The Impact of the New Technologies and the EU Climate Objectives on the Steel Industry

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1 Introduction

In recent years, seven drivers of change for the industrial technological transformation in Europe have been identified (Murri et al. 2021),[1] as follows: 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 and 7. Evolution of customer requirements. In this context, digital transformation is considered the key enabler directly impacting on advanced manufacturing and it transversally affects the pathway towards sustainability (Neligan 2018).

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Production processes can become more effective and efficient through the implementation of digital solutions at operation/company level, such as business information systems in combination with measurement sensors, smart production services, tools from information, communication and automation technology (e.g. simulation and forecasting models, self-learning assistance systems and diagnostic tools, or lab-on-chip systems for real-time analysis). As a consequence, the flexibility of production processes will be enhanced through the application of networked machines and components communicating with each other via the Internet and form Cyber-Physical Systems (CPS) (Iannino et al. 2019) and Cyber-Physical Systems of Systems (CPSoS) (Biedermann 2019). In addition, new additive manufacturing (AM) processes, such as 3D printing technologies, can improve resource efficiency by enabling customisation of components production; optimised component structures can lead to weight savings and waste reduction, resulting in lower life cycle costs.

As far as the steel sector is concerned, current technological transformations and developments are expected to have a very relevant impact (Branca et al. 2020). The application of digital technologies in the steel production processes is mainly focused on advanced tools for the optimisation of the whole production chain (Maddaloni et al. 2015) as well as on specific technologies for product quality monitoring and optimisation (Damacharla et al. 2021), energy and resource efficiency (Matino et al. 2019a, b) and CO_2-lean production (Porzio et al. 2013).

In addition, the social innovation represents one of the key factors for the effective way of developing and implementing this technological transformation (Colla et al. 2017). This can be achieved by integrating workplace experience and demands, by upskilling the workforce and by improving working conditions and safety, creating qualified jobs and enhancing the workers' competencies through the support of digital technologies. On the other hand, digital innovation can enable social innovation through knowledge sharing, cooperative work and networking. Nevertheless, one of the most relevant barriers to overcome to effectively implement these technologies is the lack of qualified personnel.

As Energy Intensive Industries (EIIs) are responsible for about 8% of the European Union (EU)'s emissions (European Commission 2020a), to become more competitive at global level, they have to manage energy transition, energy technologies for resilience and cost reductions. On this subject, the technological development represents a key aspect to reach their environmental sustainability through emission reductions and energy saving. In the context of the sustainable development, the EU has been committed to deliver on the 2030 Agenda for the Sustainable Development Goals (SDGs), adopted by the United Nations (UN) General Assembly in 2015 (United Nations 2015), as outlined in 'Towards a Sustainable Europe by 2030' (European Commission 2019a). In this context, digital technologies could positively affect the SDGs implementation through 'green growth' development patterns (Eteris 2020), by using digital solutions in sustainability.

After the Energy Union initiative (European Commission 2015), the European Commission (EC) launched the European Green Deal (EGD) for the EU and its citizens (European Commission 2019b). This ambitious objective reflects the EC's commitment to transform Europe into the world's first climate-neutral continent by 2050 as well as into a sustainable, prosperous, modern, resource-efficient and competitive economy according to 'A New Circular Economy Action Plan' (European Commission 2020b), which is one of the main building blocks of the EGD for creating incentives to promote circular business models. The EGD will have an important impact on process industries, as EU aims at becoming the world's first climate-neutral continent, achieving net-zero greenhouse gas (GHG) emissions by 2050, cutting GHG emissions, investing in cutting-edge research and innovation. Significant opportunities and challenges for EIIs can rise to reach a strong international competitiveness (Lechtenböhmer and Fischedick 2020) as they are responsible for around 20% of total GHG emissions. Therefore, an integrated climate and industry strategy is crucial in their activities, as key element to implement the EGD objectives.

Digitalisation, as a key factor affecting the technological transformation of EIIs, is fundamental to achieve the EU climate objectives, according to the European Green Deal (European Commission 2019b). In this context, green technologies, combined with EU initiatives, aimed at Digitising European Industry (European Commission 2016), including a better and growing use of technologies, such as Big Data (Brandenburger et al. 2016) and Artificial Intelligence (AI) (Duft and Durana 2020). To this purpose, companies are committed to enclose sustainability into their business models for improving their corporate image and to save energy and material costs, resulting in industrial resource efficiency (Matino et al. 2016, 2017a). On this purpose, research activities can help industries in renewing their business model and better account for environmental sustainability in their business ecosystems (Arens 2019). Furthermore, the Processes4Planet (P4Planet) partnership aims at transforming European EIIs in order to achieve overall climate neutrality at EU level by 2050 (SPIRE 2021). In particular, the Process4Planet 2050 roadmap aims at reaching the transition to a climate neutral and circular society by both technological innovation and a holistic systemic socio-economic approach.

