# The Technological and Social Transformation of the European Steel Industry: Towards Decarbonisation and Digitalisation

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## 1 Introduction

Since the nineteenth century, when we might first begin to talk of the 'modern' steel industry, making steel has become a central feature of production and manufacturing across Europe (Bell 2020). Production was initially driven by the demand for railway infrastructure and confined to a small number of countries (e.g. Germany, the United Kingdom) (Spoerl 2004), but it is now produced in twenty-one European countries utilising blast furnace-basic oxygen furnace (BF-BOF) and electric arc furnace (EAF) production technologies to produce goods for a wide range of sectors (e.g. automotive, construction, white goods, etc.) and customers (according to Eurofer (2022a) the top three shares of total finished steel demand per sector in the EU is 37% construction, 16% automotive, 15% mechanical engineering).[1]

In many ways the fundamental processes of steel production have not changed substantially since the mid-nineteenth century when blast furnace technologies were first introduced. But, at the same time, it is indisputable that the industry has undergone significant periods of technological and social transformation. What this chapter discusses is some of those transformations, as the background to a more focused discussion of current developments—the latter being the principal focus of this volume. With regard to current developments we might say that the industry is

[1] Austria, Belgium, Bulgaria, Croatia, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom (Eurofer 2020). Some commentators (e.g. WorldSteel) include Russia, Turkey and Kazakhstan as European producers, increasing the number to twenty-four.

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entering a period of hugely fundamental and significant change, which is driven by what the European Commission (EC) has expressed as the twin challenges of (and opportunity for) decarbonisation and digitalisation (e.g. EC 2022). EC and European Union (EU) policy briefs have stressed how successfully managing the green and digital 'twin transition' is key for delivering a sustainable, just and competitive economy to future generations. If adequately regulated, the green and digital transition can be mutually reinforcing and digital technologies can catalyse greening (Muench et al. 2022)

As noted in Chap. 1, global warming and the climate crisis are driving the need for changes in the ways steel is made. Energy sources and traditional production technologies will eventually give way to processes of decarbonisation involving, for example, hydrogen and renewable energy, alongside the introduction of innovations in methods of carbon capture, storage and use (Antonazzo et al. 2021a). It is estimated, that 74 million tonnes of steel will be required for renewable energy alone, which speaks to the opportunities available for Europe's steelmakers (Eurofer 2023: 2). At the same time, the digitalisation of manufacturing processes—so-called Industry 4.0—comprising 'cyber-physical systems' of production configured upon digital networking systems and the centrality of 'big data' for 'smart factories' (Briken et al. 2017) is aimed at achieving a 'business model transformation' and greater efficiencies for industry. It is clear that digitalisation has moved from 'strategic hype' to 'operational reality' within the wider European manufacturing sector and within the steel industry specifically (Naujok and Stamm, 2017; Murri et al. 2021).[2]

The 'twin challenges' indicate the direction of travel for the steel industry in Europe and the innovations and technological transformations currently demanded of, and being experienced by, EU/European producers. The transformation of the industry in this direction perhaps represents a paradigmatic shift not experienced by the European steel industry since the mid-nineteenth century and Henry Bessemer's and Karl Wilhelm Siemens' respective innovations, the Bessemer process in 1856 and open hearth furnace in 1860, which continue to provide the foundations for steel production today (see Spoerl 2004; Bell 2020). The transformation of the industry is, however, not technological alone, but accompanied by a process of social transformation, such as in the way work is organised and the increasingly high levels of skills now required for employment in the industry (e.g. Antonazzo et al. 2021b; Bacon and Blyton 2000; Stroud 2012). When connected to the twin challenges, the latter perhaps represents a third challenge, i.e. a social challenge, focused on the recruitment, retention and continuous training of a highly skilled workforce to support the industry's transformation in Europe.

