 roadmap in preparation by the SPIRE Working Group Digital foresees an integrated and digital European Process Industry, delivering new technologies and business models enabling a fully circular society in Europe with enhanced competitiveness and impact for jobs and growth (SPIRE, 2018). According to (Stamm & Naujok, 2017), efficiency, investment in innovation and digitization will be the necessary elements for the growth and the 59% of Metals CEOs think that the technology will re-arrange the competition over the next five years. It seems that in the next 5 years, the level of digitization which is now at 33% will increase reaching a 72%, according to (PwC, 2016). In ArcelorMittal, the big data platform and the AI algorithms are vital

in some areas such as defect recognition and quality assurance, as they will lead to higher yields and lower environmental impacts, including CO2. Moreover, thanks to the digitalization, in ArcelorMittal the adoption of the common platforms and AI is transforming the supply chain and logistics. However, the focus is to create platforms and tools across the whole Group and in very different business areas, since the major benefits of the digitalization is the replicability (ArcelorMittal, 2019). In the final quarter of 2018, due to a growth of the third country imports by 16.3% year-on-year, a decrease of the domestic deliveries from EU mills to the EU market compared with the same period of 2017 has been revealed (EUROFER, 2019). The primary reason for the weakening of the EU economy in 2018, which will at least persist over the first half of 2019, has been the slowing global economic momentum and the related deteriorating contribution from net trade. The base-case scenario for the economic growth in the EU suggests that domestic economic fundamentals could offset the weakness in trade and in particular, the investment is at risk of falling behind expectations if the protectionism rise (EUROFER, 2019).

3.1 Effects of digitalization on the European steel industry workforce

Industry 4.0 has been leading significant huge changes in all industry structures, including the workforce dynamics. The key factors to drive technological advancements for Industry 4.0 transformation could be the strategic workforce planning, the right organization structure, developing partnerships and the technological standardization. Future directions and possible improvements indicate that the industrial activities could change from human labor centered production to fully automated way and in a positive way, the monotonous and physically strenuous work could finally be replaced with creative work (Pfeiffer, 2016). However, it could be also negatively associated with higher unemployment and widespread workforce de-skilling. Both negative and positive views underestimate the role of human experience in today's assembly work and the assembly is categorized as mere routine work and easily susceptible to be replaced by the new robotics. The increasing application of the digital technologies involves especially the low skilled work which includes manual operation of simple and specialized machine tools and comprises activities which can be accomplished after a brief training. In Germany, considering overall sectors, about 23% of the labour force possess no vocational qualifications (in the manufacturing sector there are, in absolute numbers, 1.2 million low-skilled workers). This trend can be seen, on one hand, as a simplification and control of the work process that up till now had been unattainable; on the other hand, the use of digital upskilling methods also provides employment opportunities for less capable employees (Hirsch-Kreinsen H. , 2016a). Some assume that low-skilled work will also be affected by upskilling processes, that means that digitalisation will lead to upgrading as a consequence of the automation of simple and low-skilled activities and, at the same time, a continuous enhancement of skilled activities (Evangelista, Meliciani , & Guerrieri, 2014). Rather than disappear the low-skilled industrial work, the level of qualification rises steadily. Others foresee a strong polarisation of jobs and skills. The thesis of the polarization is that the middle-skilled jobs are automated by computers, while digitalisation increases the productivity of the most skilled jobs and the least-skilled jobs survive because they cannot be automated nor greatly benefit from new technologies. In fact, the automated work is heavily concentrated in the middle of the skills distribution, whereas non-routine work that cannot be automated is concentrated in either the

most skilled jobs (e.g. computer engineers) or the least skilled jobs (e.g. waiters or cleaners) (Hirsch-Kreinsen H. , 2016b) (Commission, 2019).

According to Hirsch-Kreinsen (Hirsch-Kreinsen H. , 2016b) four developments paths for low-skilled work under conditions of digitalisation can be identified. The evidence of a general erosion of low skilled industrial work and the virtual consensus that simple, routine tasks which are especially threatened by the new technologies will probably disappear in the longer term can be considered only one scenario. The second path is an "upgrading of low-skilled industrial work", where a strategy of technological product improvement is paired with a highly flexible marketing orientation. In the third scenario, characterized as "digitalized low-skilled work", a high intensity application of digital technologies is demonstrated here and new forms of work, for instance "crowdsourcing" and "crowdworking", which may also be associated with new forms of low-skilled work emerging in this context. In the crowdsourcing process, there is a differentiation and an opening of production processes and the internet-coordinated inclusion of a wide range of external actors in the value-creation process (Benner, 2014). The fourth scenario is characterized as "structurally conservative stabilization of low-skilled work" and, in this path, there is no discernible change in existing employment and organizational structures. The different discussed scenarios (Hirsch-Kreinsen H. , 2016c) show that, on one hand, potential job losses due to the new technologies implementation is controversial; on the other hand, the consequences for job activities and qualifications are interpreted as the "upgrading" or "polarization" of skills. However, concrete changes depend on the influence of different factors. In particular, the kind of technology automation and its implementation process are significant aspects. For this reason, the study underlines that, in the medium term, a limited spread of digital technologies and their consequences can be expected.

The effects and the impact on the employment are also an important aspect due to the progressive digitalisation and automation of jobs and work processes. According to the model of Frey and Osborne (Frey & Osborne, 2013), about 47% of U.S. works could be automated through the application of new digital technology.

According to an estimation by The Boston Consulting Group (BCG, 2015), the greater use of robotics and computerization will increase the creation new jobs, particularly in IT and data science. Bonin et al. (Bonin, Terry , & Ulrich, 2015) demonstrate that only 12 percent of jobs in Germany are endangered through digital automation. They also predict that the probability of automation will be higher where levels of education are lower.