As the EGD achievements depend on the horizontal, cross-sectoral integration of an industrial strategy implemented throughout the full value chain, the European steel industry needs a supportive regulatory framework to ensure its international competitiveness, during and beyond the transition towards CO_2-lean production of steel (EUROFER 2020). On this subject, the agreement between EU steel industry and the EU institutions and governments can lead to set 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 achieve the EU's climate objectives by reducing CO_2 emissions by 2030 by 30% compared to 2018 (which equates to 55% compared to 1990) and by 80 to 95% by 2050.

The present work aims at analysing current and upcoming developments related to the digital transformation and Industry 4.0 in the steel sector, according to the four levers of the digital transformation (i.e. Digital Data, Automation, Connectivity and Digital Customer Access). In addition, digital technologies were presented as enabler of green technologies to achieve the climate objectives, and in accordance to the 'Green Steel for Europe' project (Green Steel for Europe 2022) and the Clean Steel Partnership (CSP) roadmap (ESTEP 2020). In the 'Green Steel for Europe' an innovative approach has developed impacts to tackle the decarbonisation of the European steel industry. On the other hand, according to the CSP and its roadmap, digitalisation, as enabler, has been included among the six areas of intervention (CDA: Carbon Direct Avoidance, SCU-CCU: Smart Carbon Usage—Carbon Capture and Utilization, SCU-PI: Smart Carbon Usage Process Integration, CE: Circular Economy, their combination and Enablers) that aim at achieving the carbon–neutral steel production. In addition, the current and upcoming role of digital technologies as support of social innovation aims to improve safety and health of employees and to enable a new way of work within efficient plants to face the new challenges and to remain competitive and sustainable at the same time. In fact, the successful implementation of new technologies strongly depends on the human perspective in all steps of the applied technical solution, integrating and encompassing the context of social innovation.

The centrality of human beings inside the manufacturing chain or in the neighbouring community is highlighted in the context of Industry 5.0 (European Commission 2021a), concerning the transition towards a sustainable, human-centric and resilient European industry, where production respects the boundaries of planet and the centrality of workers wellbeing in the production process. In addition, Industry 5.0 is based on the integration of social and environmental European priorities into the technological innovation (Paschek et al. 2019).

However, technological achievements, from human labour centred production to fully automated way (Larsson and Lindfred 2019), have different impacts on the workforce: on one hand, relieving humans from monotonous and physically strenuous work to be replaced with creative work, and, on the other hand, increasing unemployment and widespread workforce de-skilling. However, the impact of the digital technologies application on the low skilled workers is an open issue, which needs to be faced in the near future, with different approaches, such as up-, reskilling, reduction of 'middle qualification level' workers (polarisation), use of external personnel, etc. Further analyses of future impacts of digital technologies on the workforce (BEYOND 4.0 2022) suggest the combination of professional skills and digital skills on sectoral level and provide indications both for Vocational Education and Training (VET) systems and stakeholders at regional level. Furthermore, a first VET systems analysis has been performed in the ESSA project through the identification possible contributions from different systems in the member states, mainly focused on five case study countries (Germany, Italy, Poland, Spain, United Kingdom) (ESSA 2020).

Started in January 2019 (see chapters "Introduction: The Historic Importance and Continued Relevance of Steel-Making in Europe" and "The Technological and Social Transformation of the European Steel Industry: Towards Decarbonisation and Digitalisation" for more information on the project). [2]

This chapter is organised as follows: Sect. 2 introduces digital technologies as enabler of green technologies. In Sect. 3, digital technologies as a support of the

[2] The work presented in this chapter is part of the Erasmus+ Blueprint project '*New Skills Agenda Steel: Industry-driven sustainable European Steel Skills Agenda and Strategy*' (ESSA)

social innovation are analysed. Section 4 discusses the future scenario for the metal sector. Finally, Sect. 5 provides some concluding remarks.

2 Digital Technologies as Enablers of Green Technologies

As highlighted in the EGD (European Commission 2019b), digital technologies play a fundamental role as enablers of new green technologies to achieve a sustainable ecological transition. Therefore, the development of both green and digital technologies aims at a twin transition (digital and green) as the main driver for the European industry's competitiveness. For instance, digital technologies represent new opportunities for monitoring air and water pollution as well as for monitoring and optimising energy and natural resource consumption.