As the first substantive chapter in this volume, we aim to help situate the EU and European industry's current technological and social transformations and provide some context for later chapters. Hence, we provide something of a brief overview of the industry in technological and social terms, as well as an account of its place

[2] See, for example, Naujok and Stamm (2017) for an overview and Stroud and Weinel (2020) for discussion of a specific case (discussed also in Chap. 5 of this volume), as well as other chapters in this volume, which document numerous Industry 4.0 developments.

as a regional entity in the European context. The latter half of the chapter draws on data from two research projects—the European Steel Skills Agenda (ESSA) project and research commissioned by a British trade union, Community, on the 'greening' of the steel industry[3] and *Preparing for a Just Transition*—to discuss current sector processes of decarbonisation and digitalisation. We finish with a short discussion that provides an analysis of the broader implications of the industry's process of innovation, technologically and socially, and raise questions that focus particularly on the 'social consequences' of the sector's transition and transformation. First, in what follows, we situate the steel industry within its EU context— reflecting on the European industry as a steel producing region—beginning with the formation of the European Coal and Steel Community (ECSC).

## 2 The Steel Sector in Europe

The steel industry has historically been at the very basis of the European project. Since the establishment of the ECSC in 1951, the steel industry has gone through phases of expansion, consolidation, modernisation, rationalisation and (more recently) shrinkage. It is currently dealing with urgent issues, such as overproduction, dumping from non-EU competitors, protectionist measures and serious environmental concerns (including unilateral environmental measures, e.g. ETS, CBAM[4]), as well as, at the time of writing, the fall-out from the coronavirus pandemic and concerns over the stability and security of energy supply (with concomitant concerns over energy costs) and supply-chain issues because of the conflict in Ukraine.

The ECSC is one of the forerunners of the European Community, and thus the European Union. It was principally devised as a way to overcome international political and economic risks linked with a situation of overproduction and cartels formation that resembled the situation of Europe in the early 1930s (Fairbrother et al. 2004; Mason 1955). As pointed out in the Schuman Declaration of May 1950, the coming together of the European nations required first the elimination of an enduring enmity between France and West Germany. From Schuman's perspective, placing West Germany and France's coal and steel production together with that of other European countries (Belgium, Italy, Luxembourg and the Netherlands) under a common authority, would provide the common foundations for economic development and would have made any war between France and Germany 'materially

[3] The ESSA project is funded by the EU Commission's Erasmus+ programme and aims to build a Blueprint to tackle skill needs emerging from Industry 4.0 and decarbonisation. The research informing this paper is based on case studies of the sector in Germany, Italy, Poland, Spain and the UK, based on interviews and a survey with trade unions, HR managers, trainers and industry experts. The Community funded research involved interviews with five industry experts on processes of decarbonisation and a survey of 100 steelworker trade union members in the UK gathering their views on decarbonisation and green skills.

[4] The ETS is the European Trading Scheme for carbon emissions and the CBAM is the Carbon Border Adjustment Mechanism to address carbon leakage.

impossible' (EU n. y.; Mioche 1998). The High Authority of the ECSC was charged with the task of securing the modernisation of production and the improvement of its quality, the supply of coal and steel on identical terms to the markets of other member countries and the improvement of the living conditions of workers in the industries (see Mason 1955; Mioche 1998).

The immediate economic aim of the ECSC, as made clear in the founding Treaty of Paris 1951, was the constitution of a unified and competitive market, without national barriers and with strict rules of competition enforced: this was aimed at starting a process of expansion and modernisation of the European coal and steel industry (Mason 1955; Mioche 1998). However, when the Treaty of Paris expired in 2002 the ECSC ceased too. The outcome was that the ECSC's former activities became wholly absorbed by the European Community under the framework of the Treaties of Amsterdam and Nice. When the ECSC ended, the European sector's union federation (European Metalworkers' Federation, now industri*ALL*) and the employers' federation (Confederation of Iron and Steel Industries i.e. Eurofer) made a request to the European Commission to establish a social dialogue committee for the steel industry (Eurofound and Whittall 2006; Eurofound 2018). As Eurofound and Whittall (2006) note, 'the sectoral social dialogue committee for the steel industry was ratified in 2006 and is designed for constructive social dialogue between the social partners, in the spirit of the ECSC, by promoting productive relations between both sides of industry, particularly given the far-reaching changes in the steel industry in terms of competition and working practices' (see also Eurofound 2018). It remains a principal means by which the sector addresses industry challenges.

A further legacy of the ECSC is found in the Research Fund for Coal and Steel (RFCS), which funds research and innovation projects within the industry and supports research and pilot projects on many different aspects of production (Boom 2014),[5] including the implementation of key Industry 4.0 and decarbonisation technologies (see Murri et al. 2021 for a review of the latest technological developments in the sector). The social dialogue committee, the RFCS, as well as initiatives such as the European Steel Technology Platform[6] (ESTEP), remain important means by which the industry's economic and social challenges—globally and within the European region—are addressed.