The "Re-finding Industry Report" of the European Commission, it is stated that over 1.5 million net new jobs in industry have been created since 2013 and a growth of labour productivity of 2.7% per year on average since 2009, higher than both the US and Korea (0.7% and 2.3% respectively) (DIA, 2018). CEDEFOP, the European Centre for the Development of Vocational Training, in (Panorama, 2018) expects that between 2016 and 2030 will be over 151 million job openings, with 91 % being created due to the replacement needs and the remaining 9 % due to new job openings. In particular, replacement will be due to retirement (around 50% of replacement demand), migration, movement into other occupations, or workers temporarily leaving the workforce. For ICT professionals, in the same period, there will be over 1 750 000 job openings.

For this reason, in order to achieve a mix of digital and business skills, it is important to obtain an upskilled and reskilled workforce through the implementation of training activities. A life-long learning approach, to using technology in an effective, creative, critical and responsible way, is the correct way for addressing digital skills (Commission, 2017). The companies need to have stronger horizontal skillsets rather than highly specialised profiles, in particular, workers with transferable skillsets in order to provide a good level of flexibility and coordination across different departments of their companies. In addition, it becomes increasingly important for companies to have employees who are able to move across multiple tasks and intervene in different areas. Consequently, due to current job insecurity problems, transferable cross-functional skills can be a source of security for workers (Steel Sector Careers, 2019).

While current employees need to be re-skilled, responding to the requirements of digital economy, new employees need to be educated, according to the requirements of future jobs and skills. In this regard, companies, along with their productivity and competitiveness in the perspective of Industry 4.0, should develop their future workforce and adopt new business models and organizational structure (Karacay, 2018). Moreover, continuous training activities represent the key aspects for the steel companies in order to achieve a successful future.
From the current and future labour market, new skills are requested from the workers, so a proper training from the education system, the governments and interested companies has to be redesigned. Sometimes it could be a skills mismatch: skill mismatches refer to a failure of skill supply to meet skill demand. The skills mismatches can be as a stop on the economic growth as well as limit the employment and the income opportunities of individuals and prevent companies to maximize their performance (Gambin, et al., May 2016). Several actors, including CEDEFOP, the European Commission, the OECD and EU Member States, have focussed on the question of how to achieve a better alignment of skill supply and demand and understand why there is underinvestment in training (Commission, 2019).

In total 2.6 million people worked in skill shortage occupations (approximately 10% of all employment). During 2013, there were estimated to be 47,000 vacancies, 25,600 of which were reported as hard-to-fill by employers and around 23,500 as being hard-to-fill because applicants lacked the skills the employer sought (Commission, 2016).

In the steel sector, the outlook for employment is of serious concern and merits full political attention, also because 40 000 jobs have been lost in recent years, due to restructuring (Commission, 2013). However, the digitalization in the process industries, including the steel industry, provides new flexible skills and a workforce able to fast learn new digital technologies. For this reason, cognitive sciences play a key role in order to provide support, which combines situation awareness and knowledge with advanced control algorithms and optimization (SPIRE PPP Contribution DEI WG 2, 2016).

In the Industry 4.0 all employees need to have ICT skills, more than core skills. In particular, along with hard-skills, employees should have soft-skills as collaboration, communication and autonomy in order to be able to carry out their jobs in hybrid operating systems. In addition, employees should increase their ability to be adaptable and to get into the habit of continuous learning in an interdisciplinary perspective. By going into detail, for instance, in the cited European project

DROMOSPLAN, (DROMOSPLAN, 2016-2019) it has been suggested, on one hand, the need for gaining licences to operate drones, new drone control/management skills and new data analysis skills for processing sensor data. But, on the other hand, implications for the way work is organised have been also underlined (e.g. if the work is outsourced, conducted by drone teams or performed within existing teams).

Concerning the engineering, in the Industry 4.0 teaching is based on multiple disciplines and uses an increasing amount of methods, showing the complexity associated with this growing discipline. The new education requirements aim at achieving practical information and knowledge applicable to the business environment, and, in this context, different disciplines should be able to work together. For this reason, designing new integrated engineering programs may close the gap between the universities and the business environment. As Industry 4.0 includes different research areas, such as mechatronic engineering, industrial engineering, and computer science, it is necessary to work in interdisciplinary teams, realizing interdisciplinary tasks and providing interdisciplinary thinking. For this reason, the programs should be updated in order to improve the interdisciplinary skills (Cevik Onar S., 2018). Skills forecast and proactive adjustment will be done, based on the results of this report within the following activities of ESSA project (company skills and VET system requirements).

3.2 Digitalization and Economic Impact

The digital economy can offer new opportunities to companies, including the steel sector. It is important to better understand how digitalization is changing the rules of competition, in order to optimize existing business models and to develop new ones. According to McKinsey's (McKinsey, 2016), real time supply chain optimization, human robot collaboration, smart energy consumption, digital performance management and predictive maintenance are the main implementation areas in manufacturing. On this subject, different actions have to be implemented. In particular, it is necessary to define common standards at European level as well as to share ideas, knowledge and experiences. In addition, a connected economy needs to be based on a robust infrastructure, in order to connect plant and machinery in an extensive and secure way. A digital economy can be successfully achieved through a pan-European coordination based on a harmonized EU-wide approach. Furthermore, the digital transformation of the European manufacturing sector should be quickly achieved in order to be more competitive and, consequently, to avoid the new competitor actions. The most important factors related to the innovative technologies in Industry 4.0 are: reduction of energy and raw material consumption, lower OPEX and reduction of losses as well increase of product qualities and productivity (Herzog, et al., 2018). In (Danieli Automation Research Center, 2018), an automatic scrap yard and autonomous cranes applied in an EAF is depicted. Thanks to the detection and recording of volume and weight for each layer of scrap in the bucket, the recorded scrap information is transferred to EAF for the calculation of the optimized and best melting condition. In such process, the raw materials are a crucial factor and reducing the cost of raw materials is more effective than acting on the transformation cost. According to (McKinsey, 2016), the predictive maintenance can help not only increasing revenues by reducing from 10 to 40% the maintenance costs and by reducing from 10 to 20% of the wastes, but also it can optimize planned downtime, limit unplanned downtime and an estimation of a