According to the SPIRE's (Sustainable Process Industry through Resource and Energy Efficiency) new Vision 2050 (SPIRE 2018), the future of Europe will be based on a strong cooperation across industries in order to achieve physical and digital interconnection, through the development of innovative 'industrial ecology' business models addressing climate change and enabling a circular society. On this subject, developments in the future process industry will be crucial (Glavič et al. 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, Circular Economy (CE) and resource efficiency (Matino et al. 2019b; Rieger et al. 2021), supply chain integration, process design and optimisation (Colla et al. 2016), process integration (Porzio et al. 2014) and intensification, industrial ecology and life cycle thinking, industrial-urban symbiosis, product design for circularity, digitalisation, sustainable transport, green jobs, health and safety, hazardous materials and waste reduction, customer satisfaction, education and lifelong learning (Branca et al. 2021).

Consequently, several benefits can be obtained, such as preserving the EU technological leadership through the maintenance of its competitive position, enabling innovative solutions (including technical, organisational, financial, etc.) and developing new business models and social practices, which can contribute to the sustainability by reducing environmental impacts. Both Industry 4.0 and the CE aim at improving products and processes and optimising resource usage and costs. CE can drive the transition of manufacturing industries towards systemic sustainability (Bradford 2015) and Industry 4.0 can drive innovation and the digital transformation towards smart and resilient manufacturing industries.

Digital technologies as enabler of green technologies can help at reducing natural resource exploitation, enhancing material and energy efficiency. In particular, they have a strategic role in increasing technological performances with the aim of reducing and optimising energy and materials consumptions along the steel production routes. For instance, process optimisation and monitoring, as well as systems integration, are crucial for the optimal energy management along the steel production (Colla et al. 2019). In addition, real-time monitoring ensures the product quality

(Vannocci et al. 2019), leading to reduced by-products and waste production. Furthermore, the combination of novel tools for a rapid characterisation of solid and liquid slags, advanced models and complex data analytics and AI models can increase valorisation and reuse of slags, resulting in boosting the slag reuse and recycling (Matino et al. 2017b). AI-based predictive models can also be used for the optimised maintenance and production scheduling. In this context, digital technologies effectively can support the transaction to the new green production. In this context, the International Energy Agency (IEA) technology Roadmap (International Energy Agency 2020) analysed key technologies and their integration in steel sector to achieve the ambitious goal of at least 50% of CO_2 emissions reduction by 2050. On this subject, in a short term, the technology performance improvement in the current production routes will play a fundamental role, while, in the medium-long term, a new technological transformation based on carbon capture and storage/carbon capture, utilisation and storage (CCS/CCUS) and the substitution of carbon with other energy sources (i.e. hydrogen), will become increasingly important.

To transform the EU into a prosperous, modern, resource-efficient and competitive economy, major technological developments in the EU steel industry will be in line with the recent European initiatives following the Green Deal strategy and strongly oriented towards the climate objectives in Europe in terms of low-carbon steelmaking ('zero-carbon steelmaking'). For this purpose, a recent project, 'Green Steel for Europe' (Green Steel) (Green Steel for Europe 2022) aims at supporting EU towards achieving the 2030 climate and energy targets and the 2050 long-term strategy for a climate neutral Europe, through effective solutions for clean steelmaking to meet the decarbonisation of the European steel industry. The most promising technologies, in terms of CO_2 mitigation potential, were identified in Deliverable D1.2 (Green Steel for Europe 2021a). In particular, along with currently addressed CO_2 mitigation pathways in the European steel industry (i.e. 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 and Utilization (CCU), Iron Bath Reactor Smelting Reduction (IBRSR), gas injection into the BF, substitution of fossil energy carriers by biomass, high-quality steelmaking with increased scrap usage.