A global challenge that the industry is facing is certainly the environmental one. In this respect, the European Green Deal, presented in 2019, with its aims for a more resource-efficient and competitive economy across Europe, has placed particular pressures on energy intensive industries like steel, and has made it urgent to embrace technological innovation. The EU has strategised to improve energy efficiency by 32.5% by 2030, based on 1990 levels, and to cut carbon emissions by 50% by 2030,

[5] Horizon 2020, and now Horizon Europe, are also important sources of funding for supporting industry innovation.

[6] ESTEP engages in collaborative EU actions and projects on technology, which are tackling EU challenges (notably on renewable energy, climate change (low-carbon emission), circular economy) in order to create a sustainable EU steel industry. This is namely done by disseminating results of projects, by facilitating a supportive environment for collaborative projects, by the Strategic Research Agenda and by the active network of ESTEP's community. ESTEP—ESTEP at a glance.

as part of its transition to a sustainable low carbon economy. The industry is central to both the EU's Green Deal Industry Plan and integral to the Net-Zero Industry Act (Eurofer 2023). However, as reported by ESTEP (2017), 'the EU steel industry is already very close to the physical limits of conventional steelmaking technologies, in terms of $CO_2$ emissions reduction, and there is a need for further disruptive innovation to help the industry meet the targets set'. Within the context of unilateral EU environmental measures, e.g. ETS, CBAM, the long-term sustainability of the steel industry depends on the possibility of steel to become a fully circular commodity (ESTEP 2017). Hence, initiatives such as the Clean Steel Partnership[7] (CSP)—funded by RFCS and Horizon Europe and involving ESTEP and Directorates-General (DG-) RTD and DG-Grow—are an important part of tackling the industry's sustainability challenge.[8]

The necessary transformations are driven not only by technological innovation, but social innovation too and both carry significant social consequences. Technological transformations, for instance, have long had a severe effect on levels of employment in the industry (Gibellieri 1998), but workforce numbers have been in steep decline for numerous reasons over many decades. The steel industry directly employed 308,675 people in 2021 across the EU27, with an estimated 2.6 million jobs supported by the industry through its induced and indirect effects (Eurofer 2022a), but the numbers directly employed are just a fraction of what the industry once employed (as recently as 2014, 332,228 people were directly employed in the EU industry, which represents a decline of about 7.1% in the 7 years till 2021). Eurofer (2023: 2) reports that the EU industry has lost 25% of its workforce over the past decade, and there have been substantial cuts to numbers since the 1970s. As an illustration, in 1971 the UK steel industry directly employed 323,000 workers, numbers similar to those now employed across the EU27 as a whole (Eurofer 2022a). By 2020 the UK industry directly employed just 16,427 steelworkers (Eurofer 2022a). Germany is currently the largest employer in Europe with its companies directly employing 83,200 people, which is many more than its nearest competitor, Italy at 30,389 (*Ibid*).

At the same time as contributing to declining levels of employment, the technological transformation of the industry in Europe has contributed to increases in production (Gibellieri 1998). Production across the EU region went from 132 million tonnes in 1993 to an average annual production of 190 million tonnes between 2006 and 2016—admittedly with some expansion in member state numbers during these periods (ESTEP 2017). Eurofer reported a production volume for the EU-28 of 168 million tonnes in 2018, for a workforce of approximately 320,000 workers directly employed (Eurofer 2019). The fortunes of the industry in Europe ebb and flow and reflect that since the early 2000s the EU steel industry has been constantly and

[7] Started in 2021, the Clean Steel Partnership is **a mechanism to pilot and demonstrate breakthrough technologies up to Technology Readiness Level (TRL) 8 that can reduce $CO_2$ emissions stemming from EU steel.** Aligned with the European Green Deal targets, the partnership supports EU leadership in transforming the steel industry into a carbon-neutral one, serving as a catalyser for other strategic sectors. ESTEP—Clean Steel Partnership (CSP).