reduction by 2 to 10% of the operating cost is also foreseen. Machine learning and predictive maintenance are used to predict when a mechanical device will wear or break. In the metals industry, unplanned shut down time to repair or replace key components due to breakage is extremely costly. By using predictive maintenance methods, actuators can be replaced before they break (Herzog, et al., 2018). Also in the quality issues, the advanced analytics techniques like AI and machine learning can automatically define the basic causes, optimizing the optimal recipes for new products/grades and reducing the rejection rate (McKinsey, 2018).The tools developed in (Klein, et al.) by using AI and machine learning not only facilitate production planning and help to improve due date reliability but also improve overall economic success of the steelmaking company.

4 First Conclusions

The steel industry is becoming smart and more agile evolving towards industry 4.0.

The application of new technologies in this sector already supports and can further sustain the optimization of the entire production chain, although the steel production is already automated to a certain extent and often the systems work in an isolated way.

The steel industry expectations from digitalization include, first of all, the optimization and the interactions of the individual production units, within the entire production chain (and beyond), leading to reach the highest quality, flexibility, and productivity. Adaptive online control, through-process optimization, through-process synchronization of data, zero-defect manufacturing, traceability, intelligent and integrated manufacturing will be the most important digitalization trends in the future. Digitalization offers a range of opportunities to increase quality of finished products, reduce lead time and increase productivity by improving the overall production efficiency of a plant (Nauzin & Kristiaan, 2019)

Digital technologies, through the continuous adjustment and the optimization of the processes online, aim to improve the flexibility and the reliability of processes, to maximize the yield, to improve the product quality and the maintenance practices. Such technologies further contribute to increase the energy efficiency and to monitor and control the environmental performance of processes in an integrated way.

The challenge in digitalization consists in the integration of all systems and productions units, through three different dimensions: Vertical Integration (Integration of systems across the classic automation levels from the sensor to the ERP system); Horizontal Integration (Integration of systems along the entire production chain); Life-cycle Integration (Integration along the entire lifecycle of a plant from basic engineering to decommissioning (Herzog K. W., 2017). In addition, the transversal integration is based on the decisions taken during the steel production chain, considering technological, economic and environmental aspects at the same time. This will only be possible by new IT, automation and optimization technologies and by their combination in an integrated way. In addition, Predictive Maintenance techniques can be implemented by equipment monitoring combined with intelligent decision methods. Machine Learning and Data Mining techniques can be used to anticipate maintenance work before something goes wrong. Moreover,

the maintenance can be scheduled and many checks can be made remotely, resulting in significant improvements in the equipment maintenance. Furthermore, the Knowledge Management represents a key factor for the improvements to be achieved in the digitalization process. In order to overcome the barriers due to heterogeneous distribution over the individual staff members, human obliviousness, and knowledge erosion by leaving staff members, new approaches based, for instance, on the methodology knowledge-based decision support system are developing. In addition, the digitalization process needs a job based on interdisciplinary teams, tasks and thinking, in order to provide interdisciplinary skills. Innovations in science and technology have led to an information-based organization, which transform this information into knowledge to secure competitiveness and improve decision-making.

In order to further support the overall performed analysis, the main outcomes resulting from the dedicated on-line questionnaire will be integrated throughout the current document, according to the developed topics.

Glossary

AI: Artificial Intelligence

BAT: Best Available Techniques

BF: Blast Furnace

BOF: Basic Oxygen Furnace

CEDEFOP: European Centre for the Development of Vocational Training

CPPS: Cyber Physical Production System

CPS: Cyber-Physical System

CCU: Carbon Capture, Storage and Usage

CDA: Carbon Direct Avoidance

DIA: European Digital Industry Alliance

ERP: Enterprise Resource Planning

ESTEP: European Steel Technology Platform

HW: Hammerstein Wiener models

KET: Key Enabling Technologies

ICT: Information Communication Technology

IIOT: Industrial Internet of things

IT: Information Technology

IoT: Internet of Things

PI: Process Integration

RFCS: Research Fund for Coal and Steel

SMEs: Small and Medium-sized Enterprises

SPIRE: Sustainable Process Industry through Resource and Energy Efficiency

TGS: Technical Group Steel

UV: Unmanned Vehicle

Literature (Subtitles)

Abel, J., Hirsch-Kreinsen, H., & Ittermann, P. (2014). Einfacharbeit in der Industrie. Strukturen, Verbreitung und Perspektiven. 109–152.

ACASOS. (Ct No RFSR-CT-2007-0003, 1/07/2007-31/12/2017.). ACASOS, “Alternate carbon sources for sintering of iron ore”, .

AdaptEAF. (Ct. N° RFSP-CT-2014-00004, 01/07/2014-30/06/2017). *Adaptive on-line control of the EAF based on innovative sensors and comprehensive models for improved yield and energy efficiency.*

ALFORAMA. (1/07/2017 – 30/06/2020). *Innovative Al alloy For aircraft structural parts using Additive MAnufacturing technology.* Ct No 755610.

AMABLE. (1/09/2017 – 31/08/2021). *AdditiveManufacturABLE.* Ct No 768775.

AMATHO. (1/12/2016 - 30/11/2021). *A.dditive MA.nufacturing T.iltrotor HO.using .* Ct No 717194.

ArcelorMittal. (2019, April). Integrated Annual Review 2018.

