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 2)

(Status: 31.07.2021)

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:	Technische Universität Dortmund (TUDO)
Funding Scheme:	Erasmus+
Due date of deliverable:	31.07.2021
Actual submission date:	28.07.2021
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:	Maria Murri (CSM SpA) Valentina Colla, Teresa Annunziata Branca (SSSA)
Dissemination level:	Public

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

Content

Executive 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, digital transformation can be considered among the key enabler directly impacting on advanced manufacturing and transversally affecting the pathway towards sustainability. As consequence, it can be said that the technological transformation of 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-intensive industry, like steel manufacturing. 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.

In this context, the need for social innovation is considered as a key factor for the effective implementation of the technological transformation. This means not only upskilled workforce, but also changes in attitude and behaviours that can be supported by digital technologies by improving working conditions and safety, creating qualified jobs and enhancing the workers' competencies. On the other hand, digital innovation can enable and support the social innovation process, facilitating knowledge sharing, cooperative work and networking.

Starting with some necessary definitions, next paragraphs describe the current state of this technological transformation affecting the European steel industry with an analysis of the main developments funded by EU Research Programs achieved in the above fields as well as of the current literature. The list of the relevant EU projects is reported in Annex 1

Digital technologies supporting steel production are discussed in terms of complexity of the steel manufacturing chain and the need of new technologies that go far beyond the conventional automation of industrial production. In fact, such technologies can 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.

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.

However, the lack of qualified personnel is one of the barriers to overcome for an effective implementation of these technologies.

Digitization as a fundamental component of the technological transformation affecting the Energy Intensive Industries (IIEs) is necessary to reach the EU climate objectives, according to the European Green Deal for the European Union (EU) and its citizens. The ambitious objec-

tive foresees on achieving a complete reduction in net emissions of GHGs by 2050 and transforming the EU into a prosperous society, including a modern, resource-efficient and competitive economy through a well-defined Circular Economy model.

Furthermore, the Green Deal sets the transition to a sustainable economy through the identification of instruments that can help the EU to achieve its Zero Carbon ambitions through the progressive reduction of CO_2 emissions. Innovation is focused on green technologies, combined with EU initiatives aimed at Digitising European Industry, which includes a better and growing use of technologies as big data and AI.

The current state of technological transformation in steel industry also includes the analysis of the Best Available Techniques (BAT) document. It 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.

In Chapter 2, current and upcoming developments in digital transformation and Industry 4.0 are analysed, not only according to the four levers of the digital (Digital data, Automation, Connectivity and Digital Customer Access) but also in combination with the development of the green technologies to be implemented in the steel plants to reach the climate objectives. Therefore, digital technologies as enabler of green technologies are defined by the recent EU initiatives for the steel industry: the "Green Steel for Europe" project and the Clean Steel Partnership (CSP).

The "GreenSteel for Europe" project aims at developing an innovative approach based on the combined assessment of promising technologies, industrial transformation scenarios, and policy options and impacts in order to face the decarbonisation of the European steel industry. On the other hand, the CSP and its roadmap defines the R&D&I activities for a sustainable production. According to the CSP roadmap, digitalisation, as enabler, is included among the six areas of intervention comprising different technological pathways (and combinations thereof) with the target of a carbon-neutral steel production. The CSP roadmap also defines the specific contribution of the digital technologies to the development of the different green performances.

Finally, in the current and upcoming developments the role of digital technologies in supporting the social innovation is considered for enabling a wider corporate culture where processes, equipment and products are designed with the aim to improve safety and health of employees. Therefore, digital technologies allow the extensive continuous monitoring and control of processes through process automation, robotization of operations using robots to prevent contact with dangerous substances, fires and explosions, accidents at work, release heavy burdens, etc. In addition, digital technologies aim at releasing workers from process malfunctions, unexpected events, or accidents.

The impact of digitalization on the steel industry workforce as well as the future economic developments are discussed in Chapter 3, where future scenarios consider digitalization enabling a new way of work within efficient plants in order to face the new challenges and to remain competitive and sustainable at the same time. Therefore, steel industries are and will be more and more digitalized, making available vast amount of data from the whole production chain and even from the ecosystem in the areas where steel plants are located.

To describe such scenario, the new term of Industry 5.0 has been coined to highlight the centrality of human beings wherever they are, inside the manufacturing chain or in the neighbour community. Industry 5.0 harmonizes with the paradigm of Industry 4.0 through research and innovation and the transition towards a sustainable, human-centric and resilient European industry. This can allow industry achieving societal goals beyond jobs and growth, in a context where production respects the boundaries of planet and the wellbeing of the industry workers is at the centre of the production process. Furthermore, Industry 5.0 integrates social and environmental European priorities into technological innovation by shifting to a systemic approach the challenges to be faced.

Six categories have been identified to be combined with others, as a part of technological frameworks: (i) Individualised Human-machine-interaction; (ii) Bio-inspired technologies and smart materials; (iii) Digital twins and simulation; (iv) Data transmission, storage, and analysis technologies; (v) Artificial Intelligence; (vi) Technologies for energy efficiency, renewables, storage and autonomy.

The impact on workforce of technological advancements mainly concerns the foreseen change of the industrial activities from human labour centered production to fully automated way. This implies both positive and negative views: the positive view consider the aspect of relieving humans from monotonous and physically strenuous work to be replaced with creative work. Instead, the negative view can be associated with the increase of 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. However, the impact of the digitalization on the low skilled workers is an open issue to be faced in different ways, e.g. up-, reskilling, reduction of "middle" workers (polarization), use of external personnel, etc.

It should also be noted that it is not easy to forecast all the effects on the workforce following the intensive application of these technologies.

Furthermore, the impact of digital technologies on the workforce of the future is also analysed in a dedicated in EU funded project (BEYOND 4.0) whose results suggest to combine professional skills and digital skills on sectoral level and provide indications both for VET systems and stakeholders at regional level. In addition, in WP4 "VET Requirements and Regulations / National VET Systems" of the ESSA project, based on the technological developments and the skills demands, a first explorative VET systems analysis has been performed by identifying the possible and necessary contributions of the different systems in the member states, focusing specifically on five case study countries (Germany, Italy, Poland, Spain, United Kingdom).

Concerning the economic impact of digitalisation, the most important factors related to the innovative technologies in Industry 4.0 are mainly identified as: reduction of energy and raw material consumption, lower OPEX and reduction of losses as well as increase of product qualities and productivity. On the other hand, the increased energy and material efficiency is often forced by external factors such as the market competitiveness.

Technological changes also lead to a new way of managing production through the integration of ICT technologies and operational systems making possible the implementation of ICT applications to the whole supply chain. This leads to a facilitation of the relations among customers and suppliers and the implementation of circular models in a circular economy perspective. However, challenges related cybersecurity requires to be analysed and faced in terms of the safety of the production machinery and the deficiencies in data infrastructure in order to avoid

effects on the on the company's efficiency as well as on business competitiveness.
Finally, it is important to note that, despite the high expectations placed on the new technologies, their successful implementation and introduction in the plants strongly depends on the consideration of the human perspective in all steps of the applied technical solution, in a contest of social innovation.

In the last chapter of this document, the results of the survey addressed to steel companies and carried out in 2019 are reported as well as the relative questionnaire (See Annex 2). The survey results underline and confirm the desk research results by providing direct answers from company representatives.
This deliverable is the updated version the first one released on July 2019 and integrated with the survey results on November 2019.

Differently from the first version of the deliverable, the survey was not carried out because part of this survey will be integrated to form a regular (annual or bi-annual) foresight survey: ESSA European Steel Technology and Skills Foresight Panel (ESSA ETP). It includes not only technological aspects, but also questions from other surveys carried out in other WPs of the project and related to industry steel skills requirements (WP3) and VET (Vocational Education and Training) systems anticipation and support of future skills (WP4). This panel will be a central part of the ESSA Foresight Observatory (ESSA ETF), under construction.

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 waterpower 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 hearth 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 life-cycles 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 inter-connection 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 fulfil 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 fulfil 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 Technological transformation and EU climate objectives

1.4.1 The European Green Deal and the Circular Economy

Energy Intensive Industries (EIIs) are responsible for about 8% of the EU's emissions (Energy-intensive industries, n.d.). The technological development is crucial for achieving environmental sustainability in EIIs, including not only the reduction of emissions but also energy saving. In order to manage the energy transition, energy technologies for resilience and cost reductions as well as a modern policy framework are needed. This can help EIIs to be more competitive at global level. On this subject, different measures can be applied, including 'soft' measures (e.g. good management (Finnerty, 2017), actions in favour of education and behaviour changes) and 'hard' measures (e.g. investments in energy efficiency, such as upgrades or new technology installation). Over the last few years, some strategies have been already addressed at European level, focused on a more sustainable management of materials and resources, and more rational practices in waste management and recycling. In particular, in the European strategy "Europe 2020" three priorities were included: 1) smart growth, based on knowledge and innovation; 2) sustainable growth, based on improvements in the resource efficiency and a greener and more competitive economy implementation; 3) inclusive growth, focused on a high-employment economy with social and territorial cohesion (European, Commission, 2010.). This point is particularly important at the light of the pandemic effects. Concerning energy consumption, in the next few decades, it is expected to increase by 2050, particularly in the EU steel and the chemicals sectors, due to the steel production increase. In addition, the energy consumption from 2011 to 2030 will increase as well, due to the not extensive applications of emerging energy efficient technologies. Nevertheless, in the next few decades, through the commercialisation and application of breakthrough technologies in the steelmaking processes, the trend in energy consumption will become constant (Malinauskaite, 2019). In addition, the EU steel sector will remain competitive in terms of overall costs and quality, due to continuous investments and restructuring, despite increases in energy prices and raw materials, labour and regulatory costs.

Currently, the use of fossil fuels is predominant in worldwide energy consumption. In order to reduce this trend, in the coming years new policies and technological approaches in the usage of primary energy should be applied. Especially the development of low-carbon technologies and the adoption of renewable energy ones represent future challenges for reducing greenhouse gas (GHG) emissions and, consequently, global warming. This will aim to lead also to increased energy sustainability and economic development. In this regard, the International

Energy Agency (IEA) has developed the Energy Technology Perspective (ETP) model for a low-carbon future (International Energy Agency, 2010). In particular, using available technologies, 38% of CO_2 reductions can be achieved, while Carbon Capture and Storage (CCS) and renewable energy technologies can respectively reduce 19% and 17% of emissions. Concerning sustainable development, the EU has been fully committed to deliver on the 2030 Agenda for the Sustainable Development Goals (SDGs), adopted by the UN General Assembly in 2015, as outlined in "Towards a Sustainable Europe by 2030" (European Commission , 2019). Following the Energy Union initiative (European Commission, 2015), the European Commission (EC) launched the European Green Deal for the European Union (EU) and its citizens, foreseeing a new binding climate law to achieve a complete reduction in net emissions of GHGs by 2050 (European Commission, 2019). The aim of the European Green Deal is to transform the EU into a prosperous society, including a modern, resource-efficient and competitive economy. The European Green Deal is also an integral part of actions of the implementation of the 2030 Agenda and sustainable development goals of the United Nations (United Nations, 2015), which is based on 17 sustainable development goals (SDG), preventing climate change through a better natural resource management. In the European Green Deal the economic, environmental and social pillars of Sustainable Development are considered. More in detail, the industrial commitment to achieve a clean and Circular Economy (CE) is recommended, to the aim of improving recovery and recycling rates of materials, as raw materials extraction and materials, fuels and food processing account of about half of the total GHG emissions and most of biodiversity loss and water stress. Furthermore, supplying sustainable raw materials is crucial for clean technologies, space digital, and defense applications.

The European Green Deal will have a large impact of improving process industries, as Europe aims at becoming the world's first climate-neutral continent, such as net-zero GHG emissions by 2050, by cutting GHG emissions, investing in cutting-edge research and innovation and preserving Europe's natural environment. The Green Deal action plan aims at:

- boosting the efficient use of resources by moving to a clean, circular economy;
- restoring biodiversity and cut pollution.

In order to achieve these targets, the required actions include:

- Investing in environmentally friendly technologies;
- Supporting industry to innovate;
- Rolling out cleaner, cheaper, and healthier forms of private and public transport;
- Decarbonizing the energy sector;
- Ensuring that buildings are more energy-efficient;
- Working with international partners to improve global environmental standards.

"A New Circular Economy Action Plan" (European Commission, 2020b), is one of the main building blocks of the European Green Deal, the new agenda of Europe for a sustainable growth, and it should be a tool for creating incentives to promote circular business models. It includes a range of strategic priorities to the EU transition to a "sustainable economic system". In addition, in the plan, CE will induce social benefits such as skills development, the creation of 700,000 jobs and a higher quality of life for citizens. The Green Deal strategy and CE model are focused on preserving resources within the economy when the product life cycle ends, by increasing their sustainable reuse. In this way changes in the value chain, from the product design to new business and market models, are required, leading to turn waste and by-products into new resources and new consumer behavior (Kiss, Ruszkai, & Takács-György, 2019). These actions foresee system changes and technological innovations, particularly in financial models, environmental assessment, society and politics.

The EU goal to reach climate neutrality by 2050 is a key driver of innovation and growth for EU industry and its economy. On this subject, EU is committed to implement both CE and the Green Deal strategy, including more involvement of stakeholders and increase of the ecological awareness among industrial sectors. In particular, EIIs, including the steel sector, playing a key role in the European economy and, according to the European Green, are committed to their decarbonization. Furthermore, significant opportunities and challenges for EIIs can rise in order to achieve a strong international competitiveness (Lechtenböhmer, 2020). As steel, cement, basic chemicals, glass, paper, and other materials sectors in the EU and worldwide are responsible of around one fifth of total GHG emissions, it is crucial an integrated climate and industry strategy. And this strategy represents key element to implement the European Green Deal.

The European Green Deal further suggests that reaching the target requires coordinated investment in environmentally-friendly technologies, support for industrial innovation, cleaner public and private transport, energy-efficient buildings, decarbonizing the energy sector and 'working with international partners to improve global environmental standards' (Peters M. A., 2020). On this subject, the EU can unlock opportunities to successfully establish itself in the growing global climate protection markets as well as to make the transformation process fair also at the regional level.

Furthermore, the Green Deal sets the transition to a sustainable economy through the identification of instruments that can help the EU to achieve its carbon-neutral ambitions. Innovations focused on green technology, combined with EU initiatives aimed at Digitising European Industry, which includes better use of big data and AI. On this subject, companies are incorporating sustainability into their business models in order to improve the corporate image and to save energy and material costs, resulting in industrial resource efficiency. Research can help companies in renewing their business model and better account for environmental sustainability in their business ecosystems. In this context, process industries play a key role to enable a climate neutral energy system and to contribute to a CE. On this subject, the Processes4Planet (P4Planet) partnership aims at transforming European process industries to make them circular and to achieve overall climate neutrality at EU level by 2050, while increasing their global competitiveness (Processes4Planet Roadmap 2050, s.d.). The Process4Planet 2050 roadmap aims at achieving the transition to a climate neutral and circular society not only through technological innovation, but rather through a holistic systemic socio-economic approach. The roadmap outlines the contribution of the process industry to transformations and the connections along the value chains that can enable these transformations. In particular, the P4Planet partnership will aim at achieving 3 general objectives:

1. Developing and deploying climate neutral solutions by bringing technological and non-technological innovations ready for subsequent deployment. On this subject, process industries, responsible of about 749 million tons of CO_2 per yea (European Commission, 2014), will redesign their industrial processes and will rethink their interaction with the energy system.
2. Closing the energy and feedstock loops: process industries will develop and deploy sustainable circular business models by developing technological and non-technological innovations, cross-sectoral collaboration and engagement with the local ecosystem in order to evolve towards resource circularity and resource efficiency. The ambition of P4Planet is to achieve near zero landfilling and near zero water discharge in 2050. In addition, redesigning value chains can lead to recycle all materials and valorising all waste streams by 2050. In addition, in order to become fully circular, process

industries should establish new ways of cooperating (e.g. with the waste management industry and with municipalities).