[8] Directorates-General (DGs) are **European Commission** departments responsible for developing and implementing EU policies across a range of areas, from agriculture to trade.

increasingly threatened by globalisation and increased competition. For example, Chinese steel producers have multiplied their production from 128 million tonnes in 2000 to 928 million tonnes in 2018.[9] There must also be a recognition that the steel industry more widely is subject to cyclical trends and often chronic over-capacity, with consequences for company planning and strategy (Eurofer 2023; Fairbrother et al. 2004). In view of such pressures, the EU was lobbied successfully by the sector social dialogue committee to introduce anti-dumping measures in 2020. Nonetheless, over the past decade the EU industry has shifted from being a net-exporter to net-importer and lost 30 million tonnes of sales on the EU and export markets, losing 26 million tonnes of export capacity in the last decade (Eurofer 2023: 2).

But, as noted above, this is not to say that technological transformation is responsible alone for the rationalisation of workforce numbers, and it is not singularly responsible for any increases in productivity that might be reported. For example, social transformations, such as changes in work organisation, as well as in related patterns of recruitment and skill demands, have also changed the profile of the industry workforce and its productive capacities in multiple ways (Bacon and Blyton 2000; Stroud 2012). It is, moreover, important to note the consequences of globalisation and privatisation too, which have had a marked effect on the European industry and shaped processes of restructuring and rationalisation, particularly since the 1980s (Fairbrother et al. 2004). Indeed, according to Fairbrother et al. (2004), beyond the ECSC, the foundation for the EU steel industry, as a regional industry (i.e. EU/European), was laid in the 1980s and 1990s when the deregulation of the industry began, involving privatisation of the industry (away from what was largely state ownership) and the associated moves toward the establishment of a more internationally focused industry (see also Eurofound 2018).

Within Europe, this resulted in major institutional changes, with a restructuring of the industry that included increased emphasis on productivity, technological innovation and development, an emphasis on downstream activity and a re-composition of the industry via mergers and acquisitions. In effect, the foundations were laid for the materialisation of an embryonic globalised industry, with the European steel region a key component in this process, and the emergence of major steel multinationals (Tata, Arcelor-Mittal, ThyssenKrupp, etc.) (Fairbrother et al. 2004). The industry in Europe, and the EU specifically, has thus undergone a significant transformation, in numerous ways since the inception of the ECSC, and in what follows we pay more attention to its social and technological transformation, focusing particularly on the more recent areas of innovation: decarbonisation and Industry 4.0.

[9] Worldsteel data.

## 3 Social and Technological Transformations

As noted earlier in this chapter, the 'modern' steel industry is regarded to have its beginnings in the mid-nineteenth century. Iron and steel-making predates this period, of course, and we can look back 4000 years to the Iron Age to identify the first exploitation of iron-ore (Bell 2020). But, as Bell notes, it is from the sixth century onwards that we see the use of a form of blast-furnace which produced pig and cast-iron, both of which are strong but brittle because of high carbon content (see also Spoerl 2004). Much later, from 1784, puddling furnaces were introduced with the literal stirring of molten material to introduce oxygen and reduce carbon, which was a labour and fuel intensive means to produce wrought iron (Spoerl 2004; Bell 2020; Landes 1965; 1969). The first 'steel' produced was in Germany and the United Kingdom, and followed a 'cementation' furnace process to achieve the desired quantity and distribution of carbon in the product (Bell, 2020). The outcome was a form of iron with a high carbon content called blister steel that could be rolled and pressed more easily than wrought iron (Spoerl 2004; Bell 2020).

Technologically we move rapidly to the Bessemer process and Siemens' open hearth furnace, which mark the start of steel production as we currently know it; these processes introduced more efficient and higher quality steel in larger quantities by rapidly manipulating the oxygen and carbon content, along with further innovations for removing a range of impurities (Bell 2020; Spoerl 2004). The outcome was the technological basis for the Blast Furnace (BF) and Basic Oxygen Furnace (BOF) production that forms approximately two-thirds of steel production today. Later, at the turn of the twentieth century we see Paul Herloult's electric arc furnace (EAF) innovation, using an electrical charge for the production of speciality steels and steel alloys primarily from scrap (Bell 2020). From the bases of BOF and EAF we see ever refined processes of production to produce high-quality steel products (e.g. billets, blooms, slabs, wire, bar, etc.) for construction, automotive, ship-building, white goods and numerous other sectors (see Bell 2020).