Arens, M., Neef, C., Beckert, B., & Hirzel, S. (2018). Perspectives for digitising energy-intensive industries – findings from the European iron and steel industry. *eceee Industrial Summer Study*, 259-268.

AREUS. (1/9/2013-31/8/2016). *Automation and Robotics for European Sustainable manufacturing.* Ct No 60939.

AUTOADAPT. (Ct. N° RFSR-CT-2015-00030, 01/07/2015-31/12/2018). *Novel automatic model identification and online parameter adaptation for supporting the industrial deployment of model-based process control.*

BCG. (2015). *Man and Machine in Industry 4.0: How Will Technology Transform the Industrial Workforce Through 2015?*

Beltramini, L., Guarnacci, N., Intini, N., & La Forgia, C. (2017). *La Fabbrica Connessa.* 4.0 Guerini.

Benner, C. (2014). *Crowd Work - Zurück in die Zukunft.* Frankfurt am Main.

Berger, R. (2015). (M. Study commissioned by the Federation of German Industries(BDI), A cura di) Tratto da The digital transformation of industry.: www.rolandberger.com/publications/publication_pdf/roland_berger_digital_transformation_of_industry_20150315. pdf

BIOCONCO2. (1/01/2018-31/12/2021). *BIOtechnological processes based on microbial platforms for the CONversion of CO2 from ironsteel industry into commodities for chemicals and plastics.* Ct No 761042.

Bloomberg, J. (2018). *Digitization, digitalization, and digital transformation: confuse them at your peril.* Forbes.

Bogner, E., Voelklein, T., Schroedel, O., & Franke, J. (2016). Study based analysis on the current digitalization degree in the manufacturing industry in Germany. *Procedia CIRP, 57*, 14-19.

Bonin, H., Terry , G., & Ulrich, Z. (2015). Übertragung der Studie von Frey/Osborne (2013) auf Deutschland.

Botthof, A., & Hartman, E. A. (2015). Zukunft der Arbeit in Industrie 4.0,.

Brandenburger, J., Colla, V., Nastasi, G., Ferro, F., Schirm, C., & Melcher, J. (2016). Big Data Solution for Quality Monitoring and Improvement on Flat Steel Production. *IFAC-PapersOnLine,, 49 (20)*, 55-60.

Carbon4PUR. (1/10/2017-30/09/2020). *Turning industrial waste gases (mixed CO/CO2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings.* Ct No 768919.

CarbonNext. (1/09/2016-31/08/2018.). *The Next Generation of Carbon for the Process Industry.* Ct No 723678.

CAxMan. (Ct No 680448). *Computer Aided Technologies for Additive Manufacturing.* 1/9/2015 – 31/8/2018.

CerAMfacturing. (1/10/2015 – 3/09/2018). *Development of ceramic and multi material components by additive manufacturing methods for personalized medical products.* Ct No 678503.

Cevik Onar S., U. A. (2018). Industry 4.0: Managing The Digital Transformation. In A. Ustundag, & E. Cevikcan, *The Changing Role of Engineering Educa-tion in Industry 4.0 Era.* Springer Series in Advanced Manufacturing. Springer, Cham.

Chan, R. (2019, April). *What is the difference between Industry 3.0 and Industry 4.0?* Tratto da https://www.onupkeep.com/answers/predictive-maintenance/industry-3-0-vs-industry-4-0/]

Cheong, J.-H. (2016, October). The Fourth Industrial Revolution: The Winds of Change Are Blowing in the steel industry. *Asian Steel watch*.

CO2RED. (Ct No 745604, 1/03/2018-29/02/2020). Sunlight driven carbon-dioxide reduction: Hybrid catalytic systems consisting of molecular catalysts and light-harvesting Quantum-dots and semiconductors.

COCOP. (2016-2020). *Coordinating Optimisation of COmplex Industrial Processes.* Ct No 723661.

Colla, V., Matino, I., Dettori, S., Petrucciani, A., Zaccara, A., Weber, V., . . . Romaniello, L. (2019). Assessing the efficiency of the off-gas network management in integrated steelworks. *Materiaux et Tecniques, 107*(1).

Colla, V., Nastasi, G., Maddaloni, A., Holzknecht, N., Heckenthaler, T., & Hartmann, G. (2016). Intelligent control station for improved quality management in flat steel production. *IFAC-PapersOnLine, 49 (20)*, pp. 226-231.

Colla, V., Schroeder, A., Buzzelli, A., Abbà, D., Faes, L., & Romaniello, L. (2017). Introduction of Symbiotic Human-robot Cooperation in the Steel Sector: an Example of Social Innovation. *Matériaux et Techniques, Vol. 105*(No. 5-6).

Commission, E. (2013). *Action Plan for a competitive and sustainable steel industry in Europe*. Tratto da https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013DC0407

Commission, E. (2016). *Smart Steel: RFCS - Support steelmaking and use in the 21th Century.* doi:doi:10.2777/232216

Commission, E. (2016, MArch). Steel: Preserving sustainable jobs and growth in Europe. *COM(2016)*(155).

Commission, E. (2017). Digital Skills and Jobs Conference – Digital Opportunities for Europe.

Commission, E. (2017, January). Germany: Industry 4.0, Digital Transformation Monitor.

Commission, E. (2017). *Investing in a smart, innovative and sustainable Industry - A renewed EU Industrial Policy Strategy.*

Commission, E. (2018). A Blueprint for Sectoral Cooperation on Skills (Wave II): Steel. doi:doi:10.2767/735026

Commission, E. (2018). *Research and Innovation funding 2014-2020*. Tratto da https://ec.europa.eu/research/ fp7/ index_en.cfm.