3. Innovation is fundamental in order to make climate neutral and circular solution more attractive. For this reason, European process industry aims at achieving a global leadership in climate neutral and circular solutions, accelerating innovation and unlocking public and private investment. The competitive position of the European process industries will benefit from a global leadership in these economically attractive solutions.

The investment agenda for process industries over next 30 years will be defined by the partnership, particularly for the key phase in order to commercially deploy sustainable technologies by 2030 (i.e. between 2025 and 2030).

Nevertheless, the application of some specific regulations and policies, on one hand, can encourage, but, on the other hand, can limit the implementation of innovative measures in process industries, such as the steel sector, that has to operate in the global market according to regulations that other countries, out of EU, do not. For this reason, legislation and policies should be clear, consistent, and less bureaucratic. Furthermore, economic incentives can help measures implementation by providing monetary supports to companies, in order to overcome disadvantages for EU companies compared to other countries that do not have the obligation to comply with the same requirements.

1.4.2 The European Green Deal and the European steel industry

Concerning the steel sector, existing EU policy fields should be updated, combined and expanded to achieve crucial objectives, such as carbon neutrality, secure jobs and a prosperous industry. Furthermore, supporting best practice in low-carbon steelmaking can help the whole sector to achieve its goal of sustainability. On this subject, the European Green Deal (European Commission, 2019) is extremely important, as the EU can maintain its leadership in clean and climate-friendly technologies, it can provide a fundamental contribution to preserve the world's climate and resources, and it can improve the competitiveness of their industry. Over the last few decades, new ways of thinking about the relationship between environment and industrial competitiveness have been mainly focused on the involvement of innovation-based solutions, promoting both environmental protection and industrial competitiveness. On this subject, policies and legislation represent drivers for companies to adopt measures and solutions for facilitating and achieving innovation.

The European Green Deal achievements depend on the horizontal, cross-sectoral integration of an industrial strategy and they need to be implemented throughout the full value chain (EUROFER, We are ready – are you? Making a success of the EU Green Deal , 2020). In this regard, the EU steel industry can meet not only its envisaged targets of emissions reductions but also it can remain globally competitive, finding and creating sustainable markets for the green steel products. In order to ensure its international competitiveness, the steel sector, during and beyond the transition towards production of CO_2-lean steel, needs a supportive regulatory framework. The agreement between EU steel industry and the EU institutions and governments leads to establish an action plan to a market for green steel in the period from 2021 to 2030. In this regard, the EU steel industry is committed to significantly achieve the EU's climate objectives through the reduction of CO_2 emissions by 2030 by 30% compared to 2018 (which equates to 55% compared to 1990) and by 80 to 95% by 2050. In addition, steel, when properly used through design-for-dismantling engineering rules, is 100% recyclable, representing a circular material for the EU's key industries (e.g. automotive, mechanical engineering, construction, household goods, packaging, medical devices, sanitary systems, etc.). However, a smooth transition is required in order to align EU policies and regulations and the steel sector in terms of goals that will be achieved and barriers that will be overcome.

In this context, the steel sector aims at implementing new advanced technologies leading to environmental and energy efficiency improvements. However, in order to achieve radical GHGs reductions in industry not only technical and economic challenges must be faced as well as infrastructural, political and institutional challenges should be considered. For instance, by 2050 the EU steel industry will require around 400TWh of electricity CO_2-free electricity every year. This amount of energy also includes the production and the use of hydrogen for switching to hydrogen-based steel production. Furthermore, reducing GHGs requires extensive systemic changes, particularly on infrastructures, such as hydrogen pipelines, power lines, renewable energy generation capacities. In addition, measures aiming at reducing the use of materials and increasing recycling are crucial. On this subject, economic viability is also necessary as a pre-condition for the successful transformation of the steel sector in the coming years. This requires: infrastructure investment planning, implementing solutions in the frame of the European hydrogen strategy, promoting the development of renewable and green electricity at competitive prices, while maintaining the international competitiveness of energy-intensive sectors in global markets, implementing EU wide import strategy for renewable energy and green hydrogen from third countries. On the other hand, as analysed in the next chapters, the skills development in the steel industry will be also considered in order to contribute to achieve European objectives in skills identification and anticipation within this sector. In particular, a social innovation process, combining technological development and social impact by integrating the relevant stakeholder groups and beneficiaries will be developed.

In addition, the transition to a climate-neutral economy will have significant impact on regions with important EIIs. In this regard, in the OECD report specific challenges are included at regional level, aiming to exploit opportunities arising from industrial modernisation, while limiting the costs for involved communities and workers (OECD, 2019). ICT network operators use about 1% of global electricity which corresponds to 0.34% of overall global GHG emissions. On the other hand, ICT can mitigate climate change by reducing costs through energy efficiency and the uptake of renewable energy sources; in addition, ICT can deliver emissions' reductions across the wider economy. Furthermore, about the resource efficiency topic, a life-cycle perspective and end-of-life considerations should be taken into account.

Concerning research, development and innovation, several activities are ongoing in the steel sector. In particular, concerning breakthrough technologies, they include Carbon Direct Avoidance (CDA: hydrogen- and electricity-based metallurgy), Smart Carbon Usage (SCU: Process integration and Carbon Valorisation, CV, Carbon Capture and Usage, CCU) and CCS. In this context, the Clean Steel Partnership (CSP) will provide demonstrators of breakthrough technologies in steelmaking (Carbon Direct Avoidance and Smart Carbon Usage) supported by the Horizon Europe framework programme and the Research Fund for Coal and Steel (RFCS) funds to concretely deliver outcomes according to the European Green Deal mandate. To achieve this goal, the RFCS will provide additional resources for the Clean Steel aims to Horizon Europe and existing R&D programs, such as "Low CO2 Emissions Industry Alliance", Important Projects of Common European Interest (IPCEI) in synchrony with the Next Generation EU (NGEU) instrument. On the other hand, other EU funded programmes are focusing on skills improvements and employment implications (e.g. European Social Fund (ESF), Youth Employment Initiative (YEI), Erasmus for Young Entrepreneur, Programmes managed by EACEA, Erasmus+ - Key Action 3 - Civil Society Cooperation in the field of Youth, etc.).

1.4.3 Industry 4.0 and Circular Economy

In the European industrial context, CE is defined as an economy of closed loops that is restorative or regenerative, and shifting toward the use of renewable energy sources. Although the possible link between resource efficiency and digitization is often not perceived, digital transformation offers great potentials. In particular, digital technologies as enabler of green technologies can help to reduce the consumption of natural resources in the manufacturing industry, enhancing the potential for increasing material and energy efficiency. For instance, process optimisation and monitoring, as well as systems integration, are fundamental for the optimal energy management along the steel production routes. At the same time, the real-time monitoring ensures the product quality, resulting in reducing by-products and wastes. Moreover, the combination of novel tools for a rapid characterization of solid and liquid slags, advanced models and complex data analytics and AI models allows, for instance, the valorization and reuse of slags (one of the main by-products of the steelmaking process) so maximizing the reuse and recycling of slags and implementing the concept of CE.

This leads to several benefits: preservation of the European technological leadership through the maintenance of its competitive position, enabling innovative solutions (including technical, organizational, financial, etc.) and developing new business models, contributing to sustainability by reducing environmental impacts. Both Industry 4.0 and the CE aim at improving products and processes and optimizing resource usage and costs. On one hand, CE can drive the transition of manufacturing industries toward systemic sustainability[1] and, on the other hand, Industry 4.0 can drive innovation and the digital transformation toward smart and resilient manufacturing industries.

The Sustainable Development Goals (SDGs), adopted during the United Nations (UN) General Assembly in 2015, aims at reaching several goals to 2030 (United Nations, 2015). On this subject, digital technologies could have positive effects on SDGs implementation through "green growth" development patterns (Eteris, 2020). In particular, some directions in using digital solutions in sustainability have been defined:

- digital economy and society issues can allow citizens and businesses having full advantage of digital opportunities, although high percentage of population still require some level of digital skills;
- creation of conditions for digital networks and services by EU member states actions with the support from the EU institutions;
- increasing digital priorities in the member states' socio-economic development, including data protection;
- the commercial aspects of the "EU digital society" strategy allow a better access to online goods for consumers and businesses, helping the member states using platforms to enable the creation of focused marketplace

Particularly for the "green growth", digitalisation represents a strong enabler for the implementation of green technologies aiming at the CO_2 reduction. A detailed discussion is reported in

[1] The challenge of Systemic Sustainability is understood as a process global in reach, systemic in scale, and urgent. This requires deliberate decisions to abandon "business-as-usual" approaches, to rethink current practices and engage in actions to transform the underlying fundamentals in order to avoid the collapse and catastrophe of systems that average people depend upon for normal life. https://www.brookings.edu/research/systemic-sustainability-as-the-strategic-imperative-for-the-post-2015-agenda/

the sub-section 2.1, by also highlighting the digital solutions and their contribution to develop green technologies for the steel production.

An important property of industry 4.0 consists in the digital vertical integration of different levels within companies and the digital horizontal integration between different actors in a value chain. On this subject, the companies goal consists in the optimization of production processes, products, and services. In particular, implementing digital solutions should be focused on management system and resources of companies, that, consequently, are defined as smart or intelligent factories. For instance, digital solutions can be implemented in order to optimize material or energy consumptions of specific processes. Furthermore, energy and material savings in the production processes can be achieved through the optimization of machine utilization to an intensive optimum of machines. Overall, the resource-efficient digitization at the process level can result in:

- providing the standardization of information on material and energy consumption;
- processing measurement data via uniform interfaces in information models;
- providing real-time key performance indicators.

On the other hand, CE is appropriate to ensure sustainable growth and continuous improvements in process industries. Their main challenges consist in adopting CE practices, and how the application of data analytics in the framework of Industry 4.0 can help to overcome them (Krishnakumari, 2021).

Making production processes more effective and efficient can be reached by implementing digital solutions on operation/company level, such as business information systems in combination with measurement sensors, smart production services, solutions from information, communication and automation technology (e.g. simulation and forecasting models, self-learning assistance systems and diagnostic tools, or lab-onchip systems for real-time analysis). These changes can make production processes more flexible through the use of networked machines and components that communicate with each other via the Internet and form Cyber-Physical Systems (CPS) and Cyber-Physical Systems of Systems (CPSoS) (see also the well-known concept of “smart factory”) (Biedermann, 2019, July). In addition, the increase in resource efficiency can be achieved through new additive manufacturing processes such as 3D printing technologies, by individualizing the production of components; optimized component structures can lead to weight savings, waste reduction and, consequently, to improved life cycle costs. On the other hand, the introduction of lean management methods within the manufacturing processes can lead to improve resources efficiency, through a continuous process optimization which encompasses the efficient design of the entire value chain. Lean management aims at coordinating all processes and activities in order to avoid any kind of waste along the value chain.

1.5 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.

1.6 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.

Finally, the ongoing project **RoboInspect** (RoboInspect, 1/07/2020-31/12/2023) will develop different types of UVs for autonomous inspections during running production in dangerous areas or near humans. The development will be based on dedicated software for autonomous navigation indoors and outdoors and image analysis to handle large data streams of visual material generated by the UVs’ sensors.

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.
- **Burner 4.0** (Burner4.0, 01/06/2019-30/11/2022): in this ongoing project, combined Industry 4.0 technologies are applied in different areas, such as process optimisation and predictive maintenance, to improve the combustion system, leading to a breakthrough burner concept in the steel industry. IoT, Smart Sensors, Big Data Analytics are among the technologies used and integrated in the existent burners.
- **BLEMAB** (BLEMAB, 01/07/2020-31/12/2023): this ongoing project aims at developing a new measurement device for the Blast Furnace (BF) process stability and management, leading to the optimisation of the resources and energy consumption. The new measurement system is based on the imaging capability of a muons absorption technique to investigate the inner zone of the BF stack and to provide new measures for improving the BF on-line process monitoring.

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 on-going 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. The increased control systems security in steel industry is the objective of the ongoing RFCS project **AutoSurveillance** (AutoSurveillance, 01/06/2019-30/11/2022) where solutions for detecting anomalies along the process route reheating furnace, rolling mill and cooling will be developed. In particular, the system will be able to announce threats, and distinguish between faults and intentional attacks.

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 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~~.~~ A workshop on the concept and operational benefits of the Digital Twins in the steel sector has been held in Brussels (ESTEP, 2018), while a more recent web-workshop was organised to analyze consequences and opportunities offered by AI in steel industry (ESTEP, 2020).

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).

1.7 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 colour 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.

1.8 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 projects 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.

1.9 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 **Al-ForAMA** (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 **HyPro-Cell** (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 reordered.

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.

2.1 Digital technologies as enabler of green technologies

The development of new green technologies needs the digital transformation and tools as enablers, as outlined in the European Green Deal in addressing the role of digital technologies in achieving a sustainable future and a sustainable ecological transition. Therefore, the investments in research and development for green and digital technologies must proceed together leading to a twin transition (digital and green) as the main driver for the European industry's competitiveness. The "green transition" is a good opportunity for EU member states and Europe needs a digital sector that puts sustainability and green growth at its heart, as digital technologies present new opportunities for monitoring of air and water pollution as well as for monitoring and optimising the consumption and usage of energy and natural resources.

The SPIRE (Sustainable Process Industry through Resource and Energy Efficiency)'s new Vision 2050 "Towards the next generation of European Process Industries—Enhancing our cross-sectoral approach in research and innovation" foresees an integrated and digital European Process Industry, delivering new technologies and business models that address climate change and enable a fully circular society in Europe with enhanced competitiveness and impact for jobs and growth (A.SPIRE , 2018). According to the SPIRE's Vision, the future of Europe is based on a strong cooperation across industries to become physically and digitally interconnected. Innovative "industrial ecology" business models will be developed to foster redesigning the European industrial network. On this subject, four "technology drivers" were defined in order to help process industries to achieve their SPIRE ambitions and two transversal enabling topics (i.e. Industrial Symbiosis and Digitalization), that aim at supporting these transformations:

1. "Electrification of industrial processes as a pathway towards carbon neutrality. It aims at adapting industrial processes to the switch towards renewable electricity.
2. Energy mix and use of hydrogen as an energy carrier and feedstock: renewable electricity, low-carbon fuels, bio-based fuels, waste-derived fuels.
3. Capture and use of CO_2 from industrial exhaust gases.
4. Resource efficiency and flexibility. This includes full re-use, recycling or recovery of waste as alternative resources, all possible resource streams to be considered and explored, zero water discharge, maximal recovery of sensible heat from wastewater, full traceability of value chains as a crucial instrument to deploy circular business models and customers' growing demand for product-related information.
5. Industrial symbiosis technologies including industrial–urban symbiosis models.

6. Digitalization of process industries as a potential to accelerate change in resource management, process control, and in the design and the deployment of disruptive new business models”.

The future of the process industry is closely related to the development of several areas (Glavič, 2021), such as climate change with GHGs emissions and ecosystems, energy with renewable sources and efficiency, (critical) raw materials and other resources, water resources and recycling, zero waste and circular economy and resource efficiency, supply chain integration, process design and optimization, process integration and intensification, industrial ecology and life cycle thinking, industrial–urban symbiosis, product design for circularity, digitalization, sustainable transport, green jobs, health and safety, hazardous materials and waste, customer satisfaction, education, and lifelong learning.