In addition, different barriers, such as technical, organisational, regulatory, or societal, and financial ones, (Collection of possible decarbonisation barriers, D1.5) (Green Steel for Europe 2021b) have been identified. On the other hand, significant investments and economic efforts will be needed up to 2050 for the decarbonisation technologies deployment (Green Steel for Europe 2021c). As a joint collaboration among the steel industry and other stakeholders for achieving the Green Deal decarbonisation targets is crucial, the Clean Steel Partnership (CSP) (ESTEP 2020) initiative under the framework of Horizon Europe is associated with the creation of focused Public Private Partnerships (PPP). The CSP Roadmap provides six areas of intervention corresponding to the identified technological pathways and including digitalisation and skills as enablers for the implementation of the technologies and combination of technologies for carbon–neutral steel production. In particular, the

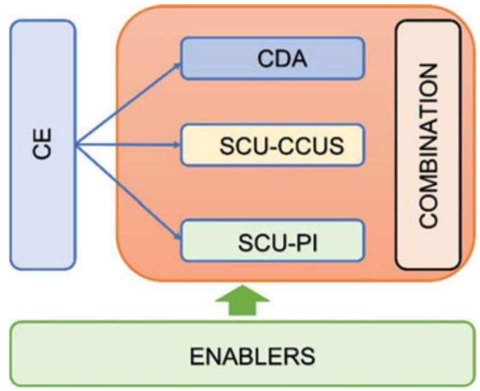

Fig. 1 Connection among the 6 areas of intervention for carbon–neutral steel production

six areas of intervention (CDA, SCU-CCU, SCU-PI, CE, their combination and Enablers) are shown in Fig. 1.

The 'Enablers & support actions' aim at integrating the most recent digital technologies, such as AI and digital solutions in industrial production as well as new measurement systems and digital tools for monitoring and control, by using Internet of Things (IoT) (Xia et al. 2012; Zhang et al. 2016) in the new steel production. In addition, further examples are represented by new predictive and dynamic models and scheduling tools, tailored to process planning, assessment and optimisation. Beside digitalisation also skills and competences are seen as a relevant enabler to unfold the full potential of new solutions at the workplace.

Based on a technology 'building blocks' (BB) approach (see Table 1), each block represents basic actions for providing decarbonisation technologies, such as digital technologies for developing green technologies in different intervention areas, to reach the effective decarburisation of steel production.

For instance, under CE frame (BB9), a major contribution is expected through the definition of a common Life Cycle Inventory for residues, and design and development of a tool for continuous monitoring of effects of circular approach/solutions on CO_2 emissions. On the other hand, in the dedicated building block on 'Enablers (skills, digitalisation) for clean steel development', enablers are necessary for implementing technical and organisational conditions to plan and manage a sustainable steel production. In this context, new technologies will be crucial for the integration of new digital tools for monitoring and control as well as the extensive use of Industrial IoT (IIoT) approach. Such approach allows, for instance, fast integration of new measurement techniques into the set of data streams to be monitored and used for controlling process. For this purpose, Machine Learning (ML), AI techniques and Cybersecurity will play an ever-increasing role. In the standardised description of the Information and Communications Technology (ICT) and automation systems (see Fig. 2), the automation levels of Plant Control, Scheduling and Production Planning and Control are involved.

Additionally, it has been underlined in Colla et al. (2020) that a full exploitation of the potential of the data collected through all the steps of the manufacturing processes,

Table 1 Building blocks contributions to the six areas (ESTEP 2020)

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	Minor	Major	Major	Major	Major
10. Enablers (skills, digitalisation)	Major	Minor	Major	Minor	Major	Major
11. Low CO_2 emissions downstream processes	Major	Major	Major	Minor	Major	Major
12. Innovative steel applications for low CO_2 emissions	Major	Minor	Minor	Minor	NO	Minor

in the light of the transformation of traditional plants and machineries into CPSoS, is only possible through a gradual transition from the classical pyramidal structure depicted in Fig. 2 to a flat and flexible architecture, such as the exemplar RAMI4.0 (Schweichhart 2019).

Process optimisation and monitoring, as well as systems integration, are important for the energy management along the steel production. In particular, AI-based predictive models are used for optimised maintenance and production scheduling. This shows, as digital technologies effectively support the new green technologies, that they are also contributing to their development at early stages. On this subject, two current EU-funded projects, such as Retrofeed (Implementation of a smart RETROfitting framework in the process industry towards its operation with variable, biobased and circular FEEDstock) (Retrofeed 2022) and REVaMP (Retrofitting equipment for efficient use of variable feedstock in metal making processes) (REVaMP 2022) are focused on how digital technologies can support