Commission, E. (2018). *Sustainable Process Industry*. Tratto da http://ec.europa.eu/research/industrial_technologies/sus¬tainable-process-industry_en.html.

Commission, E. (2019). *The Impact of the Digital Transformation on EU Labor Markets.* Brussels.

CoPro. (01/11/2016- 30/04/2020). *Improved energy and resource efficiency by better coordination of production in the process industries.* Ct No 723575.

CSM. (2019). *DroMoSplan, Workers safety improvement and significant reduction of maintenance costs by monitoring and inspecting steel plants with a new type of autonomous flying drones"*. Tratto da http://www.dromosplan.eu/homepage

CyberMan4.0. (2018-2021). *Cyber-Physical System-based approach for intelligent data-driven maintenance operations applied to the rolling area.* Ct. No. 800657, 01/09/2018-28/02/2022.

CyberPos. (Ct No. 709669, 01/07/2016-31/12/2019). *Virtual Design of Cyber-Physical Production Optimization Systems for Long Production Factories.*

Danieli Automation Research Center. (2018). Application of digital twinning in the melting shop. Experiences. *ESTEP Workshop on Digital Twinning tecniques.* Charleroi.

DEBACOAT. (1/1/2013 - 31/12/2014). *Development of high-performance barrels with innovative gradient coatings.* Ct No 315417 .

DESDEMONA. (2018-2021). *Detection of steel defects by enhanced monitoring and automated procedure for selfinspection and maintenance.* Ct. N° 800687, 01/06/2018-31/05/2021.

DESTINY. (1/10/2018-31/03/2022). *Development of an Efficient Microwave System for Material Transformation in energy INtensive processes for an improved Yield.* Ct No 820783.

Dettori, S., Matino, I., Colla, V., Weber, V., & Salame, S. (2018). Neural Network-based modeling methodologies for energy transformation equipment in integrated steelworks processes. *Energy Procedia, 158*, 4061-4066.

DIA. (2018). *Industry 4.0 : trends & needs*. Tratto da https://digitalindustryalliance.eu/2018/07/05/industry-4-0-trends-needs/

DIA. (2018). *Re-Finding Industry - Report from the High-Level Strategy Group on Industrial Technologies.*

Directive, C. (2010). *Directive 2010/75/EU of the European Parliament and of the Council.*

DISIRE. (01/01/2015-31/12/2017). *Integrated Process Control based on Distributed In-Situ sensors into raw material and energy feedstock).* Ct n°636834.

DROMOSPLAN. (2016-2019). *Drones for autonomous monitoring of steel plants.* Ct. N° 710066, 01/07/2016-31/12/2019.

DYNERGYSTEEL. (Ct. No. RFSR-CT-2014-00029, 01/07/2014-31/12/2017). *Integrated dynamic energy management for steel production.*

E15.CZ. (2018, September 26). *Českým firmám může ujet inovační vlak, čtvrtina z nich nemá žádnou koncepci digitalizace*. Tratto da https://www.e15.cz/byznys/technologie-a-media/ceskym-firmam-muze-ujet-inovacni-vlak-ctvrtina-z-nich-nema-zadnou-koncepci-digitalizace-1351646

ENCOP. (Ct No RFSR-CT-2009-00032, 1/07/2009 - 31/12/2013). *Development of tools for reduction of energy demand and CO2-emissions within the iron and steel industry based on Energy register, Co2-monitoring and waste heat power generation.*

ESTEP. (2017). *Strategic Research Agenda (SRA).* Tratto da https://www.estep.eu/assets/SRA-Update-2017Final.pdf

ESTEP. (2018, November 21 - 22). *Digital Twin technology in the steel industry:.* Tratto da https://www.estep.eu/assets/Final-Programme-Digital-Twin-WS-21-22-November.pdf

Eureka. (2018). *Eureka projects*. Tratto da http://www.eurekanetwork. org/eureka-projects

EUROFER. (2018, February). DISCUSSION PAPER: Towards an EU Masterplan for a Low Carbon-Competitive European Steel Value Chain.

EUROFER. (2019). ECONOMIC AND STEEL MARKET OUTLOOK 2019-2020 EUROPEAN STEEL SQUEEZED BETWEEN RISING IMPORT PRESSURE AND A DEPRESSED HOME MARKET. Bruxelles.

European, C. (2017). Digital Scoreboard based on Eurostat Community survey ICT usage and e-commerce in enterprises. *EDPR - Europe's Digital Progress Report 2017* .

Eurostat. (2018, March). *Digital economy and society statistics - enterprises.*

EVALHD. (01/07/2012-31/12/2015). *"Refinement of flat steel quality assessment by evaluation of high-resolution process and product data.* Ct No RFSR-CT-2012-00040.

Evangelista, R., Meliciani , V., & Guerrieri, P. (2014, November). The economic impact of digital technologies in Europe. *Economics of Innovation and New Technology, 23*(8). doi:10.1080/10438599.2014.918438

FACTS4WORKERS. (01/12/2014-30/11/2018). - *Worker-Centric Workplaces for Smart Factories.* Grant Agreement n. 636778, H2020. Tratto da http://facts4workers.eu/

Flatt, H., Schriegel, S., Jasperneite, J., Trsek, H., & Adamczyk, H. (2016). Analysis of the Cyber-Security of industry 4.0 technologies based on RAMI 4.0 and identification of requirements. *2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA).* Berlin, Germany.

Forum, W. E. (2017). Digital Transformation Initiative: Mining and Metals Industry.

Foundation, E. M. (2013). Towards the circular economy . Cowes, Ellen MacArthur Foundation.

FreSMe. (1/11/2016-31/10/2020). *From residual steel gasses to methanol .* Ct No 727504.