Such objectives will bring about a clean energy transition strongly supported by the EU also through targeted research funding programs for the decarbonisation and modernisation of the EIIs, including the steel industry. Therefore, a strategy as a key driver of innovation and growth for industry and to transform the EU into a prosperous, modern, resource-efficient and competitive economy will be implemented. In this context, major technological developments in the coming years in the European steel industry will be in line with the recent European initiatives following the Green Deal strategy and strongly oriented towards the climate objectives in terms of CO_2 reduction and energy and resource efficiencies.

A recent EU initiative directly affecting the steel industry is the project “Green Steel for Europe” (GreenSteel) fostered by EC with a dedicated call in 2019 to supports the EU towards achieving the 2030 climate and energy targets and the 2050 long-term strategy for a climate neutral Europe, with effective solutions for clean steelmaking. To this aim, thanks to the significant stakeholders’ involvement, the project develops an innovative approach based on the combined assessment of promising technologies, industrial transformation scenarios, and policy options and impacts in order to face the decarbonisation of the European steel industry.
In the technology assessment and road mapping report (GreenSteel D1.2, s.d.), the most promising technologies and combination of technologies for carbon-neutral steel production are identified and reported in terms of CO_2 mitigation potential.
Inside the currently addressed CO_2 mitigation pathways in the European steel industry - Carbon Direct Avoidance (CDA), Process Integration (PI) and Carbon Capture and Usage (CCU)- the identified technologies are: Hydrogen-based Direct Reduction (H2-DR), Hydrogen Plasma Smelting Reduction (HPSR), Alkaline Iron Electrolysis (AIE), Molten Oxide Electrolysis (MOE), Carbon Dioxide Conversion & Utilization (CCU), Iron Bath Reactor Smelting Reduction (IB-RSR), gas injection into the BF, substitution of fossil energy carriers by biomass, high-quality steelmaking with increased scrap usage.
The current technological current maturity is also reported in terms of readiness level and their expected development, also in view of the influencing framework conditions, to get out a roadmap.
In a separate report (Collection of possible decarbonisation barriers, D1.5) (GreenSteelD1.5, s.d.), a comprehensive overview is given of all major barriers. Different barriers can be identified, such as technical, organisational, regulatory, or societal, and financial ones. They were identified also via consultations involving steel producers and covering more than 80% of the European steel industry’s CO_2 emissions.
From an economic point of view, the investment needs and the big economic effort requested up to 2050 for the decarbonisation technologies deployment are reported in D2.2 (GreenSteel, s.d.). They range from few hundred MEuro to achieve a first-of-a-kind plant up to 1–2 Billion

Euro to deployment (also some more for more advanced technologies as those based on electrolysers and for combination of technologies with integrated CO_2 storage systems and hydrogen transport infrastructures). The order of magnitude of such costs is much higher (1-2 orders of magnitude) than what available as funding support in Institutional (EU, National) programs (see report 2.4 on Funding) (GreenSteelD2.4).

This calls for blending and sequencing funding strategies (forthcoming D2.5) and the crucial role of the Clean Steel Partnership. All in all, the steel industry and other stakeholders will need to jointly collaborate the technological and economic challenges to face to achieve the Green Deal decarbonisation targets.

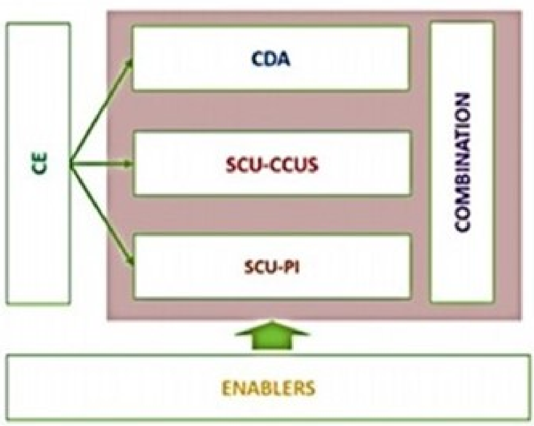
A further EU initiative for the steel industry, under the framework of Horizon Europe associated with the creation of focused Public Private Partnerships (PPP), is the Clean Steel Partnership (CSP), being finalised (ESTEP, 2020). The associated CSP Roadmap, resulting from Steel Producers, R&D&I players and more in general, stakeholders in steel industry, defines the R&D&I activities for a sustainable production by establishing six areas of intervention corresponding to the identified technological pathways and including digitalization and skills as enablers for the implementation of the technologies and combination of technologies for carbon-neutral steel production.

For the steel R&D&I players, the CSP roadmap foresees a technology "building blocks"(BB) approach, where each block is intended as basic actions to provide for decarbonisation technologies. A well-defined "building block" is assigned to enablers also involving digitalization to be treated hereinafter separately. On the other hand, the CSP Roadmap clearly identify the contribution of the digitalization to the development of the green technologies in the different intervention areas, in order to reach the effective decarburisation of steel production.

The CSP Roadmap is hereinafter taken as reference for evidencing how digitisation, among the overall enablers' category, is considered and the role envisaged.

As a matter of fact, more explicitly, in CSP Roadmap - Chapter 2: Research and Innovation Strategy, enablers are included among the six areas of intervention comprising different technological pathways (and combinations thereof) with the target of a carbon-neutral steel production. In *Figure 1* the six areas of intervention are shown based on the technological pathways (CDA: Carbon Direct Avoidance, SCU-CCU: Smart Carbon Usage- Carbon Capture & Utilization, SCU-PI: Smart Carbon Usage Process Integration) and their combination. CE and Enablers are represented by the respective areas of intervention linked to the other ones.

More precisely, enablers are defined as "activities that can support the successful implementation of solutions developed under the other five areas of intervention as well as the global competitiveness of the EU steel industry".



Source: Author's elaboration on consultation with ESTEP members

Figure 1. Link among areas of intervention for carbon-neutral steel production. (Source: CSP Roadmap).

The so-called "Enablers & support actions" are classified under the aim of "strengthening the global competitiveness of the EU steel industry in line with the EU industrial strategy for steel". To this scope, integration is envisaged of the latest technologies, AI and digital solutions in industrial production, as well as the development of new measurement systems and digital tools for monitoring and control, with a massive use of IoT, in the new steel production technologies.
A further line is represented by new predictive and dynamic models and scheduling tools, tailored to process planning, assessment and optimization.
Referring to the technology "building blocks" (BB) approach in the CSP roadmap, enablers are linked to all other technology "building blocks" to provide for decarbonisation technologies.
An overview is given in Table 1.

Table 1. Building blocks contribution's to the six areas (Source: CSP Roadmap)

	Areas of intervention					
Building Blocks (1-12)	CDA	SCU-CCUS	SCU-PI	CE	Combination	Enablers
1.Gas Injection	Major	Minor	Major	Minor	Major	**Minor**
2.Metal oxide reduction	Major	Minor	Major	Major	Major	**Minor**
3.Melting Technology	Major	NO	Major	Minor	Major	**Minor**
4.Adjustment production	Major	Major	Major	Major	Major	**Major**
5.CO/CO_2 utilisation	NO	Major	Major	Minor	Major	**NO**
6.Raw materials preparation	Major	NO	Minor	Major	Major	**Major**
7.Heat generation	Major	Minor	Major	Minor	Major	**Minor**
8.Energy management	Major	Minor	Major	Major	Minor	**Major**
9.Steel specific CE solutions	Minor	Major	Major	Major	Major	**Major**
10.Enablers (Skills, Digitalisation)	**Major**	**Minor**	**Major**	**Minor**	**Major**	**Major**
11.Low CO2 emissions downstream processes	Major	Major	Major	Minor	Major	**Major**
12.Innovative steel applications for low CO2 emissions	Major	Minor	Minor	Minor	NO	**Minor**

Source: Author's elaboration on consultation with ESTEP members.

In some "building blocks", enablers, even with a specific support role, are seen as ancillary to provide on safety, measuring and process control, as well as on integration of steel plants (e.g., EAF) in smart electrical networks, as tools to mitigate network fluctuations or on new sensors and models. In other ones, they are claimed to be relevant. For instance, in BB4 "Production adjustment", new tools are needed to plan and handle those states. In BB8 "Energy", R&D&I in the field envisages, for example, experimentation of analytical methods to identify impurities in scrap and how to remove them before use in EAF. In BB7 "Heat Generation", important know-how and concrete technologies as those involving measurements and control can partly be rated as enablers for future hydrogen-based ironmaking. Besides, under circular economy frame (BB9), a major contribution is expected via definition of a common life cycle Inventory for residues, and design & development of a tool for continuous monitoring of the effects of circular approach/solutions on CO_2 emissions. Concerning the dedicated building block on "Enablers (skills, digitalisation) for clean steel development", enablers are needed to implement the technical and organisational conditions for the planning and management of an effective sustainable steel production.

Particularly, digitalization is expected to ensure that the potential of the latest technologies (e.g. AI, Machine Learning) will be fully exploited for both the global and local control of the integrated manufacturing system and the corresponding tasks. Besides, the activities will consider the key aspect of legacy systems requiring digital technologies to be compatible and interoperable with the new ones, thus ensuring a quick and economically effective application to the industrial production. The new technologies are expected to take benefit from the integration of new digital tools for monitoring and control as well as the extensive use of Industrial Internet of Things (IoT) approach. Such approach allows, for example, the easy and fast integration of the new measurement techniques into the set of data streams to be monitored and used for process setup and control and knowledge extraction. To handle the new process conditions and the corresponding new issues, Machine Learning and AI techniques will play an ever-increasing role, as well as cybersecurity with dedicated strategies.

Taking as a reference the standardized description of the ICT and automation systems (see Figure 2), all three automation levels of Plant Control, Scheduling and Production Planning and Control are involved, with new predictive and dynamic models and intelligent scheduling techniques accounting for the new conditions and issues to enable the automation and execution of the new processes and process chains.

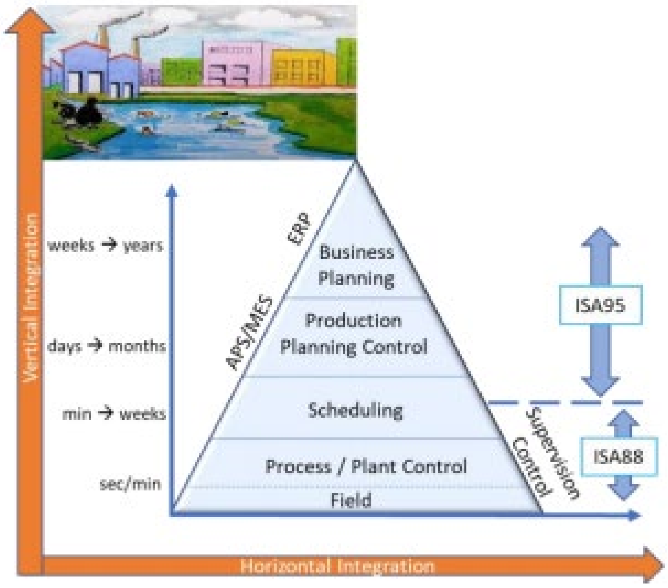


Figure 2. Standardized description of the ICT and automation systems (Source: CSP Roadmap)

The overview of the contribution of digitalisation for clean steel developments to the areas of intervention in CSP is shown in *Figure 3*.

CDA - Major contribution	• The new CDA techniques need new measurement technologies and digital tools e.g. to handle new safety issues (e.g. handling of hydrogen) and upskill/support of staff regarding the new processes with intelligent scheduling of resources and AI-enabled event management.
SCU-CCUS - Minor contribution	• Integration of SCU-CCUS in the process systems needs new measuring technologies and digital tools (e.g. for control of gas circuits)
SCU-PI - Major contribution	• The realisation of SCU-PI technologies needs new measuring technologies and digital tools, this applies in particular for the intermediate transition states (e.g. to handle the influences on gas circuits) • PI in its general definition includes also the optimised combination resp. coordination of processes inside the process chain, thus, this area of intervention also considers techniques which are needed across the whole process chain for optimum process integration inside the future carbon-free steel production chains (closely linked to the area of intervention "Combination of technological pathways").
CE - Minor contribution	• New digital tools are needed to plan, schedule, monitor and control the new material cycles • New tools to support life cycle impact assessment are needed
Combination – Major contribution	• The decarbonisation often includes combinations of techniques which will create several needs for the enablers considered in this building block, e.g. regarding planning, scheduling and automation tools with the extended application of process Digital Twins for in-line and off-line analyses (scenario evaluation, risk assessment etc.)
Enablers & Support Actions - Major contribution	• There are strong links due to the similar focus of building block and area of intervention

Source: Author's elaboration on consultation with ESTEP members.

Figure 3. Contribution of the 'enablers' building block to the six areas of intervention (Souce: CSP Roadmap).

More specifically, process optimisation and monitoring, as well as systems integration, are fundamental for the energy management along the steel production routes. AI-based predictive models can be used for the optimized maintenance and production scheduling. Therefore, digitalisation effectively supports the transaction to the new green technologies, and, at the same time, it will contribute to their development currently at early stages.

Recent EU funded projects, Retrofeed (Retrofeed, 01/11/2019-30/04/2023) and REVaMP (REVaMP, 01/1/2020-30/03/2023) are examples of how digitalisation can provide effective support to the implementation of process improvements in steel production aimed at achieving the materials and energy efficiency. The use of renewable feedstock and industrial residues to complement the current furnace feedstock supply (Retrofeed) and the management of feedstock variability and selection (REVaMP) in steelmaking are different approaches developing resource efficiency and low-carbon technologies in the existent steel plants. Advanced monitoring and control systems as well as a Decision Support System are fundamental in Retrofeed for the supervision of the retrofitting activities and the assessment of the best retrofitting capabilities along the whole production chain.

Similarly, in REVaMP, retrofitting technologies, based on the introduction of sensors for the chemical characterisation of metal scrap, require advanced monitoring and control of the melting process for their adaptation and integration in the existing processes.

Further examples can be provided about digital technologies as enabler of green technologies. One of them concerns the green recycling in the steelmaking, based on EAF, through digital technology applications can be provided. As in the steel production process by EAF the recycled raw material, such as steel-scrap, substitutes the natural raw materials, such as iron ore and coal, steel scrap has become the greenest material of the steel industry, which can gradually enhance the steel quality. The high-tech manufacturing of EAF adapts the recycled steel scrap for reproducing various new steel products, which will make great global contributions in terms of pollution and nature mineral resources. In this context, the concept of ABSC (Activity-Based Standard Costing) integrated into Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) was proposed in order to reach an efficient production management in a digital environment (Tsai, 2019). This analysis aims at supporting smart manufacturing, which includes work forecasting, status monitoring, WIP tracking, throughput tracking and capacity feedback. In addition, ABSC can be used as a costing tool to enhance the business operating abilities of quality, cost, delivery, service, resources, and productivity.

Another example is represented by the RFCS iSlag project, entitled “Optimising slag reuse and recycling in electric steelmaking at optimum metallurgical performance through on-line characterization devices and intelligent decision support systems” (iSlag, 01/07/2020-31/12/2023). It aims at improving EAF slag valorisation, supporting good practices and exploring new recycling paths by integrating innovative measurement devices with modelling and simulation systems, leading to sustainable practices and to reduce slag disposal costs, according to the CE concept. Among other aspects, it aims at developing decision support concepts and systems helping to implement smart slag conditioning practices and optimal slag handling for its internal and external reuse and recycling. This will result in providing operators with easy-to-use tools to support Industrial Symbiosis and CE practices. Furthermore, the RFCS project EnerMIND (EnerMIND, 01/07/2020-31/12/2023) aims at optimizing energy management in steelworks by applying a pioneering software, based on a new IoT/IIoT architecture, able to connect the energy market with the internal energy management. Innovative AI/ML models will be developed for anomaly recognition in energy management so demonstrating the strong contribution of AI techniques to improve the efficiency of the Energy Management System at full scale in the EAF steelmaking route.