From these beginnings, the competitiveness of the European industry has further relied on the development of a range of technological and production (e.g. lean/just-in-time and flexible) innovations. From the 1990s onwards, in particular, new casting and rolling mill technologies, such as thin slab casting and strip casting facilities, along with smelting and direct reduction technologies and the introduction of Near Net Shape Casting changed the way steel was produced and improved the competitiveness of the European sector (Gibellieri 1998). There is, moreover, a greater emphasis on a faster and more comprehensive service, higher quality products, and better levels of customer service. To facilitate this new responsiveness to customer demand, steel companies increasingly looked to decentralise their operations and make the way production is organised more flexible. Such developments have impacted on the steel industry workforce in a number of different ways.

Most evidently, this is in the way that work in the steel industry is organised, its levels of employment and the skills profile of the industry. As organisations look to become more flexible and responsive, steel producers adopt new working practices e.g. team working, high performance working and recruit differently for a more diverse and highly skilled workforce. Indeed, technological transformations and related production developments have been paralleled by concomitant transformations in the role that skilled labour plays in steel production. That said, while we may have travelled some considerable distance since workers were, for example, first employed in the labour-intensive process of 'puddling' (Spoerl 2004) or recruitment relied on a supply of unqualified labour from generations of family (Stroud 2012), the changes and challenges that workers might experience to the material realities of their work and employment from the insertion of new technologies and other industry developments are as present today as they have always been (see Edwards and Ramirez 2016; Stroud and Weinel 2020).

Current technologies and processes might, for example, make for a safer workplace from when the strenuous labour, heat and fumes of 'puddling' could mean a very short life expectancy for 'puddlers' (Spoerl 2004; Landes 1965; 1969), but there remains the potential for intensified labour and deskilled work and/or job losses from more recent developments (see Stroud and Weinel 2020). This requires some reflection on the relations of power and control, as well as regulation, which are critical to the development, selection and deployment of workplace technology, often driven by the seemingly irresistible logic of efficiency and productivity. On this basis we might view the insertion and use of technology along with its effects as socially and politically variable, i.e. the decision to deskill, upskill or 'rationalise' is a management decision, but it is one that is shaped by wider forces (see, for example, Pfeiffer's (2017) analysis of Industry 4.0 as a discourse promoted by 'economic elites' to increase control over labour).

Hence, while new technologies might have the potential to improve, for example, safety, by means of increased levels of automation, it is only with legislation, regulation and codes of practice (e.g. International Labour Organisation 1981 code of practice), as well as training, leadership and increased management accountability that safety begins to improve. Worldsteel data shows that significant improvements in lost time to injury between 2006 and 2019—by some 82%—are not only accountable to new automated processes but the result of social transformation in health and safety cultures supported by strong international and national legislation and codes of practice (Worldsteel 2022). Equally, we might then view the rationalisation and restructuring of the industry workforce as a process not only informed by its technological transformation, but also subject to cultural, social, economic and political forces too.

In view of such discussions, we now reflect on the findings of two research projects, *ESSA* and *Preparing for a Just Transition*, to shed some further light on the 'twin challenges' of digitalisation and decarbonisation, as the main focus of this volume.