Frey, C., & Osborne, M. (2013). The Future of Employment: How susceptible are jobs to computerisation? *Oxford Martin*. Tratto da https://www.oxfordmartin.ox.ac.uk/publications/the-future-of-employment/

FUDIPO. (01/10/2016- 30/06/2020). *FUture DIrections for Process Industry Optimization.* Ct No 723523.

Gambin, L., Hogarth, T., Murphy, L., Spreadbury, K., Warhurst, C., & Winterbotham, M. (May 2016). Research to understand the extent, nature and impact of skills mismatches in economy. *BIS research paper number 265*.

GASNET. (Ct No. RFSR-CT-2015-00029, 01/07/2015-30/06/2019). *Optimization of the management of the process gases network within the integrated steelworks.*

GREENEAF. (Ct No RFSR-CT-2009-00004, 1/7/2009-30/06/2012). *Sustainable EAF steel production.*

GREENEAF2. (Ct n° RFSP-CT-2014-00003, 01/07/2014-30/06/2016). *Biochar for a sustainable EAF steel production.*

GrInHy. (Ct No 700300, 1/3/2016- 28/2/2019.). Green Industrial Hydrogen via Reversible High-Temperature Electrolysis.

Groover, M. P. (2001). *Automation, production systems and computer-integrated manufacturing.* 2nd ed. Upper Saddle River, NJ: Prentice Hall,.

Group, S. (2014, July 3). *Datengetriebenes Prognosemodell für den BOF-Konverter – Anwendung von Data Mining in der AG der Dillinger Hüttenwerke, Pressetag Data Mining/ Industrie 4.0 – Vorhersage und Steuerung von Prozessen.* Tratto da https://idw-online.de/de/at¬tachmentdata36931.pdf

H2Future. (Ct No 735503, 01/01/2017-30/06/2021). *Hydrogen Meeting Future Needs of Low Carbon Manufacturing Value Chains.*

Hecht, M. (2017). Industrie 4.0 der Dillinger Weg. *Stahl und Eisen, 137*(4).

Herzog, K. W. (2017). The Digitalization of Steel Production. *BHM Berg- und Hüttenmännische Monatshefte, 162*(11), 504-513.

Herzog, K., Günther, W., Kurka, G., Ankermann, K., Binder, R., & Ringhofer, M. (2018). *The digital transformation of steel production.* Primetals Technologies.

Hirsch-Kreinsen, H. (2016). The future of low skilled-industrial work. *FRIEDRICH-EBERT-STIFTUNG – Division for Economic and Social Policy*.

Hirsch-Kreinsen, H. (2016a). Digitalisation and low-skilled work. *WISO Diskurs*(19).

Hirsch-Kreinsen, H. (2016b). *The future of low-skilled industrial work.* Tratto da https://www.researchgate.net/publication/321635390_THE_FUTURE_OF_LOW-SKILLED_INDUSTRIAL_WORK

Hirsch-Kreinsen, H. (2016c). Digitization of industrial work: development paths and prospects. *Journal for Labour Market Research*, 1-14.

Hirsch-Kreinsen, H., & Ittermann, P. e. (2015). Digitalisierung industrieller.

HISARNA. (1/07/2011-31/12/2014). *Hisarna experimental campaigns B and C.* Ct No RFSR-CT-2011-00002.

Hsu, C.-Y., Kang, L.-W., & Weng, M.-F. (June 20–21, 2016). Big Data Analytics: Prediction of Surface Defects on Steel Slabs Based on One Class Support Vector Machine. *ASME 2016 Conference on Information Storage and Processing Systems.* Santa Clara, California, USA.

HYBRIT. (2016-2024). *Hydrogen Breakthrough Ironmaking Technology.* Tratto da https://www.nordicenergy.org/wp-content/uploads/2017/11/171115-HYBRIT-COP23-Bonn-IEA.pdf

HYPROCELL. (1/11/2016–31/10/2019). *Development and validation of integrated multiprocess HYbrid PROduction CELLs for rapid individualized laser-based production.* Ct No 723538.

I2MSteel. (01/07/2012-31/12/2015). *Development of a new automation and information paradigm for integrated intelligent manufacturing in steel industry based on holonic agent technology.* Ct N° RFSR-CT-2012-00038.

I3UPGRADE. (01/06/2018-31/12/2021). *Integrated and intelligent upgrade of carbon source through hydrogen addition for steel industry.* Ct No 800659.

Iannino, V., Vannocci, M., Vannucci, M., Colla, V., & Neuer, M. (2018). A multi-agent approach for the self-optimization of steel production. *International Journal of Simulation: Systems, Science and Technology, 19 (5)*, pp. 20.1-20.7.

Ibarra, D., Ganzarain, J., & Igartua, J. I. (2018). Business model innovation through Industry 4.0: A review. *Procedia Manufacturing, 22*, 4-10.

IConSys. (01/07/2012-31/12/2015). *Intelligent control station for improved quality management in flat steel production by a next generation decision support system.* Ct. No RFSR-CT-2012-00037.

IDEOGAS. (1/3/2006 – 28/2/2009). *Industrial demonstration of hot gas injection at the blast furnace.* Ct No RFSP-CT-2006-00001.

IERO. (Ct No RFSR-CT-2010-00002, 1/07/2010-30/06/2014). Iron production by electrochemical reduction of its oxide for high CO2 mitigation.

ILO. (2012). Working towards sustainable development: Opportunities for decent work and social inclusion in a green economy. Geneva.

ILO. (2018). The future of work in a changing natural environment: Climate change, degradation and sustainability. Geneva.