Lastly, the challenge of a sustainable steel production with reduced energy consumption and CO_2 emissions is worldwide treated in (International Energy Agency, 2020). The I.E.A. technology Roadmap analyses the key technologies and their integration in steel industry to reach the ambitious goal of at least 50% of CO_2 emissions reduction by 2050. The technological evolution foresees, in a short term, a fundamental role of the technology performance improvement in the current production routes, while in medium-long term new technology based on CCS/CCUS and the substitution of carbon with other energy sources, i.e. hydrogen, will become more and more essential.

Digitalization plays a strategic role in improving the technology performance with the aim of reducing energy and materials consumptions. Process optimisation and monitoring, as well as systems integration, are fundamental for the energy management along the steel production routes. AI-based predictive models can be used for the optimized maintenance and production scheduling. Therefore, digitalisation effectively supports the transaction to the new green technologies, and, at the same time, it will contribute to their development currently at early stages.

2.2 Digital Technologies supporting social innovation

Sustainability refers to the reduction of energy consumption and GHG emissions, to avoid depletion and degradation of natural resources. In order to design a “Green New Deal” it is also crucial to consider the transition as a key issue. To this purpose, in the last few years, progresses have been achieved. In particular, in 2015, guidelines for a just ecological transition (ILO, 2015) and for the Future of Work (ILO, 2019) have been developed. So far, the effort on decarbonisation and climate adaptation efforts with climate and social justice have been focused on (Bergamaschi, 2020):

- creating new quality jobs and inclusive transition processes;
- building resilience to protect groups most exposed to climate impacts;
- achieving the objectives of the Paris Agreement to ensure climate justice for all and for future generations;
- recognising and addressing particular challenges faced by specific sectors, regions, cities and communities most vulnerable to change.

In the next few decades, the draft of National Energy and Climate Plan (NECP) (European Commission, 2019b) has shown that important occupation changes will take place, in particular new jobs in the renewable sector and in the fossil fuels sector. In this context, in EIIs, such as steel, cement and aluminium, and the car manufacturing industry, due to the technological changes, the employment landscape will change. To this aim, governments, industry leaders, associations and trade unions should design and implement new plans for the coming changes.

Due to the need of skills, aiming to achieve a carbon neutral economy by 2050 and the zero-pollution goal, as enshrined in the European Green Deal, EU governments should include up-skilling and reskilling for the energy transition into their National Recovery and Resilience Plans. These plans will outline all projects to be implemented up to 2026. They will have to devote at least 37% of the foreseen expenditure to green investments and reforms to progress towards the achievement of climate action and environmental objectives (Skills for the Energy Transition - A Policy Brief from the Policy Learning Platform on Low-carbon econ-omy, 2021). In this context, it is crucial to look at good practices and policies on energy skills in order to achieve better knowledges on how to promote them for the transition in the next few years to come. In particular, concerning the EU policy and support, the key aspects are:

- stronger climate action under the European Green Deal in order to implement the Paris Agreement will need a review of EU targets on energy efficiency and renewable for 2030;
- the need of actions in order to ensure that workers possess an adequate skillset;
- the nexus between skills and the new transformations is tackled in the Renovation Wave, the Pact for Skills and the European Climate Pact, adopted by the Commission.

In addition, from a regional perspective, it is important:

- setting up a dedicated structure to promote skills to support energy transition;
- establishing regional energy agencies to improve energy efficiency skills and defining the mission/focus of the dedicated structures;
- pushing for adopting fiscal measures in order to carry out renovation works through project proposals on energy efficiency in specific sectors;
- introducing incentives in order to engage SMEs in energy efficiency and support employment at regional level.

Concerning the steel industry, the current deep transformation of this sector is mainly due to the application of digital technologies in all production areas of the steelworks, although this is an ongoing process, and in some company's digital transformation is still marginal. Digital technologies, like AI and AM, can help to optimise resource efficiency and minimising waste. In addition, resilience refers to the development high robustness in industrial production, to support against disruptions and to provide critical infrastructure in times of crisis. This can lead to significant improvements in terms of process efficiency, product quality as well as in socio-economic and environmental sustainability (Colla V. P. C., 2020). On the other hand, the European steel industry is committed to remarkable challenges to address workforce and skill demands to exploit the potential of new technologies (Branca, 2020). From the company perspective, digital transformation aims at using digital technologies and business models to adapt to a changing market and to further improve its performance. This can be successful if it is part of the corporate culture and if it also involves employees. On this subject, it is also important to design a process, its equipment, and products in order to enable safety and health protection of employees. The use of process monitoring and control, automation, even robots to prevent contact with dangerous substances, fires and explosions, accidents at work, release heavy burdens, etc. In addition, digital technologies aim at releasing workers from process malfunctions, unexpected events, or accidents. Significant results of field testing of a robotic workstation have been recently achieved in order to support steelworks operators in the maintenance of the ladle sliding gate (Colla V., 2021). This innovative system represents a human–robot cooperative environment implementation in a harsh and complex workplace. Among other significant features, it can contribute to improve workers' health and safety conditions, promote upskilling of the technical personnel, especially concerning digital skills. In addition, the proposed solutions can be applied to other types of sliding gate in the steel sectors in order to reduce the number of operations which require the human intervention.

On the other hand, digital innovation has a great potential for enabling and supporting the social innovation process, facilitating knowledge sharing, cooperative work and networking. In particular, the integration of digital technological innovations within a social innovation process facilitates collaboration across different backgrounds, and it allows engaging participants on process. In this context, digital technologies are promising tools that can support the collaboration, the knowledge sharing and the networking of various stakeholders, leading not only to emerging skills but also to promote, in particular, the upskilling process.

In this context, a novel approach to the technological development can overcome skills mismatch. Training can ensure the available skillset better matches the skills requirements in industry. This approach, specific for the steel sector, is just the one developed in ESSA project (Sector Skills Alliances - Blueprint "New Skills Agenda Steel": Industry-driven sustainable European Steel Skills Agenda and Strategy) (The ESSA project, n.d.). The same approach is also adopted in two Horizon 2020 projects, such as SAM (Sector Skills Strategy in Additive Manufacturing) (The SAM Project, s.d.) and SPIRE-SAIS (Skills Alliance for Industrial Symbiosis – a cross-sectoral Blueprint for a sustainable Process Industry) (The SPIRE-SAIS project, s.d.).

Concerning digital skills, the World Manufacturing Forum has identified a top-10 of skills that will be needed in future manufacturing, four of them refer to digital skills, such as "digital literacy, AI and data analytics," "working with new technologies," "cybersecurity", and "data-mindfulness". The other six skills are more transversal and linked to creative, entrepreneurial, flexible and open-minded thinking (WMF, 2019). In addition, training and education activities should include:

- upskilling and reskilling regional schemes, based on the results analysis in order to identify missed skills or skills that require upgrading;
- integration of energy efficiency skills into vocational education & training (VET) programmes offered, with flexible and innovative approaches;
- including such concepts into the offer of university-level programmes strictly cooperating with the academic institutions.

Concerning education, the study of science, technology, engineering, and mathematics (STEM) should be promoted and encouraged, because they are fundamental for developing sustainable technologies and processes and the CE.

The above topics are the focus of two complementary WPs of the ESSA project (The ESSA project, n.d.): the WP3 "(Company) Skills Requirements and Foresight" and WP4 "VET Requirements and Regulations / National VET Systems". In particular, the available deliverables[2] of the two WPs provided a first identification and specification of the new skills and training needs within the steel sector, in the context of a growing digitalization (WP3), and, based on the technological developments and the skills demands, a first explorative VET systems analysis, by identifying the possible and necessary contributions of the different systems in the member states, focusing specifically on five case study countries (Germany, Italy, Poland, Spain, United Kingdom) (WP4).

In addition, the situation of the European steelmaking workforce, in terms of the most needed skills, both current and future needs, is analysed in a study carried out in (Steel Sector Careers, 2019). The study also includes the analysis of the current and future skills gaps also due to the increased use of digital technologies in steel plants and the lack of suitable educational programmes.

Finally, the transition to a CE and a sustainable society can be promoted not only by creating the condition of new financial investments, but also by political agreements and legal norms that impose restrictions on countries and companies.

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

[2] https://www.estep.eu/essa/download-area/deliverables/

the weakness in trade and in particular, the investment is at risk of falling behind expectations if the protectionism rise (EUROFER, 2019).

The report (https://new.abb.com/metals/future#Report) describes a future scenario for metal industry where digitalization drives a new way of work within efficient plants in order to face the next 20 years challenges, such as difficulties in the supply of raw materials and energy, plants adaptation for CO_2 abatement, lack of skills following the digitalization and changes in steel consumptions due to new urbanization trends.
The scenario considers that the steel industries are and will be more and more digitalized, making available vast amount of data from the whole production chain and even from the ecosystem in the areas where steel plants are located.
The acquired data need to be opportunely managed and integrated along the production chain, also including the resources optimization and the equipment maintenance, in order to improve the plants efficiency. Furthermore, due to the improved process automation, plants' operator intervention is mainly required for maintenance and the management of unforeseen situations. Operators can be real time supported by augmented reality tools during maintenance activities, while wireless technologies allow the remote control and the real-time supervision of the processes. Finally, advanced material tracking systems, based on technologies able to communicate the material's properties, can allow identifying the products along their life cycle up to the recycling.
The above vision is in line with the transition towards Industry 5.0 where digital technologies can support the social innovation also by improving the working conditions and valorising the worker's competences. In example, artificial intelligence (AI) or robotics contribute to workplace innovation as well as the optimisation of human-machine interactions where, thanks to his expertise, the worker can act as supervisor so avoiding strenuous jobs.

Such transition has already started and some ongoing European projects in Horizon 2020 are already focusing on this direction. Industry 5.0 harmonizes with the paradigm of Industry 4.0 through research and innovation to the transition to a sustainable, human-centric and resilient European industry. This can allow industry achieving societal goals beyond jobs and growth, in a context where production respects the boundaries of planet and the wellbeing of the industry workers is at the centre of the production process (Breque, 2021). On this subject, some actions are foreseen as next steps to Industry 5.0:

- Increasing awareness in industry, but also with European social partners.
- Implementation of a technological landscape to enable the transition for Industry 4.0 to Industry 5.0.
- Identify existing actions and opportunities for the development of Industry 5.0 across Europe.
- Checking regulatory barriers to innovation relevant for Industry 5.0.
- Exploring open innovation and testing new forms of sharing research and innovation results in line with the compliancy to the directives on competitiveness.
- Promoting the hallmark features of Industry 5.0 as guiding principles for the development of common technology roadmaps under the Strategic Innovation Agendas (European Commission, 2020b).
- Outreach to other policy areas, as transition into Industry 5.0 will require a number of policy actions in areas such as social policy, education, taxation, energy, industrial policy, etc.

The continuous innovation in its production processes can allow the European industry improving its efficiency, increasing the flexibility of its production systems. In particular, innovation coming from applying advanced digital technologies, such advanced sensorization, big data and AI, can increase automation, interconnection and optimisation of industrial processes, and this innovation will continue to accelerate. On the other hand, innovation includes not only technological and economic factors, but also environmental and social dimensions.

Concerning Industry 5.0, the integration of social and environmental European priorities into technological innovation and shifting to a systemic approach are crucial aspects. On this subject, 6 categories have been identified to be combined with others, as a part of technological frameworks: (i) Individualised Human-machine-interaction; (ii) Bio-inspired technologies and smart materials; (iii) Digital twins and simulation; (iv) Data transmission, storage, and analysis technologies; (v) Artificial Intelligence; (vi) Technologies for energy efficiency, renewables, storage and autonomy. On the other hand, social changes and transitions will have a profound impact on industry. Some of current political priorities at European level can affect industry. On this subject, the Green Deal, the strategy for making Europe climate-neutral by 2050, will require a transition to a more circular economy and a reliance on sustainable resources including energy. In addition, "Europe Fit for the Digital Age" (European Commission, 2020c) aims at increasing technological innovation in Europe, making digital a priority for Europe, and will offer innovation potentials; furthermore, the European Research Area (ERA) (European Commission, 2020d) will stimulate research and innovation in Europe, while the new European Industrial Strategy (European Commission, 2021a) and Skills Agenda (European Commission, 2020e) aims to address skills shortages. The White Paper on a regulation of AI (European Commission, 2020f), and the European Data Strategy (European Commission, 2020g) show the importance that the European Commission attaches to the societal impact of digital technologies.

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 labour cantered 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).

In the future scenario, Industry 5.0 can positively affect both workers and companies. The benefits for industry comprise better talent attraction and retention, energy savings and increased general resilience. In the long-term, the overall benefit for European industry consists in continued competitiveness while in the shorter-term coordinate investments in Industry 5.0 are required. On this subject, the impact of digital technologies on the workforce of the future is analysed in the project BEYOND 4.0 (01/01/2019-31/12/2022). Key findings of the project can be extended and interpreted also in the steel sector as discussed during the ESSA Mid-term web-conference on 28th May 2020 (Kohlgrüber, 2021). The project BEYOND4.0 (Inclusive Futures for Europe BEYOND the impacts of Industrie 4.0 and Digital Disruption) addresses the general priorities of the H2020 Work Programme (2018-2020) “Europe in a changing world - Inclusive, innovative and reflective societies”. It aims at delivering an inclusive European future by examining the impact of the new technologies on the future of jobs, business models and welfare. This can be done through the analysis of the new technologies on the future of jobs, business models and welfare.

The main results of the projects are:

- Expectable skill gaps. In particular, basic digital skills are needed in 90% of all jobs, as only 58% of individuals in the EU possess these skills.
- The impact on skill shortages for the digital future depends on the responsiveness of national VET systems that is very different. To this aim, in WP4, a first explorative VET systems analysis has been performed by identifying the possible and necessary contributions of the different systems in the member states, focusing specifically on five case study countries (Germany, Italy, Poland, Spain, United Kingdom)[3]
- In order to fill vacancies, it is important the role not only of education and training providers but also the role of employers.

These achieved results in BEYOND4.0 can be useful for different aspects. In particular, it is fundamental to:

- combine professional skills and digital skills on sectoral level.
- train digital and transversal skills by employers, if not provided by the VET systems.
- achieve a strong collaboration of relevant actors at a regional level.
- providing job opportunities for female and older workers, migrants to mitigate skill shortages.

Furthermore, two recent EU projects are mainly focused on the improvement of working con-

[3] https://www.estep.eu/essa/download-area/deliverables/

ditions. In particular, Optimasteel (Optimasteel, 01/06/2019-28/02/2021) addresses the ergonomics problems due to human computer interaction, especially for the ageing workforce. Advanced technological solutions are analyzed in order to provide holistic systems that consider, at the same time, the steel industry needs and the improvement of working conditions for older workers.

About the aging workforce and their difficulties in using the new technologies, the Steel Careers report (Steel Sector Careers, 2019) recommends reverse mentoring, from young to old, particularly for the training on digital skills. That is a sort of exchange in knowledge between workers being the mentorship usually more focused on the training of the young workers by the older ones.

Furthermore, WISEST (WISEST, 01/09/2018-28/02/2022) aims at developing advanced tools where I4.0 enabling technologies are applied both to steelmaking processes and people, by considering the interaction between them, for the assessment of the whole system and for improving working conditions and safety.

Finally, in (IndustriAll, 2020), the impact of COVID-19 pandemic on the European steel sector and its workers is discussed. IndustriAll European Trade Union represents workers across Europe's manufacturing, mining and energy sectors, including the steel sector. Starting from the economics effects on the workforce (temporary layoff and reduced working), several recommendations are addressed to Member States, public authorities and steel companies. Among these, recommendations for a skilled workforce adequate to the technological transformation as well as to the recovery of the European steel industry post pandemic are provided. While investments in workforce upskilling and reskilling are suggested to steel companies, public authorities should focus on "emerging and disappearing occupational profiles and on future skills" and the increase in implementation of pathways between work and education.