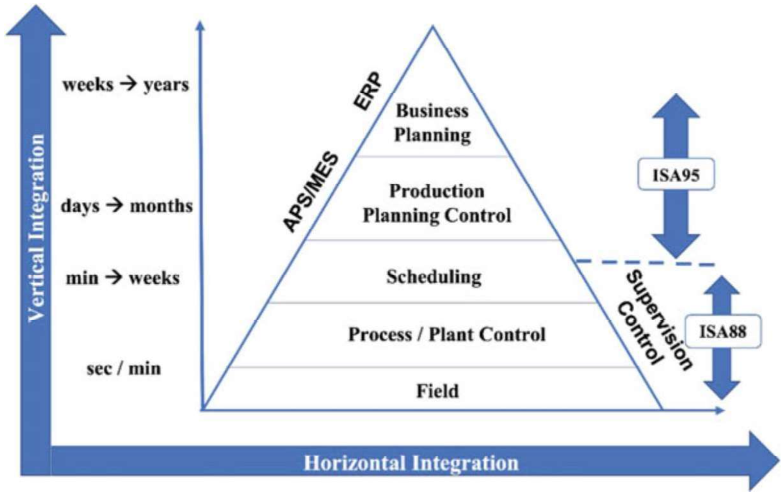

Fig. 2 Standardised description of the ICT and automation systems (ESTEP 2020)

to implementation of process improvements to achieve materials and energy efficiency in the steel production. The use of renewable feedstock and industrial residues as a complement of the furnace feedstock supply (Retrofeed) and the management of feedstock variability and selection (REVaMP) in steelmaking are two different approaches on resource efficiency and low-carbon technologies in existing steel plants. In particular, in the Retrofeed project advanced monitoring and control systems and a Decision Support System for supervising retrofitting activities and evaluating the best retrofitting capabilities along the production chain have been developed. On the other hand, in the REVaMP project retrofitting technologies, based on sensors for the chemical characterisation of metal scrap, advanced monitoring and control of the melting process for the adaptation and the integration in existing processes have been applied.

Further digital technologies as enabler of green technologies in the steel sector concern green recycling in the Electric Arc Furnace (EAF) steelmaking route. In particular, the introduction of the concept of ABSC (Activity-Based Standard Costing) integrated into Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) aimed at achieving an efficient production management in a digital environment (Tsai 2019), supporting smart manufacturing, such as work forecasting, status monitoring, Work In Process (WIP) tracking, throughput tracking and capacity feedback. Furthermore, ABSC as costing tool can enhance the business operating abilities of quality, cost, delivery, service, resources and productivity. Additionally, an ongoing project co-funded by the EU Research Fund for Coal and Steel (RFCS), entitled 'Optimising slag reuse and recycling in electric steelmaking at optimum metallurgical performance through on-line characterization devices and intelligent decision support systems (iSlag)' (iSlag 2022), is focused on the improvement of EAF slag valorisation, supporting good practices and exploring new recycling paths by integrating innovative measurement devices with modelling and simulation systems. By developing decision support concepts and systems, which help the implementation of smart slag conditioning practices and optimal slag handling for its internal and external reuse and recycling, iSlag will provide operators with easy-to-use tools to support Industrial Symbiosis and CE practices as well as to reduce slag disposal costs. A further ongoing RFCS project, entitled 'Energy Management in the Era of Industry 4.0' (EnerMIND) (EnerMIND 2022) aims at optimising 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. Through innovative AI/ML models for anomaly recognition in energy management this project aims at demonstrating the strong contribution of AI techniques in improving energy efficiency in the electric steelmaking route.

3 Digital Technologies as a Support of the Social Innovation

In order to design a 'Green New Deal' it is also fundamental to consider the transition as a key issue, and, over the last few years, progresses have been achieved in this direction. In particular, guidelines for a just ecological transition (International Labour Organization 2015) and for the Future of Work (International Labour Organization 2019) have been developed.

On the other hand, social transitions will have a deep impact on industry. In addition, current European political priorities can affect industry. In particular, the EGD (European Commission 2019b) will need a transition to a more circular economy and a reliance on sustainable resources including energy and 'Europe Fit for the Digital Age' (European Commission 2020c) aims at increasing technological innovation in Europe, making digital a priority for Europe; the European Research Area (ERA) (European Commission 2020d) will promote research and innovation in Europe, while the new European Industrial Strategy (European Commission 2021b) and Skills Agenda (European Commission 2020e) will address skills shortages. Finally, the White Paper on a regulation of AI (European Commission 2020f), and the European Data Strategy (European Commission 2020g) highlighted the importance that EC ascribes to the social impact of digital technologies.

In addition, up to now decarbonisation and climate adaptation efforts with climate and social justice have been mainly focused on (Bergamaschi 2020):

- creating new quality jobs and inclusive transition processes;
- building resilience activities for protecting groups most exposed to climate impacts;
- achieving the Paris Agreement objectives (Paris Agreement 2015) to ensure climate justice for people and future generations;
- recognising and addressing specific challenges faced by specific sectors, regions, cities and communities most vulnerable to change.