INFOMAP. (Ct. N° RFSR-CT-2015-00008, 01/07/2015-31/12/2018). *Integration of complex measurement information of thick products to optimise the through process geometry of hot rolled material for direct application.*

i-SCOOP. (2016). *Digitization, digitalization and digital transformation: the differences.* Tratto da https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/

Jäger, A., Moll , C., & Dr. Lerch, C. (2015). *Fresh look at the use of robots shows positive effect of automation*. (F. ISI, A cura di) Tratto da https://ec.europa.eu/digital-single-market/news/fresh-look-use-robots-shows-positive-effect-automation

Karacay, G. (2018). Talent Development for Industry 4.0. . In G. Karacay, *Industry 4.0: Managing The Digital Transformation.* Springer Series in Advanced Manufacturing. Springer, Cham.

Klein, C., Ptaszyk, K., Runde, W., Dr. Ohm, T., Dr. Bleskov, I., Passon, M., . . . Klein, C. (s.d.). Application of advanced artificial intelligence in the manufacturing execution sistem for metals industry.

KnowDec. (RFSR-CT-2009-00031, 01/07/2009-31/12/2012). *Knowledge management and decision support with special focus to process and quality optimization.*

Liu, S. X. (2016). Innovation Design: Made in China 2025. *Research Gate*.

LoCO2Fe. (1/05/2015-31/10/2018). *Development of a Low CO2 Iron and Steelmaking Integrated Process Route for a Sustainable European Steel Industry.* Ct No 654013.

LOWCARBONFUTURE. (Ct No 800643, 01/04/2018- 31/03/2020.). *Exploitation of projects for low-carbon future steel industry.*

M4CO2. (1/01/2014-31/12/2017). *Energy efficient MOF-based Mixed Matrix Membranes for CO2 Capture.* Ct No 608490.

Marchiori, F., Belloni, A., Benini, M., Cateni, S., Colla, V., Ebel, A., . . . Pietrosanti, C. (2017). Integrated Dynamic Energy Management for Steel Production. *Energy Procedia, 105*, pp. 2772-77.

Marchiori, F., Benini, M., Cateni, S., Vignali, A., Ebel, A., Neuer, M., & Piedimonte, L. (2018). Agent-based approach for energy demand-side management. *Stahl und Eisen, 138 (2)*, pp. 25-29.

Matino, I., Dettori, S., Colla, V., Weber, V., & Salame, S. (2019). Application of Echo State Neural Networks to forecast blast furnace gas production: pave the way to off-gas optimized management. *Energy Procedia, Vol 158*, pp. 4037-42.

Matino, I., Dettori, S., Colla, V., Weber, W., & Salame, S. (2019). Two innovative modelling approaches in order to forecast consumption of blast furnace gas by hot blast stoves. *Energy Procedia, Vol 158*(pp. 4043-48).

McKinsey. (2016). Industry 4.0 after the initial hype: Where manufacturers are finding value and how they can best capture it.

McKinsey. (2018). Unlocking the digital opportunities in metals. *Metals and Mining Practice*.

MORSE. (1/10/2017-30/9/2021). *Model-based optimization for efficient use of resources and energy.* Ct No 768652.

Nauzin, J., & Kristiaan, v. (2019). Digitalziation innovation in automotive strip production. *METEC & 4th ESTAD.* Dusseldorf.

Neef, C., Hirzel, S., & Arens, M. (2018). *Industry 4.0 in the European Iron and steel industry: towards an overview of implementation and perspectives.* Fraunhofer, Institute for Systems and Innovation Research ISI.

NewTech4Steel. (Ct No 800677, 01/06/2018-30/11/ 2021). *Enhanced process stability and product quality in steel production by exploitation of break-through technologies for real-time monitoring, control and forecasting inspired by Big Data concepts.*

Nils Naujok, H. S. (2017). Industry 4.0 in Steel: Status, Strategy, Roadmap and Capabilities. *Future Steel Forum.* Warsaw. Tratto da https://futuresteelforum.com/content-images/speakers/Dr-Nils-Naujok-Holger-Stamm-Industry-4.0-in-steel.pdf

online, O. (2016). digitization, n. Oxford University Press.

OptiScrapManage. (Ct. N° RFSR-CT-2014-00007, 01/07/2014-30/06/2017). *Optimization of scrap charge management and related process adaptation for EAF performances.*

OS'KOVO. (2019). *Private Communication.*

Oxford English Dictionnary, o. (2016). *automation, n.* Oxford University Press.

Oxford English Dictionnary, o. (2016). digitization, n. Oxford University Press.

Panorama, S. (2018, 5). *Skills Forecast: key EU trends to 2030.* Tratto da https://skillspanorama.cedefop.europa.eu/en/analytical_highlights/skills-forecast-key-eu-trends-2030#_drivers_of_occupational_change

Peters, H. (2017). How could Industry 4.0 transform the steel industry? *Future Steel Forum.* Warsaw.

Pfeiffer, S. (2016). Robots, Industry 4.0 and Humans, or Why Assembly Work Is More than Routine Work. *Societies, 6*(16). doi:doi:10.3390/soc6020016

Pfeiffer, S. (2016). The Vision of Industrie 4.0^in the Making—a Case of FutureTold,Tamed,andTraded. *Nanoethics*. doi:10.1007/s11569-016-0280-3

Pfeiffer, S. (2017). Industry 4.0 In The Making - Discourse Patterns and Digital Despotism On The Rise. In K. C. Briken, *The New Digital Workplace: How New Technologies Revolutionise Work.* London: Palgrave.

PLANTTEMP. (Ct. N° RFSP-CT-2015-00026, 01/07/2015-30/06/2018). *Plant wide control of steel bath temperature.*

PRESED. (Ct. No. RFSR-CT-2014-00031, 01/07/2014-31/12/2017). *Predictive Sensor Data mining for Product Quality Improvement.*

PwC. (2016). Strategy& Global Industry 4.0 Survey.