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.

The economic benefits coming from the growing application of the digital technologies in steel industry are clearly identified from both the analysis of the EU funded projects and the results of the survey addressed to the steel companies (paragraph 4.2). However, the economic impact of a digitized solution should be evaluated by a quantitative analysis considering both the investment costs and the costs savings.

A model for the evaluation of the economic impact of a digitalization project is presented in (Cheng, 2020) where the proposed quantitative analysis identifies the main factors for cost savings corresponding to the Company's areas more affected by the economic improvements: maintenance, productivity, downtime, quality and personnel. The last one is due to the reduced time in performing low skilled jobs.

As previously mentioned, the implementation of new solution based on digital technologies leads to increased energy and material efficiency, often forced by external factors such as the market competitiveness. This is very important in the current times when there is high pressure to reduce costs caused by competition and environmental issues (Miśkiewicz, 2020). Technological changes can be also achieved through the application of IT technologies and communication systems in managing production. In addition, it is crucial to integrate the IT and operating technologies and to analyse the extent to which this integration met the requirements of resistance to cybersecurity. This is very important, as cybersecurity breaches, exploiting production machinery weaknesses, can lead to negative effects on the company's efficiency as well as on business competitiveness. However, in order to implement circular models, industries are currently facing difficulties, include financial barriers, lack of awareness on the benefits, lack of technical skills, deficiencies in data infrastructure, poor government support and legislation, and a lack of support from the marketplace.

In this context, the challenge to achieve Circular Economy and Bioeconomy in a digital era can be achieved through an integrated and interdisciplinary framework to promote digitalization and innovation in the perspective of sustainability. In this regard, a recent interdisciplinary and multicriteria tool to enable a digicircular model was developed to improve the current models by adding the possibility to customize the choices in a global vision (De Felice, 2021).

4 Survey Analysis

A survey has been carried out to determine the current state of the digital transformation in the European Steel Industry, starting from the existing level of plant automation and considering the possible adoption of the new paradigm of Industry 4.0 as well as the resulting impact on the workforce. To this aim, a questionnaire (See Annex 2) addressed to the European steel

companies was launched at the beginning of June 2019, and made online available up to the end of October 2019 at the following link:
https://cardiff.qualtrics.com/jfe/form/SV_cOVWH19wfk28kdL
After some questions related to the general information, the structure of the questionnaire has been divided in three main areas: Strategy, Technical Aspects and Human Resources.
In the following paragraphs the analysis of the results for each area based on the collected answers is reported. Despite of the consistent number of accesses at the questionnaire, only 28 recorded answers have been considered valid in terms of completeness of the provided information.
Although the sample size is not optimal, a first analysis of the survey results can be drafted considering its representativeness in terms of general information: country of origin of respondents, company size, production route and product types. The respondents are from steel companies located in several European countries. Most of the answers come from large enterprises, involving different professional profiles, i.e. board of director, plant managers, ICT, HRs, etc. All the production routes are represented (with a prevalence of blast furnace route), as well as the product type (with a majority of flat products).

4.1 Strategy

The first part of the questionnaire aimed to assess the state of digitalization and plant automation in the steel industry before the Industry 4.0 paradigm, and the level of both knowledge and interest concerning the I4.0 enabling technologies.
The answers reflect a significant level of plant automation (77,78%) in the steel industry with small percentages of opposite extremes: Basic Automation and full Process Integration.

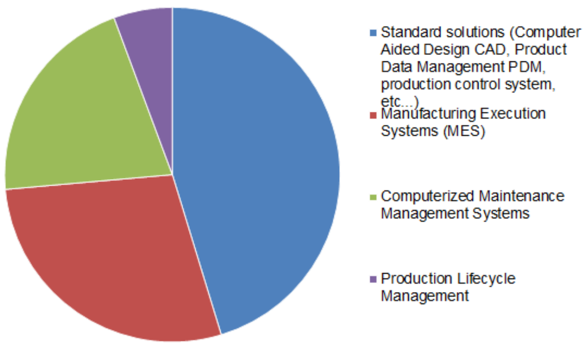


Figure 4 -Traditional solutions currently applied in the steel Companies

Standard solutions like Computer Aided Design (CAD), Product Data Management (PDM), production control system, etc. are generally adopted as shown in *Figure 1*. Such result was expectable, due to the majority of large Companies in the sample, and it confirms that the European steel industry has been moving towards technological improvements in order to be more competitive.
Concerning the I4.0 technologies, it has been required to the participants to rank them according to the company's priority and importance. Apart from the Additive Manufacturing (AM) (the majority of the respondents say to be aware of the AM opportunities and threats to the steel sector), more or less all the listed technologies are interesting for the companies, with a major focus on Internet of Things (IoT), Analytics, Cyber Security and Process Integration (horizontal and vertical). The last one, being an advanced level of automation overcoming the today's hierarchical automation pyramid, is a coherent result given the current automation level in the steel industry. In addition, Process Integration is strongly based on IoT, allowing the communication among different units, but also leading to security problems. Therefore, the listed priorities reflect, in some way, the future trends in terms of interconnectivity and automation.

There is a general and wide knowledge of the new technologies, as expected by the majority of respondents, but not all of these are applied yet. Most of current applications regard IoT, Cloud Computing, Analytics, Cyber Security and Product/Process Virtual Simulation.
The company's investment plans are coherent with the strategic importance of the selected technologies especially within the short term (i.e. 3 years). In fact, the majority of respondents say that there is a strong intention to invest in almost all the I4.0 technologies, with high percentage for Cyber Security, Analytics and IoT applications, as shown in Figure 5.

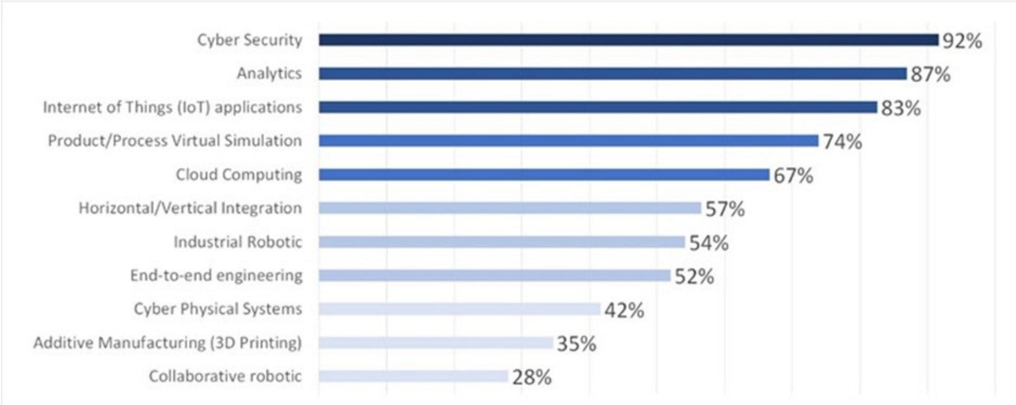


Figure 5 - Planned investments in I4.0 technologies within 3 years

The above results seem to confirm that the steel industry is moving towards I4.0 with several operative applications aiming at increasing its competitiveness. Such trend is supported by the companies' investments mainly planned within the next three years.
The impact of the digital technology adoption on the workforce, according to the answers to a specific question, is considered pretty high by most of the respondents, mainly concerning the aspects related to the need of suitable skills. As a consequence, the major impact is on increasing training, requirement of new skills and upgrading of the existing ones, while workforce deskilling is considered generally less affected.
A strong impact is also reported concerning the aspects directly affecting the employees, like a general improvement of the work conditions, both for the workplace environment and health and safety, as well as the increasing of working time and work-life balance.
Finally, concerning the involvement in the European joint research projects on digitalisation, although the majority of the respondents is participating or plan to participate, a significant percentage is not involved in such projects. Among the participants, about half is currently involved in few projects (< 5) and the remaining is equally divided in a greater number: up to 10 or more. Although no funding programme was mentioned, the respondents show a growing interest in joint research projects.

4.2 Technical Aspects

The technical aspects have been investigated in terms of areas within the company where the digital technologies are most widely applied, considering the expected benefits and major barriers to overcome for their application.
According to the answers, the digitalization is widespread applied in all the listed company's areas with some picks in the process chain control and where the management of large amounts of data is required, i.e. production, business, etc. Maintenance, administration, quality control and HR management are also mentioned among the areas where digitalisation is mostly applied, as shown in *Figure 6*.

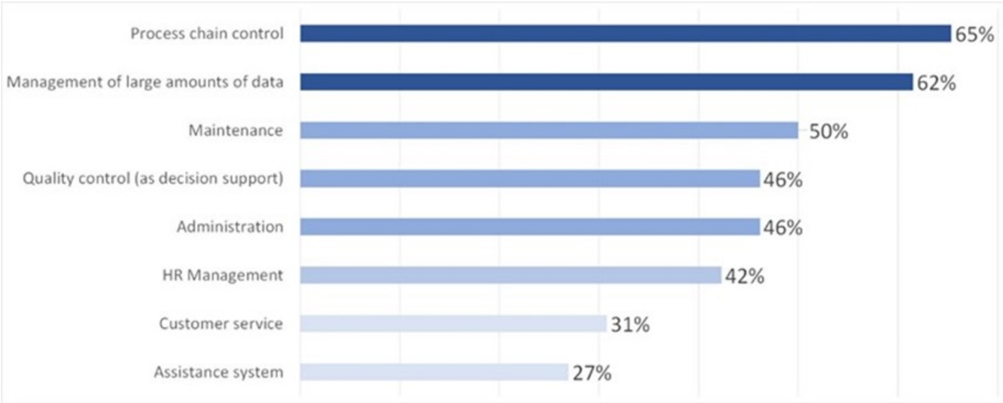


Figure 6 - The level of digitalisation diffusion in the companies' areas

As far as the expected benefits from adopting enabling technologies are concerned, the answers are well distributed among the listed benefits with a small majority focused on production in terms of cost reduction and quality improvement. It is also noteworthy that the benefits for the workers, especially for the increase of workplace safety, are immediately classified after those for production. Environmental benefits, like reduction of wastes, emission, resources are also significantly ranked in the results *(Figure 7*).

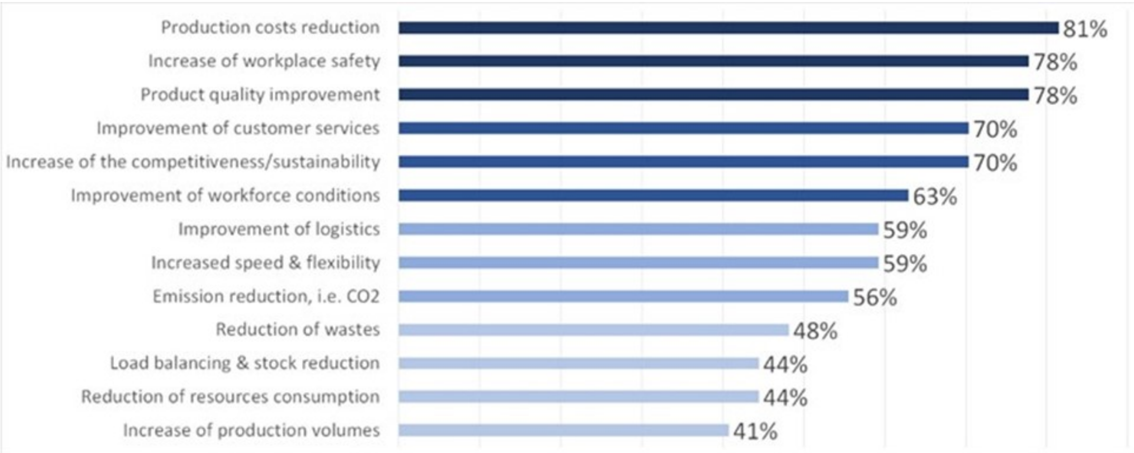


Figure 7- Main expected benefits from the adoption of the enabling technologies

Regarding the major barriers for the adoption and the application of enabling technologies, most of the answers are concentrated in the central categories on the base of their importance (*Less important, Moderately important, Very important*). *Figure 8* shows such distribution, where all the proposed barriers are enough uniformly distributed as *Moderately important*, while the cost of the investment seems to be the most significant barrier within *Important* category.

Conversely, the know-how protection is not considered as an important barrier.

The barriers related to workforce topics (lack of highly skilled workforce, skills gap and acceptance of the new technologies by the workforce) are highlighted as moderately important, but they are also relevant among the important ones.

Among the most important barriers also the obsolescence of plant/infrastructures and equipment have been highlighted as well as the compatibility with existing technologies and process.

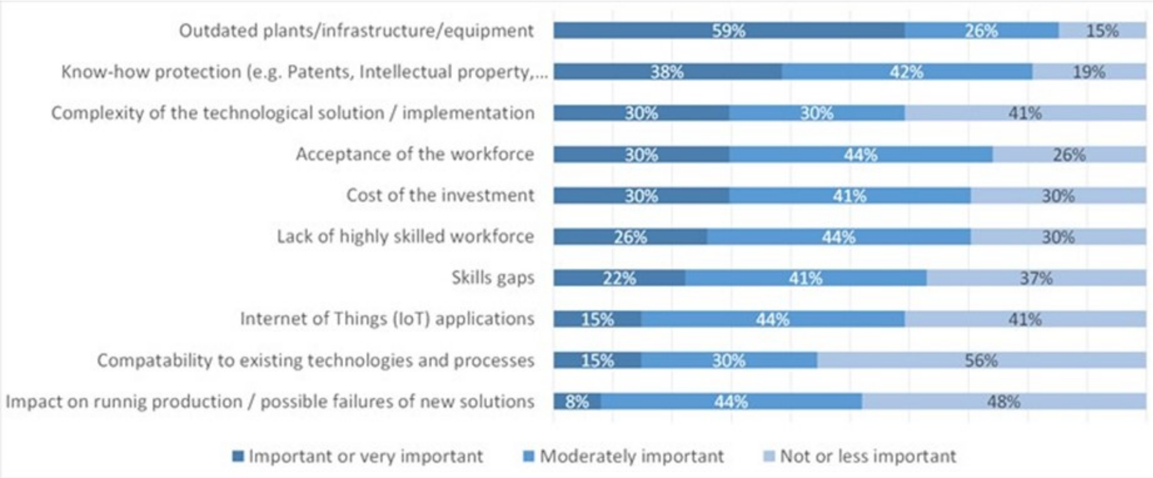


Figure 8 - Main barriers for the application of the enabling technologies

4.3 Human resource

This section focuses on the workforce profiles in the last 5 years considering age and education.
Unfortunately, the answers in this section have not been provided by all the respondents. Therefore, the results are relative to a number of answers (about 19) less than the complete sample.
When considering human resource, one of the key-point of the discussion is related to the gender balance. According to the survey results, within the sample there is an imbalance of male and female percentages in favour of males in all the three considered areas: operations, administration and services. As expected, the maximum imbalance is in the operation area.
Concerning the age profile, the values are not always reported in percentage, as required, but in absolute value. Therefore, due to data inhomogeneity, it is not possible to correctly estimate an effective average value for each age class.
However, according to the available valid data, in the period 2015-2019, the respondents reported a slight workforce age redistribution. In particular, for the workforce less than 25 years old, after a maximum peak in 2015, the percentage has been stabilized in the subsequent years.
Regarding the workforce between 25 and 34 years old, there is an overall stability around, with a slight peak in 2019.There is a substantial rising in the 35-44 age group from 2015-2016 to 2017-2019, opposite to the 45-54 age class, which decreased from 2015-2016 to 2019. The workforce between 55 and 64 years old is enough stabilized in the overall considered period, while the over 64 age group has seen a moderate increase leading to the same percentage in the extreme classes: younger and older workers.
The majority of the production managers and engineers within the respondent companies have a higher education (i.e. Universities, Occupational Colleges, etc.), compared to technicians, operators and apprentices/trainees.
Regarding the future evolution of the companies' workforce (in the next 3-5 years), the respondents are more or less divided between increase the personnel and not. However, the positive answers also evidence a high interest to employ more women to enhance the diversification within teams, and more high qualified people, mainly because of the use of new technologies.
Another important aspect in the human resource field is the awareness of the employee related to the needs for digital competences. Almost all the respondents state that their production

managers and engineers are the most aware, while technicians, operators and apprentices/trainees seems less aware.
Even if to optimally respond to the I4.0 challenges the staff training programs on these topics should be helpful, the majority of the respondents have no scheduled training, whether specific or not on I4.0. The few training programs scheduled are related to training on company's digital products and services, communication, technology, innovation.

This survey was not repeated for this version of the deliverable, because it was decided to integrate part of it to form a regular (annual or bi-annual) foresight survey: ESSA European Steel Technology and Skills Foresight Panel (ESSA ETP). It will include not only technological aspects, but also questions from other surveys carried out in other WPs of the project and related to industry steel skills requirements (WP3) and VET (Vocational Education and Training) systems anticipation and support of future skills (WP4).The panel will be a central part of the ESSA Foresight Observatory (ESSA ETF), under construction.

5 Conclusions So Far

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.

On the other hand, as sustainable processes implementation is a highly interdisciplinary process, it includes an efficient waste management, covering the reuse, recycling, and processing of waste into value-added products, fuels, secondary raw materials, or energy recovery. In addition, it is crucial to develop sustainable technologies, including key enabling technologies and sustainable processes, supply chains, and networks that foster higher efficiency, waste reduction, closed loops, and eco-design. However, the society transformation from a linear to a circular economy will need changes in many areas of society, such as business, education, finance, politics, legislation, and society as a whole.

In this context, research into industrial resilience can help to develop and implement mitigation strategies for the industry in the future. In particular, innovative techniques, such as more modular production lines, remotely operated factories, use of new materials, and real-time risk monitoring and management, can help industry to achieve its resilience. Digital technologies will enable a host of resilient technologies, including data gathering, automated risk analysis and automated mitigation measures. However, as an increased dependence on digital technologies could lead to industrial technical disruptions, due to malfunctions as well as cyberattacks, research and innovation can play a key role in developing the cybersecurity for the resilient industry of the future.

The survey results underline and confirm the desk research results by providing direct answers from Company representatives.
The survey analysis highlighted a significant level of automation in the steel plants as a starting point to evolve towards a technological improvement. Among the I4.0 technologies, in general widely known, the companies' interest and priority are oriented on Internet of Things (IoT), Analytics, Cyber Security and Process Integration (both horizontal and vertical), which are also the most already applied. The same technologies are also mentioned among the planned investment mainly within short time (i.e. 3 years).
The impact of the digital technology on the workforce is considered pretty high both for the need of suitable skills and other aspects directly affecting the employees, like a general improvement of the work conditions, both for the workplace environment and health and safety, as well as the increasing of working time and work-life balance. There is also a growing interest on joint European research projects (no funding programme mentioned for the current and planned ones), although a significant respondents' percentage states to be not yet involved in such projects.

The digitalisation is generally widespread applied in all the company's areas, especially in the process chain control and where the management of large amounts of data is required (i.e. production, business, etc.). The major expected benefits are focused on production (i.e. cost reduction and quality improvement), positive impact on workforce in terms of safer and healthier workplaces, and environmental improvements, i.e. reduction of wastes, emissions, and resources consumptions.

The main barrier for the adoption and the application of the enabling technologies has been essentially individuated in the cost of the investment, that need to be also evaluated considering the obsolescence of plant/infrastructures and equipment as well as the compatibility to existent technologies. It is important also to highlight the barriers related to workforce topics, such as the lack of highly skilled workforce, skills gap and acceptance of the new technologies by the workforce.

In this context, digital transformation and climate change represent the main driver of innovation for European industry. In particular, digital technologies help to increasing energy and resource efficiency and contribute to keeping materials in use for a longer time. In addition, exploiting the synergies between the different EU initiatives can support the CE and companies in their digital transformation. Furthermore, Industry 5.0 will enhance the skills of workers but in the future new skills should be developed, by taking into account possible impacts of AI as well as conflicts between humans and AI. In this context, investments in Industry 5.0 activities can produce benefits both for workers and companies, due to the attraction and retention of talented people and resulting in improving companies' competitiveness.

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

Bibliography

A.SPIRE . (2018). *SPIRE 2050 Vision.* Retrieved from https://cefic.org/app/uploads/2019/02/SPIRE-vision-2050.pdf

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.*

AutoSurveillance. (01/06/2019-30/11/2022). *Automatic surveillance of hot rolling area against intentional attacks and faults.* Ct. No 847202.

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.

Bergamaschi, L. (2020). *There Is No Green Deal without a Just Transition. IAI Commentaries.*

Berger, R. (2015). (M. Study commissioned by the Federation of German Industries(BDI), Ed.) Retrieved from The digital transformation of industry.: www.rolandberger.com/publications/publication_pdf/roland_berger_digital_transformation_of_industry_20150315. pdf

Biedermann, H. (2019, July). Increasing Resource Efficiency Through Digitalization–Chances and Challenges for Manufacturing Industries. *International Joint conference on Industrial Engineering and Operati-ons Management* (pp. 1-11). Springer, Cham.

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.

BLEMAB. (01/07/2020-31/12/2023). *BLast furnace stack density Estimation through on-line Muons ABsorption measurements.* Ct. N°899263.

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,.

Branca, T. F. (2020). The challenge of digi-talization in the steel sector. *Metals, 10*(2), 288.

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.

Breque, M. D. (2021). *Industry 5.0: towards a sustainable, human-centric and resilient European industry.* Luxembourg, LU: European Commission, Directorate-General for Research and Innovation.

Burner4.0. (01/06/2019-30/11/2022). *Development of a new burner concept: Industry 4.0 technologies applied to the best available combustion system for the Steel.* Ct. N°847237.

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?* Retrieved from https://www.onupkeep.com/answers/predictive-maintenance/industry-3-0-vs-industry-4-0/]

Cheng, J. &. (2020). Effects of Digitalization in Steel Industry: Economic Impacts & Investment Model.

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., M. R. (2021). Human-Centered Robotic Development in the Steel Shop: Improving Health, Safety and Digital Skills at the Work-place. *Metals, 11*(4), 647.

Colla V., P. C. (2020). Environment 4.0: How digitalization and machine learning can improve the environmental footprint of the steel production processes. *Matériaux & Techniques, 108*(5-6), 507.

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*. Retrieved from 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*. Retrieved from https://ec.europa.eu/research/ fp7/ index_en.cfm.

Commission, E. (2018). *Sustainable Process Industry*. Retrieved from 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.

Commission, E. (2020). *A New Industrial Strategy for Europe.* Bruxelles.

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”.* Retrieved from 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.

De Felice, F. &. (2021). An interdisciplinary framework to define strategies for digitalization and sustainability: Proposal of a ‘digicircular’ model. *IET Collaborative Intelligent Manufacturing, 3*(1), 75-84.

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*. Retrieved from 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*. Retrieved from 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.*

Energy-intensive industries. (n.d.). Retrieved from https://ec.europa.eu/growth/industry/policy/energy-intensive-industries_en

EnerMIND. (01/07/2020-31/12/2023). *Energy Management in the Era of Industry 4.0.* Ct. No899345.

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

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

ESTEP. (2020). *Proposal for a European Partnership under Horizon Europe Clean Steel - Low Carbon Steelmaking.* Retrieved from https://www.estep.eu/assets/Uploads/ec-rtd-he-partnerships-for-clean-steel-low-carbon-steelmaking.pdf

Eteris, E. (2020). SUSTAINABILITY AND DIGITALIZATION: DOUBLE STRATEGY GUIDELINES IN NATIONAL DEVELOPMENT. *Acta Prosperitatis*(11), 42-185.

Eureka. (2018). *Eureka projects*. Retrieved from 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.

EUROFER. (2020). *We are ready – are you? Making a success of the EU Green Deal* . Retrieved from https://www.eurofer.eu/assets/publications/position-papers/a-green-deal-on-steel update/2020-10-14-EUROFER-Policy-paper-A-Green-Deal-on-Steel_V5.pdf

European Commission . (2019). *Reflection Paper: 'Towards a Sustainable Europe by 2030'.* Brusselles: European Commission.

European Commission. (2014). *A policy framework for climate and energy in the period from 2020 to 2030. Communication, COM(2014) 015 final.* Brussels: European Commission.

European Commission. (2015). *A Framework Strategy for A Resilient Energy Union with A Forward-Looking Climate Change Policy." COM/2015/080 final.* Brussels: European Commission.

European Commission. (2019). *The European Green Deal.* Bruxelles.

European Commission. (2019b). *National energy and climate plans (NECPs)* . Retrieved from https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en

European Commission. (2020b). *A new Circular Economy Action Plan For a cleaner and more competitive Europe. (COM no. 98, 2020).* Brussels, Belgium: European Commission.

European Commission. (2020b). *A new European Research Area: Commission sets new plan to support green and digital transition and EU recovery.* Retrieved from https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_20_1749/IP_20_1749_EN.pdf

European Commission. (2020c). Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age_en

European Commission. (2020d). Retrieved from https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/our-digital-future/era_en

European Commission. (2020e). Retrieved from https://ec.europa.eu/social/main.jsp?catId=1223&langId=en

European Commission. (2020f). *WHITE PAPER On Artificial Intelligence - A European approach to excellence and trust.* Retrieved from https://ec.europa.eu/info/sites/default/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf

European Commission. (2020g). Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en

European Commission. (2021a). Retrieved from https://ec.europa.eu/growth/industry/policy_en

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

European, Commission. (2010.). *Communication No. 2020, 2010. Europe 2020—A Strategy for Smart, Sustainable and Inclusive Growth; (COM no. 2020, 2010).* Brussels, Belgium: Commission of European Communities.

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. Retrieved from http://facts4workers.eu/

Finnerty, N. S. (2017). Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: A methodology. *Energy, 136*, 16-31.

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*. Retrieved from 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.*

Glavič, P. P. (2021). Process Design and Sustainable Development—A European Perspective. *Processes, 9*(1), 148.

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.*

GreenSteel D1.2. (n.d.). *Technology Assessment and Roadmapping (Deliverable 1.2)*. Retrieved from https://www.estep.eu/assets/Uploads/210308-D1-2-Assessment-and-roadmapping-of-technologies-Publishable-version.pdf

GreenSteel. (n.d.). *INVESTMENT NEEDS*. Retrieved from https://www.estep.eu/assets/Uploads/GreenSteel-D2.2-Investment-Needs-Publishable-version.pdf

GreenSteelD1.5. (n.d.). *Collection of possible decarbonisation barriers (Deliverable 1.5)*. Retrieved from https://www.estep.eu/assets/Uploads/210308-GreenSteel-D1-5-Decarbonisation-Barriers-Publishable-version.pdf

GreenSteelD2.4. (n.d.). *REPORT ON FUNDING OPPORTUNITIES TO DECARBONISE THE EU STEEL INDUSTRY.* Retrieved from https://www.estep.eu/assets/Uploads/210319-GreenSteel-D2.4-Publisable-version.pdf

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.* Retrieved from 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.* Retrieved from 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.* Retrieved from 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. (2015). *Guidelines for a Just Transition Towards Environmentally Sustainable Economies and Societies for All.* Retrieved from https://www.ilo.org/global/topics/green-jobs/publications/WCMS_432859.

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

ILO. (2019). *Global Commission on the Future of Work.* Retrieved from https://www.ilo.org/global/topics/future-of-work/WCMS_569528.

IndustriAll. (2020). *European Steel Action Plan.* Brussels: industriAll European Trade Union.

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.*

International Energy Agency. (2010). *Energy technology perspectives: scenarios & strategies to 2050.*

International Energy Agency. (2020). *Iron and Steel Technology Roadmap.* France.

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

iSlag. (01/07/2020-31/12/2023). *Optimising slag reuse and recycling in electric steelmaking at optimum metallurgical performance through on-line characterization devices and intelligent decision support systems.* Ct No 899164 (2020).

Jäger, A., Moll , C., & Dr. Lerch, C. (2015). *Fresh look at the use of robots shows positive effect of automation*. (F. ISI, Editor) Retrieved from 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.

Kiss, K., Ruszkai, C., & Takács-György, K. (2019). Examination of Short Supply Chains Based on Circular Economy and Sustainability Aspects. *Resources, 8*, 161.

Klein, C., Ptaszyk, K., Runde, W., Dr. Ohm, T., Dr. Bleskov, I., Passon, M., . . . Klein, C. (n.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.*

Kohlgrüber, M. (2021). *BEYOND4.0 .* Retrieved from https://www.estep.eu/assets/Uploads/ESSA-Mid-Term-Conference-Kohlgrueber.pdf

Krishnakumari, P. K. (2021). Industry 4.0 and Circular Economy Digitization and Applied Data Analytics. In *An Introduction to Circular Economy* (pp. 349-367). Singapore: Springer.

Lechtenböhmer, S. &. (2020). An integrated climate-industrial policy as the core of the European green deal . In *Energie.* Wuppertal Institut für Klima, Umwelt.

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.

Malinauskaite, J. J. (2019). Energy efficiency in industry: EU and national policies in Italy and the UK. *Energy*, 255-269.

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*.

Miśkiewicz, R. &. (2020). Practical Application of the Industry 4.0 Concept in a Steel Company. *Sustainability, 12*(14), 5776.

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. Retrieved from https://futuresteelforum.com/content-images/speakers/Dr-Nils-Naujok-Holger-Stamm-Industry-4.0-in-steel.pdf

OECD. (2019). *Regions in Industrial Transition: Policies for People and Places.* Retrieved from https://doi.org/10.1787/c76ec2a1-en.

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

Optimasteel. (01/06/2019-28/02/2021). *Optimum working conditions for ageing workers in Steel Industry.* Ct. N° 839990.

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.* Retrieved from 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.

Peters, M. A. (2020). Biodigital technologies and the bioeconomy: The Global New Green Deal? 1-12.

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.*

Processes4Planet Roadmap 2050. (n.d.). Retrieved from https://www.spire2030.eu/content/p4planet-roadmap-2050

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.* Retrieved from https://projekte.ffg.at/projekt/1819895/pdf

Retrofeed. (01/11/2019-30/04/2023). *Implementation of a smart RETROfitting framework in the process industry towards its operation with variable, biobased and circular FEEDstock.* Ct. N° 869939, 01/11/2019-30/04/2023.

REVaMP. (01/1/2020-30/03/2023). *Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes.* Ct. N° 869882.

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.

RoboInspect. (1/07/2020-31/12/2023). *MOBILE ROBOTS FOR INSPECTION OF STEEL PLANTS.* Ct N° 710066.

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.

(2021). *Skills for the Energy Transition - A Policy Brief from the Policy Learning Platform on Low-carbon econ-omy.*

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.* Retrieved from 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.* Retrieved from 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*. Retrieved from 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 (Ed.). 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. (n.d.). *A Concept Map*. Retrieved from 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.*

The ESSA project. (n.d.). Retrieved from https://www.estep.eu/essa/essa-project/

The SAM Project. (n.d.). Retrieved from https://www.skills4am.eu/theproject.html

The SPIRE-SAIS project. (n.d.). Retrieved from https://www.spire2030.eu/sais

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.*

Tsai, W. H. (2019). Activity-based standard costing product-mix decision in the future digital era: green recycling steel-scrap material for steel industry. *Sustainability, 11*(3), 899.