Quality4.0. (Ct N° 788552, 01/06/2018-30/11/ 2021). *Transparent product quality supervision in the age of Industry 4.0.*

RECOBA. (1/1/2015-31/12/2017). *Cross-sectorial real-time sensing, advanced control and optimization of batch processes saving energy.* Ct No 636820.

REGTGF. (Ct No RFSR-CT-2003-00036, 1/09/2003-31/12/2006.). Improvement of top gas fired reheating and direct reduction furnaces for high temperature using innovative regenerative burners.

Reifferscheid, M. (2017). Digitalization in the steel industry.

RenewableSteelGases. (01/03/2017-29/02/2020). *Einbindung erneuerbarer Energie in die Stahlproduktion zur Energieeffizienzsteigerung und Reduktion der CO2-Emissionen.* Tratto da https://projekte.ffg.at/projekt/1819895/pdf

ROBOHARSH. (2016-2019). *Robotic workstation in harsh environmental conditions to improve safety in the steel industry.* Ct. No. 709553, 01/07/2016-30/06/2019.

Roudier, S., Sancho, L. D., Remus, R., & Aguado-Monsonet, M. (2013). *Best Available Techniques (BAT) reference document for iron and steel production: Industrial emissions directive*

2010/75/EU: integrated pollution prevention and control. Seville: Joint Research Centre (Seville site).

RUN2Rail. (1/9/2017- 31/8/2019). *Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles.* Ct No 777564.

S2, O. (Ct No 2017-01327). *Utilisation of organic sludge in metal industry.* 01/05/2017-01/11/2019.

SALCOS. (Ct No 768788, 1/10/2017-30/09/2022). Development of new methodologies for industrial CO2-free steel production by electrowinning.

Schumacher, A. S. (2016). Automation, digitization and digitalization and their implications for manufacturing processes,. *International scientific conference on Innovation and Sustainability,*, pp. 1-6.

SHOCOM. (Ct No RFSR-CT-2005-00001, 1/07/2005-30/06/2008). Short term CO2 mitigation for steelmaking.

SIDERWIN. (1/10/2017-1/09/2022). *Development of new methodologieS for InDustrial CO2-freE steel pRoduction by electroWINning.* Ct No 768788.

SOPROD. (Ct No. RFSR-CT-2014-00028, 01/07/2014-31/12/2017). *Economic and flexible decentral self-optimising production.*

SPIRE PPP Contribution DEI WG 2. (2016). *Strengthening Leadership in Digital Technologies and in Digital Industrial Platforms -Digitization in the Process Industries through the SPIRE PPP.*

SPIRE, A. (2018). *SPIRE 2050 Vision: towards the next generation of European Process Industries.* Tratto da https://www.spire2030.eu/sites/default/files/users/user85/Vision_Document_V5_Pages_Online_0.pdf

SSAB. (2017, May 5). *SmartSteel gets support from Vinnova– The journey toward the "Internet of materials" continues.* Tratto da https://www.ssab.com/company/newsroom/media-archive/2017/05/05/07/01/smartsteel-gets-support-from-vinnova---the-journey-toward-the-internet-of-materials-continues

Stahl. (2016). *Annual report of Steel institute VDEh 2016 - Summary of main topics of technical-scientific joint cooperation and work*. Tratto da https://en.stahl-online.de/wp-content/uploads/2017/04/Jahresbericht_VDEh_2016_E.pdf

Stamm, H., & Naujok, N. (2017). Industry 4.0 in Steel: Status, Strategy, Roadmap and Capabilities. In P. D. Services (A cura di). Warsaw.

Steel Sector Careers. (2019). Blueprint for sectoral cooperation on skills: towards an EU strategy addressing the skills needs of the steel sector.

STEELANOL. (1/05/2015-31/10/2018). *Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry.* Ct No 656437.

STEPWISE. (1/05/2015-30/04/2019). *SEWGS Technology Platform for cost effective CO2 reduction the in the Iron and Steel Industry.* Ct No 640769.

Systems, C.-P. (s.d.). *A Concept Map*. Tratto da http://cyberphysicalsystems.org/

TeleRescuer. (Ct. N° RFCR-CT-2014-00002, 01/07/2014-30/06/2017). *System for virtual TELEportation of RESCUER for inspecting coal mine areas affected by catastrophic events.*

Tokody, D. (2018). Digitising the European industry–holonic systems approach. *Procedia Manuf, 22*, 1015-1022.

TORERO. (Ct No 745810, 1/05/2017-30/04/2020). TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration.

TRACKOPT. (Ct. N° 753592, 01/01/2018-30/06/2021). *Consistent ladle tracking for optimisation of steel plant logistics and product quality.*

ULCOS. (Ct No 515960, 1/9/2004 – 31/8/2010). *Ultra-Low CO2 steelmaking.*

Ustundag, A., & Cevikcan, E. (2017). *Industry 4.0: managing the digital transformation.* Springer.

(Grant Agreement No 695820). *WaterWatt.*

World Economic Forum. (2017, January). Digital Transformation Initiative - Mining and Metals Industry.

Xia, F., Yang, L., Wang, L., & Vinel, A. (September, 2012). Internet of things. *International Journal of Communication Systems, 25*(9), 1101-1102.

Xun, X. (2012, February). From cloud computing to cloud manufacturing. *Robotics and Computer-Integrated Manufacturing, 28*(1), 75-86. doi:https://doi.org/10.1016/j.rcim.2011.07.002

Zhang, F., Liu, M., Zhou, Z., & Shen, W. (2016). An IoT-based online monitoring system for continuos steel casting. *IEEE Intern. Things J, 3*(6), 1355-1363.

Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent manufacturing in the context of industry 4.0: a review. *Engineering, 3*(5), 616-630.

Zhou , K., Liu, T., & Lifeng , Z. (15-17 August 2015). Industry 4.0: Towards Future Industrial. *12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD) .* Zhangjiajie, China.