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

United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development; A/RES/70/1.* New York, NY, USA: United Nations.

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

(Grant Agreement No 695820). *WaterWatt.*

WISEST. (01/09/2018-28/02/2022). *4.0 Lean System integrating workers and processes.* Ct. N°793505.

WMF. (2019). *The WMF's Top Ten Skills for the Future of Manufacturing*. Retrieved from https://www.worldmanufacturingforum.org/skills-for-future-manufacturing

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.

Annex 1: Relevant EU funded projects (ordered by Acronym)

Technologies	Description	Acronym	Dates	Program
CO_2 Mitigation: Process Integration (PI)	Alternate carbon sources for sintering of iron ore	**ACASOS**	1/07/2007-31/12/2017	RFCS
Production line simulation / Self-organizing production	Adaptive on-line control of the EAF based on innovative sensors and comprehensive models for improved yield and energy efficiency	**AdaptEAF**	01/07/2014-30/06/2017	RFCS
Additive Manufacturing	Innovative Al alloy For aircraft structural parts using Additive MAnufacturing technology	**ALFORAMA**	1/07/2017 – 30/06/2020	H2020
Additive Manufacturing	AdditiveManufacturABLE	**AMABLE**	1/09/2017 – 31/08/2021	H2020
Additive Manufacturing	A.dditive MA.nufacturing T.iltrotor HO.using	**AMATHO**	1/12/2016 - 30/11/2021	H2020
Robot-Assisted Production	Automation and Robotics for European Sustainable manufacturing	**AREUS**	1/9/2013-31/8/2016	FP7
Self-organizing production	Novel automatic model identification and online parameter adaptation for supporting the industrial deployment of model-based process control	**AUTOADAPT**	01/07/2015-31/12/2018	RFCS
CyberSecurity	Automatic surveillance of hot rolling area against intentional attacks and faults	**AutoSurveillance**	01/06/2019-30/11/2022	RFCS
Sustainable Development	Inclusive Futures for Europe BEYOND the impacts of Industrie 4.0 and Digital Disruption	**BEYOND 4.0**	01/01/2019-31/12/2022	H2020
CO_2 Mitigation: Carbon Capture, Storage and Usage (CCU)	BIOtechnological processes based on microbial platforms for the CONversion of CO_2 from iron steel industry into commodities for chemicals and plastics.	**BIOCONCO2**	1/01/2018-31/12/2021	H2020
Measurement Devices	BLast furnace stack density Estimation through on-line Muons ABsorption measurements	**BLEMAB**	01/07/2020-31/12/2023	RFCS

Technologies	Description	Acronym	Dates	Program
IoT/Analytics/Process simulation/AM	Development of a new burner concept: Industry 4.0 technologies applied to the best available combustion system for the Steel Industry	**BURNER 4.0**	01/06/2019-30/11/2022	RFCS
CO2 Mitigation: Carbon Capture, Storage and Usage (CCU)	Turning industrial waste gases (mixed CO/CO2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings	**Carbon4PUR**	1/10/2017-30/09/2020	H2020
CO2 Mitigation: Carbon Capture, Storage and Usage (CCU)	The Next Generation of Carbon for the Process Industry	**CarbonNext**	1/09/2016-31/08/2018	H2020
Additive Manufacturing	Computer Aided Technologies for Additive Manufacturing	**CAxMan**	1/9/2015 – 31/8/2018	H2020
Additive Manufacturing	Development of ceramic and multi material components by additive manufacturing methods for personalized medical products	**CerAMfacturing**	1/10/2015 – 3/09/2018	H2020/ FOF
CO2 Mitigation: Process Integration (PI)	Sunlight driven carbon-dioxide reduction: Hybrid catalytic systems consisting of molecular catalysts and light-harvesting Quantum-dots and semiconductors	**CO2RED**	1/03/2018-29/02/2020	H2020
Cross-sectorial digital solution/Monitoring and Control	Coordinating Optimisation of COmplex Industrial Processes	**COCOP**	1/10/2016-31/3/2020	H2020/ SPIRE
Cross-sectorial digital solution/Monitoring and Control	Improved energy and resource efficiency by better coordination of production in the process industries	**CoPro**	01/11/2016-30/04/2020	H2020/ SPIRE
BigData Analytics & Cloud Computing Cyber Physical System Predictive Maintenance	Cyber-Physical System-based approach for intelligent data-driven maintenance operations applied to the rolling area	**CyberMan4.0**	01/09/2018-28/02/2022	RFCS
Production line simulation Self-organizing production Cyber Physical System	Virtual Design of Cyber-Physical Production Optimization Systems for Long Production Factories	**CyberPos**	01/07/2016-31/12/2019	RFCS

Technologies	Description	Acronym	Dates	Program
Additive Manufacturing	Development of high-performance barrels with innovative gradient coatings	**DEBACOAT**	1/1/2013 - 31/12/2014	FP7-SME
Robot-Assisted Production/Self-organizing production	Detection of steel defects by enhanced monitoring and automated procedure for self-inspection and maintenance	**DESDEMONA**	01/06/2018-31/05/2021	RFCS
CO2 Mitigation: Process Integration (PI)	Development of an Efficient Microwave System for Material Transformation in energy INtensive processes for an improved Yield	**DESTINY**	1/10/2018-31/03/2022	H2020/ SPIRE
Cross-sectorial digital solution/Integrated Process Control	Integrated Process Control based on Distributed In-Situ sensors into raw material and energy feedstock	**DISIRE**	01/01/2015-31/12/2017	H2020/ SPIRE
Robot-Assisted Production	Drones for autonomous monitoring of steel plants	**DROMOSPLAN**	01/07/2016-31/12/2019	RFCS
Self-organizing production Vertical/Horizontal Integration	Integrated dynamic energy management for steel production	**DYNERGYSTEEL**	01/07/2014-31/12/2017	RFCS
Production line simulation	Refinement of production scheduling through dynamic product routing, considering realtime plant monitoring and optimal reaction strategies	**DynReAct**	01/06/2019-30/11/2022	RFCS
CO2Mitigation: Process Integration (PI)	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.	**ENCOP**	1/07/2009 - 31/12/2013	RFCS
IoT/IIoT Artificial Intelligence/ Machine Learning	Energy Management in the Era of Industry 4.0	**EnerMIND**	01/07/2020-31/12/2023	RFCS
I4.0 technologies (Analytics, AI/LM) for product quality	Refinement of flat steel quality assessment by evaluation of high-resolution process and product data	**EVALHD**	01/07/2012-31/12/2015	RFCS
Worker-centric & data-driven technology	Worker-Centric Workplaces for Smart Factories	**FACTS4WORKERS**	01/12/2014-30/11/2018	H2020

Technologies	Description	Acronym	Dates	Program
CO2 Mitigation: Carbon Capture, Storage and Usage (CCU)	From residual steel gasses to methanol	**FreSMe**	1/11/2016-31/10/2020	H2020
Cross-sectorial digital solution/Optimization ML models	FUture DIrections for Process Industry Optimization	**FUDIPO**	01/10/2016-30/06/2020	H2020/ SPIRE
Production line simulation / Smart supply market	Optimization of the management of the process gases network within the integrated steelworks	**GASNET**	01/07/2015-30/06/2019	RFCS
CO2 Mitigation: Process Integration (PI)	Sustainable EAF steel production	**GREENEAF**	1/7/2009-30/06/2012	RFCS
CO2 Mitigation: Process Integration (PI)	Biochar for a sustainable EAF steel production	**GREENEAF2**	01/07/2014-30/06/2016	RFCS
CO2 Mitigation/Reduction	Green Steel For Europe	**GREENSTEEL**	01/01/2020-30/06/2021	RFCS
CO2 Mitigation: Carbon Direct Avoidance (CDA)	Hydrogen Meeting Future Needs of Low Carbon Manufacturing Value Chains	**H2Future**	01/01/2017-30/06/2021	H2020 Hydrogen Europe & N.ERGHY
CO2 Mitigation: Process Integration (PI)	Hisarna experimental campaigns B and C	**HISARNA**	1/07/2011-31/12/2014	RFCS
Additive Manufacturing	Development and validation of integrated multiprocess HYbrid PROduction CELLs for rapid individualized laser-based production	**HYPROCELL**	1/11/2016–31/10/2019	H2020/ FOF
I4.0 Enalbing technologies for integrated manufacturing	Development of a new automation and information paradigm for integrated intelligent manufacturing in steel industry based on holonic agent technology.	**I2MSteel**	01/07/2012-31/12/2015	RFCS
CO2Mitigation: Captur Carbon Capture, Storage and Usage (CCU)	Integrated and intelligent upgrade of carbon source through hydrogen addition for steel industry	**I³UPGRADE**	01/06/2018-31/12/2021	RFCS
Automatic Monitoring and Control	Intelligent control station for improved quality management in flat steel production by a next generation decision support system	**IConSys**	01/07/2012-31/12/2015	RFCS
CO2 Mitigation: Process Integration (PI)	Industrial demonstration of hot gas injection at the blast furnace	**IDEOGAS**	1/3/2006 – 28/2/2009	RFCS
CO2 Mitigation: Carbon Direct Avoidance (CDA)	Iron production by electrochemical reduction of its oxide for high CO2 mitigation	**IERO**	1/07/2010-30/06/2014	RFCS

Technologies	Description	Acronym	Dates	Program
Self-Organizing Production	Integration of complex measurement information of thick products to optimise the through process geometry of hot rolled material for direct application	**INFOMAP**	01/07/2015-31/12/2018	RFCS
Circular Economy/Decision Support System	Optimising slag reuse and recycling in electric steelmaking at optimum metallurgical performance through on-line characterization devices and intelligent decision support systems	**iSlag**	01/07/2020-31/12/2023	RFCS
Digitalization of knowledge management	Knowledge management and decision support with special focus to process and quality optimization	**KnowDec**	01/07/2009-31/12/2012	RFCS
CO2 Mitigation: Process Integration (PI)	Development of a Low CO2 Iron and Steelmaking Integrated Process Route for a Sustainable European Steel Industry	**LoCO2Fe**	1/05/2015-31/10/2018	H2020
CO2 Mitigation: dissemination	Exploitation of projects for low-carbon future steel industry	**LOWCARBONFUTURE**	01/04/2018-31/03/2020	RFCS
CO2 Mitigation: Carbon Capture, Storage and Usage (CCU)	Energy efficient MOF-based Mixed Matrix Membranes for CO2 Capture	**M4CO2**	1/01/2014-31/12/2017	FP7-ENERGY
Cross-sectorial digital solution/resources optimisation	Model-based optimization for efficient use of resources and energy	**MORSE**	1/10/2017-30/9/2021	H2020
BigData Analytics & Cloud Computing	Enhanced process stability and product quality in steel production by exploitation of breakthrough technologies for real-time monitoring, control and forecasting inspired by Big Data concepts	**NewTech4Steel**	01/06/2018-30/11/ 2021	RFCS
Human computer interaction & Health	Optimum working conditions for ageing workers in Steel industry	**Optimasteel**	01/06/2019-28/02/2021	RFCS
Production line simulation	Optimization of scrap charge management and related process adaptation for EAF performances	**OptiScrapManage**	01/07/2014-30/06/2017	RFCS

Technologies	Description	Acronym	Dates	Program
CO2 Mitigation: Process Integration (PI)	Utilisation of organic sludge in metal industry	**OSMet S2**	01/05/2017-01/11/2019	Swedish Innovation Agency
Self-Organizing Production	Plant wide control of steel bath temperature	**PLANTTEMP**	01/07/2015-30/06/2018	RFCS
Big data Analytics and Cloud Computing/Self-Organizing Production	Predictive Sensor Data mining for Product Quality Improvement	**PRESED**	01/07/2014-31/12/2017	RFCS
BD Analytics &Cloud Computing/Smart supply Network/Vertical/Horizontal Integration	Transparent product quality supervision in the age of Industry 4.0	**Quality4.0**	01/06/2018-30/11/ 2021	RFCS
Cross-sectorial digital solution/process optimiation	Cross-sectorial real-time sensing, advanced control and optimization of batch processes saving energy	**RECOBA**	1/1/2015-31/12/2017	H2020/ SPIRE
CO2 Mitigation: Process Integration (PI)	Improvement of top gas fired reheating and direct reduction furnaces for high temperature using innovative regenerative burners.	**REGTGF**	1/09/2003-31/12/2006	RFCS
CO2 Mitigation/Process Integration (PI)/ Control system&DSS	Implementation of a smart RETROfitting framework in the process industry towards its operation with variable, biobased and circular FEEDstock	**Retrofeed**	01/11/2019-30/04/2023	H2020/ SPIRE
CO2Mitigation/Process Integration (PI)/Control system&DSS	Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes	**REVaMP**	01/1/2020-30/03/2023	H2020/ SPIRE
Robot-assisted production	Robotic workstation in harsh environmental conditions to improve safety in the steel industry	**ROBOHARSH**	01/07/2016-30/06/2019	RFCS
Robot-Assisted Production	Mobile robots for inspection of steel plants	**RoboInspect**	1/07/2020-31/12/2023	RFCS
Additive Manufacturing	Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles	**RUN2Rail**	1/9/2017-31/8/2019	H2020
CO2 Mitigation: Carbon Direct Avoidance (CDA)	Development of new methodologies for industrial CO2-free steel production by electrowinning	**SALCOS**	1/10/2017-30/09/2022	-

Technologies	Description	Acronym	Dates	Program
CO_2 Mitigation: Process Integration (PI)	Short term CO_2 mitigation for steelmaking	**SHOCOM**	1/07/2005-30/06/2008	RFCS
CO_2 Mitigation: Carbon Direct Avoidance (CDA)	Development of new methodologieS for InDustrial CO_2-freE steel pRoduction by electroWINning	**SIDERWIN**	1/10/2017-1/09/2022	H2020/ SPIRE
Production line simulation/ Self-organizing production	Economic and flexible decentral self-optimising production	**SOPROD**	01/07/2014-31/12/2017	RFCS
CO_2 Mitigation: Carbon Capture, Storage and Usage (CCU)	Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry	**STEELANOL**	1/05/2015-31/10/2018	H2020
CO_2 Mitigation: Process Integration (PI)	SEWGS Technology Platform for cost effective CO_2 reduction the in the Iron and Steel Industry	**STEPWISE**	1/05/2015-30/04/2019	H2020
Augmented Reality	System for virtual TELEportation of RESCUER for inspecting coal mine areas affected by catastrophic events.	**TeleRescuer**	01/07/2014-30/06/2017	RFCS
CO_2 Mitigation: Process Integration (PI)	TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration	**TORERO**	1/05/2017-30/04/2020	H2020
IoT/BD Analytics/Cloud Comp./Self-Organizing Production/Self-driving logistics vehicles	Consistent ladle tracking for optimisation of steel plant logistics and product quality	**TRACKOPT**	01/01/2018-30/06/2021	RFCS
CO_2 Mitigation: Carbon Direct Avoidance (CDA)	Ultra-Low CO_2 steelmaking	**ULCOS**	1/9/2004 – 31/8/2010	FP-NMP
I4.0 Enalbing technologies for energy efficiency	Improvement of energy efficiency in industrial water circuits using gamification for online self-assessment, benchmarking and economic decision support	**WaterWatt**	1/4/2016-31/3/2019	H2020
I4.0 Enabling technologies for processe&people	4.0 Lean System integrating workers and processes (Worker Integration SystEm in STeal processes)	**WISEST**	01/09/2018-28/02/2022	RFCS

Annex 2: ESSA Questionnaire

Questionnaire ESSA

ESSA Survey for digital transformation in European Steel Industry

INTRODUCTION

Background
Economic, digital and technological developments as well as energy efficiency demands are challenging the Steel Industry. Such rapid and constant change necessitates updated qualifications, knowledge and skills. For the Steel Industry this is relevant because of innovation in high-tech production processes and energy efficiency. A continuously updated skilled workforce is required to stay competitive, to adapt to digital transformation processes (Industry 4.0) and to improve energy efficiency, along with associated changes in new working practices and patterns of work organisation (for a highly qualified, specialised and multi-skilled workforce). Skills shortages, recruitment difficulties and talent management are other challenges facing the Steel Industry.

Objectives
The main objective of the project is to develop a blueprint for a sustainable, *steel industry driven* and coordinated European steel skills agenda and strategy for an on-going and short-termed implementation of new skills demands. This will be piloted by the development of modules and tools for awareness and new skills for a global competitive industry, ready to anticipate new skills demands and to allow pro-active practical activities to meet the future requirements of the industry. The project addresses:
Proactive skills adjustments;
New training and curricula requirements including new ways of short term implementation within both companies and education and training institutions;
Political support measures by mobilising and integrating stakeholders and policy makers of the EU and national level;
Successful sectorial upskilling schemes and efficient management of knowledge;
More attractiveness of the Steel Industry and careers for talented people (recruitment and retention);
Key Performance Indicators (KPIs) to monitor success and adjustment needs continuously.

Survey
This survey aims to determine the current state of digital transformation of the European Steel Industry, starting from the existing level of plant automation and considering the possible adoption of the new paradigm of Industry 4.0 (i.e. the adoption of innovative digital technologies to enhance both the production operation and the information management). The required information can involve several professional areas within the company (HR, R&D, etc.). In the following, you will find a brief description of the technologies here mentioned. Filling in the questionnaire will not take long (about 10 minutes), but will help us to create the base for future scenario evaluation and the related impact on the personnel in terms of skills needs and development in the steel sector. <u>You can leave the survey and re-enter it at some later stage in case you need to consult your colleagues and/or gather further information, but please be aware that this only works when you</u>

Page 1 of 23

use the same computer on which you started the survey and when your browser does not delete the stored qualtrics cookies (i.e. do not delete your browsing history while completing the survey). The data provided are protected by confidentiality and will be processed according to the GDPR (General Data Protection Regulation). Data will remain within the consortium and will be published anonymously for statistical purposes only. When submitting the survey, you give your consent for the data processing. You have the right to withdraw the consent at any time. At the end of the data analysis, you will get the results of the survey.

Brief description of the main digital technologies Industry 4.0

I4.0 paradigm is the application of new technologies to implementing the digitalization transformation into the Industry, which hence requires new competencies, skills and business model. **IoT (Internet of Things)** can be seen as an evolution of the Internet network through which each physical device, i.e. machine, vehicles, component, etc.., can represent itself digitally. IoT is based on web-enabled smart devices that use embedded processors, sensors and communication hardware to collect, send and act on data they acquire from their environments. IoT devices share the sensor data they collect by connecting to an IoT gateway or other edge device where data is either sent to the cloud to be analyzed or analyzed locally. The devices do most of the work without human intervention, although people can interact with the devices -- for instance, to set them up, give them instructions or access the data. The connectivity, networking and communication protocols used with these web-enabled devices largely depend on the specific IoT applications deployed. The IoT application in the industrial environment are usually known as "Industrial Internet" or, with a wider meaning, included under the paradigm "Cyber-Physical Systems". **Vertical/Horizontal integration** represents a new structure for Process automation based on intelligent, flexible and autonomous units to overcame the today's hierarchical automation pyramid. Thanks to IoT, every unit can communicate directly with other units such as Smart Sensors (Vertical integration of data and functions, e.g. of machines, automation, monitoring, products, services, knowledge etc..). Horizontal integration assures a strong communication between all processes along the production chain not only for neighboured plants but for all plants in order. A 100% material tracking is necessary for a complete horizontal integration. **Cyber Physical Systems (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. CPS integrates the dynamics of the physical processes with those of the software and networking, providing abstractions and modeling, design, and analysis techniques for the integrated whole. In synthesis, CPS is another name of any embedded system that use output of different connected sensor to change the output of a system. Although IoT and CPS have some common aspects, i.e. distributed sensors in CPS provide data used to modify the output of other systems or other CPS, the difference is that IoT is about connecting "Things" (Objects and Machines) to the internet and eventually to each other; while CPS are integration of computation, networking and physical process. However, we have not come across clear comparison/ distinction so far. **Cloud computing** makes computer system resources, especially storage and computing power, available on demand without direct active management by the user. The term is generally used to describe data centers available to many users over the Internet. The resources can be broadly dived into three categories: Infrastructure-as-a-Service (IaaS, for virtual machine, storage, etc..), Platform-as-a-Service (PaaS, i.e. environment providing functionalities, like smart device management, DBMS, data analytics, etc..) and Software-as-a-Service (SaaS, for online hosting data and software applications). **Analytics** consist of methodologies and tools for Big Data management and processing coming from different data sources in the manufacturing plants. More concretely, in the industrial environment, analytics includes the applications of new techniques and tools to extract the hidden knowledge from data and make it available for quick decision support, i.e. Business Intelligence, Visualization, Simulation and Forecasting. **Cyber Security** technologies and services are applied for the protection of internet-connected systems, including hardware, software and data, from cyber-attacks. In a computing context, security comprises cyber security and physical security -- both are used by enterprises to protect against unauthorized access to data centers and other computerized systems. Information security, which is designed to maintain the confidentiality, integrity and availability of data, is a subset of cyber security. **Additive manufacturing (3D Printing)**, respect to the traditional production process (material removal or plastic deformation), additive manufacturing is a new productive approach where an object (i.e. component of a machine/engine) is created through its "stamp", layer after layer. **End to End engineering**: the end-to-end engineering integration results in integration which enables the creation of customized products and services across the value chain. Industrial Robotic: refers to robot systems used for manufacturing. **Industrial robots** are automated, programmable and capable of movement on three or more axes. **Collaborative Robotic**: refers to compact, lightweight and dexterous robotic systems designed to interface with the operator.

GENERAL INFORMATION

Name of the Company

____

Position (person completing the questionnaire and email)

____

Country

▼ Austria (1) ... United Kingdom (28)

Company size

○ SME (< 50 employees)

○ Medium Enterprise (51 < employees < 250)

○ Large Enterprise (>251 employees)

Type of product

☐ Long

☐ Flat

☐ Pipes

☐ Beams

☐ Other (please specify):____

Production route

☐ Blast Furnace (BF)

☐ Electric Arc Furnace (EAF)

☐ Processing Industry

Production output (million tonnes/year)

○ < 1

○ 1 < tonnes < 3

○ 3 < tonnes < 5

○ > 5

STRATEGY

I.1 Before Industry 4.0 paradigm, which traditional solutions for the production process management (I3.0) have been applied in your Company so far?

- ☐ Standard solutions (Computer Aided Design CAD, Product Data Management PDM, production control system, etc...)
- ☐ Production Lifecycle Management
- ☐ Manufacturing Execution System (MES)
- ☐ Computerized Maintenance Management System
- ☐ Others (please, specify in the text box):

____

I.2 Which of the following statements describes most accurately the state of digitalization in your company?

- ○ Low: basic automation, Level 1
- ○ Medium: automation Level 2 and Level 3
- ○ High: full processes integration
- ○ Other levels (please, specify in the text box):

____

Please, rank your choices according to your company's priorities using such values and indicate which of the following are already known and/or applied in you Company:

	Not important	Less important	Moderately important	Important	Very important
Industrial Robotic	○	○	○	○	○
Collaborative robotic	○	○	○	○	○
Internet of Things (IoT) applications	○	○	○	○	○
Cloud Computing	○	○	○	○	○
Analytics	○	○	○	○	○
Cyber Security	○	○	○	○	○
Product/Process Virtual Simulation	○	○	○	○	○
End-to-end engineering	○	○	○	○	○
Cyber Physical Systems	○	○	○	○	○
Additive Manufacturing (3D Printing)	○	○	○	○	○
Horizontal/Vertical Integration	○	○	○	○	○
Other (please specify):	○	○	○	○	○

Please, rank your choices according to your company's priorities using such values and indicate which of the following are already known and/or applied in you Company:

	Not Aware / Not Known (1)	Only Known (2)	Known but not yet applied (3)	Known and Applied (4)
Industrial Robotic	○	○	○	○
Collaborative robotic	○	○	○	○
Internet of Things (IoT) applications	○	○	○	○
Cloud Computing	○	○	○	○
Analytics	○	○	○	○
Cyber Security	○	○	○	○
Product/Process Virtual Simulation	○	○	○	○
End-to-end engineering	○	○	○	○
Cyber Physical Systems	○	○	○	○
Additive Manufacturing (3D Printing)	○	○	○	○
Horizontal/Vertical Integration	○	○	○	○
Other (please specify):	○	○	○	○

I.3 **Which technologies/techniques will be adopted according to your company's investment plans (please, consider the next 3-5 years)?**

	No	Yes, within short term (i.e. 3 years)	Yes, within medium term (i.e. 4 to 6 years)
Industrial Robotic	○	○	○
Collaborative robotic	○	○	○
Internet of Things (IoT) applications	○	○	○
Cloud Computing	○	○	○
Analytics	○	○	○
Cyber Security	○	○	○
Product/Process Virtual Simulation	○	○	○
End-to-end engineering	○	○	○
Cyber Physical Systems	○	○	○
Additive Manufacturing (3D Printing)	○	○	○
Horizontal/Vertical Integration	○	○	○
Other Technologies (please, specify in the text box):	○	○	○

I.4 How much does the adoption of new digital technologies affect the workforce of your company? (Where 1 stands for "not at all" and 5 stands for "fully affected")

	1	2	3	4	5
Reduction of monotonous work (1)	○	○	○	○	○
Improvement of the workplace environment (2)	○	○	○	○	○
Workforce deskilling (3)	○	○	○	○	○
Improvement of the health and safety (4)	○	○	○	○	○
Changes in the organisation of work and work activities (5)	○	○	○	○	○
Increase of training, skills and employability (6)	○	○	○	○	○
Increase of working time and work-life balance (7)	○	○	○	○	○
Improvement of scheduling and coordination of tasks (8)	○	○	○	○	○
Upgrading the existing skills (9)	○	○	○	○	○
Development of new skills (10)	○	○	○	○	○
Others (please specify): (11)	○	○	○	○	○

Comments:

____

I.5 Is your company involved in any joint research projects on digitalisation (RFCS, H2020, etc.)?

- ☐ No
- ☐ Completed Projects
- ☐ Current Projects
- ☐ Future/planned Projects

Skip To: QID106 If I.5 = Completed Projects
Skip To: QID107 If I.5 = Current Projects
Skip To: QID108 If I.5 = Future/planned Projects

Display This Question:
If I.5 = Completed Projects

How many completed projects?

- ○ < 5 projects
- ○ 6 < projects < 10
- ○ > 10

Display This Question:
If I.5 = Current Projects

How many current projects?

- ◯ < 5 projects
- ◯ 6 < projects < 10
- ◯ > 10 projects

Display This Question:

If I.5 = Future/planned Projects

How many future/planned projects?

- ◯ < 5 projects
- ◯ 6 < projects < 10
- ◯ > 10 projects

Display This Question:

If I.5 = Completed Projects

And I.5 = Current Projects

And I.5 = Future/planned Projects

Please specify in the text box for each project, the funding programme, the involved technologies and the duration:

	Name of the project (1)	Funding Programme (e.g. RFCS, H2020, ...) (2)	Involved Technologies (3)	Start and end of the Project (4)
. (1)				
. (2)				
. (3)				
. (4)				
. (5)				

End of Block: STRATEGY

Start of Block: TECHNICAL ASPECTS

II.2 Is your Company aware of the opportunities and threats that additive manufacturing represents for the steel sector?

- ◯ No at all
- ◯ Only partially
- ◯ Yes
- ◯ Yes, completely

Comments

____

____

____

____

____

II.3 In which area of your Company is the digitalization most widely applied? (multiple choices allowed)

- [ ] HR Management
- [ ] Administration
- [ ] Customer service
- [ ] Quality control (as decision support)
- [ ] Maintenance
- [ ] Assistance system
- [ ] Management of large amounts of data
- [ ] Process chain control
- [ ] Others (please specify in the text box):

____

Page 14 of 23

II.4 What are the main expected benefits from adopting enabling technologies? (multiple choices allowed)

- [ ] Production costs reduction
- [ ] Increase of production volumes
- [ ] Product quality improvement
- [ ] Reduction of resources consumption
- [ ] Emission reduction, i.e. CO_2
- [ ] Increase of workplace safety
- [ ] Improvement of workforce conditions
- [ ] Reduction of wastes
- [ ] Increase of the competitiveness/sustainability
- [ ] Increased speed & flexibility
- [ ] Load balancing & stock reduction
- [ ] Improvement of customer services
- [ ] Improvement of logistics
- [ ] Others (please, specify in the text box): ____________________

II.5 What are the major barriers for the adoption/ application of enabling technologies?

	Not important (1)	Less important (2)	Moderately important (3)	Important (4)	Very important (5)
Cost of the investment	○	○	○	○	○
Lack of highly skilled workforce	○	○	○	○	○
Internet of Things (IoT) applications	○	○	○	○	○
Skills gaps	○	○	○	○	○
Outdated plants/infrastructure/equipment	○	○	○	○	○
Know-how protection (e.g. Patents, Intellectual property, Trade Marks, Copyright, etc.)	○	○	○	○	○
Acceptance of the workforce	○	○	○	○	○
Complexity of the technological solution / implementation	○	○	○	○	○
Compatability to existing technologies and processes	○	○	○	○	○
Impact on runnig production / possible failures of new solutions	○	○	○	○	○
Others (please specify in the text box):	○	○	○	○	○

End of Block: TECHNICAL ASPECTS

HUMAN RESOURCES - CURRENT AND FUTURE WORKFORCE ORGANIZATION

Start of Block: HUMAN RESOURCES - CURRENT AND FUTURE WORKFORCE ORGANIZATION

III.1a **Gender Balance: Please specify the current percentages of the males and females in your company**

	Male (1)	Female (2)
Operations		
Administration		
Services		
Others:		

Age profile: Please insert a percentage of your workforce over the last 5 years:

	<24	25 < age < 34	35 < age	45 < age < 54)	55 < age < 64	> 65
2019						
2018						
2017						
2016						
2015						

Please, specify for each category the percentage of employers with Higher Education Institution (i.e. Universities, Occupational Colleges, ..) in your company.

	.../100 (1)
Production Managers	
Engineers	
Technicians	
Operators	
Apprentices/Trainees	

III.1b How will the size of your workforce evolve in the next 3-5 years?

	Yes (1)	No (2)
Do you plan to employ more people?	☐	☐
Do you plan to employ more women?	☐	☐
Do you plan to employ more highly qualified people?	☐	☐
Other (please specify):	☐	☐

Display This Question:

If III.1b = Do you plan to employ more people? [Yes]

Indicate the reason

○ Use of new technologies

○ Regulatory requirements

○ Simple expansion of operation

○ Other (please, specify): ____

Display This Question:

If III.1b = Do you plan to employ more women? [Yes]

Indicate the reason

- Use of new technologies
- Regulatory requirements
- Simple expansion of operation
- Other (please, specify): ____

Display This Question:

If III.1b = Do you plan to employ more highly qualified people? [Yes]

Indicate the reason

- Use of new technologies
- Regulatory requirements
- Simple expansion of operation
- Other (please, specify): ____