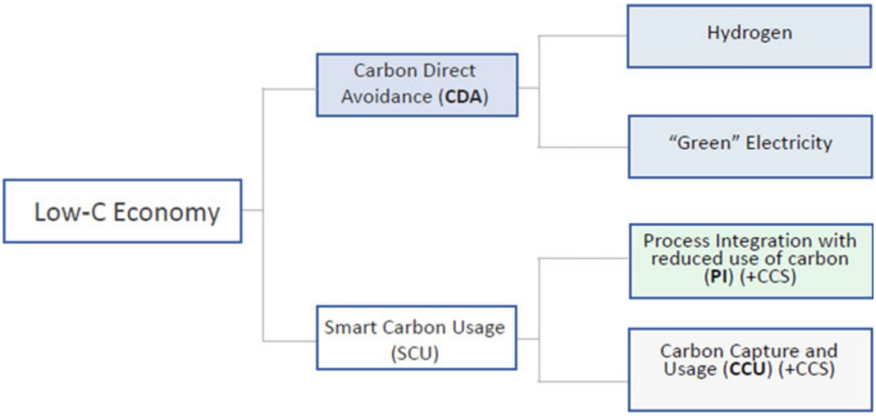


**Fig. 1** Technological pathways to reduce $CO_2$ emissions in the steel sector. *Source* BFI 2019

### *Decarbonising the Steel Industry*

A strong socio-political force shaping steel production is the transition to net-zero and the European Commission's commitment to a sustainable low carbon economy (this was clearly expressed in the European Green Deal). The steel industry currently contributes the largest share of global $CO_2$ emissions of all manufacturing, approximately 27%. It is also energy intensive and has the largest single energy-related $CO_2$ emissions globally by industry, at 7.2% (Ritchie and Roser 2016). Greening efforts are heavily reliant on technological innovation, particularly decarbonising by means of carbon capture and usage/storage and greener sources of energy (e.g. renewables, hydrogen). In what follows we draw on data from the ESSA project and a project funded by the Community trade union, *Preparing for a Just Transition*, to discuss current approaches to decarbonising the industry and the extent to which the workforce is prepared for making 'green' steel (see Antonazzo et al. 2021a).

When considering the prospects for decarbonisation, it is possible to distinguish between two principal approaches (see Fig. 1):

1. *Carbon Direct Avoidance*: using hydrogen and/or electricity for producing iron and steel. The use of electricity directly to electrolyse iron ore[10] is still at an early research stage and not ready for commercial implementation. The hydrogen-based process is potentially ready, dependent on hydrogen supply.
2. *Smart carbon usage*: making processes more efficient so that less energy input is required, thus partially cutting emissions. This can be complemented by carbon capture and storage (CCS), or carbon capture and usage (CCU) to transform $CO_2$ into by-products for other industries.

However, a third approach, a *circular approach*, whereby the carbon input is substituted by utilising other by-products as carbon carriers might also present an

[10] See also Worldsteel (2022).

opportunity for necessary reductions (Antonazzo et al. 2021a). Industry experts interviewed for the Community project remarked that these (three) approaches are not mutually exclusive and companies will likely adopt a combination of different approaches and technologies to cut their emissions:

> We believe that we will need all of this. We will need to use CCS and CCU, we are going to have hydrogen in some places, renewables […] it will depend on what kind of resources you have available. If you are in a place where there is natural gas and great storage, why not use it in forming blue hydrogen, you start to store the $CO_2$ […] if you have plenty of renewables or biomass, then you should go ahead and use that (Community Research: Steel Industry Environment and Climate Change Expert)

Hydrogen-based steelmaking has a promising future, but meeting the relatively short-term target for reducing emissions will require other solutions more at hand:

> Hydrogen probably has a role as a fuel at some point in the future when there's genuinely green hydrogen, but that is the longer term 2050 perspective. And essentially all industry has got to work on the 2035 [target], because you can't operate as you do and get your 50% reduction (Community Research: Steel Industry HR Manager)

As a recent report by Syndex and the Material Processing Institute (2021) has remarked, in a mid-term scenario blast furnaces and DRI furnaces[11] will remain the main routes for European steel producers, and EAF-based steel will only reach a share of 40% of production by 2050. But, large European companies are now engaged in the development of a DRI-Hydrogen solution, including a transition from blast furnaces to Electric Arc Furnaces (EAF) over the next 20 years. Such solutions will need an increased amount of $CO_2$-free electricity, thus the issue of energy supply and costs is an important part of the green transition. Policy support is key to provide the industry with resources, as well as overarching national and EU strategies that factor in direct investments along with infrastructure and the cost of energy supply.

Wide-ranging technological transformations like the ones outlined bring about legitimate concerns about the effects that these will have on employment levels in the industry (as well as on the composition of the workforce). For a greener industry, experts have pointed to a two-phase scenario. The first 'transition' phase will likely increase employment and could last up to 2050. The second phase might result in a reduced workforce, mainly because of the resizing of the plants and leaner processes:

> The build phase, transition phase, always absorbed people. So, we are going to have more assets constructed and deconstructed in the next 20 years because of the change. […] if an asset has got a carbon footprint that's unsustainable, it's going to be replaced in the next 15 to 20 [years], regardless (Community Research: Steel Industry HR Manager)

Planning ahead and strengthening social dialogue is likely to be key to ensure a smooth and just transition: workers need to have a clear understanding of the companies' prospects and to trust that no one is going to be left behind as the industry

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[11] The direct-reduced iron (DRI) process reduces iron ores directly to sponge iron using gaseous reducing agents. In the electric steel process, crude steel is made from the sponge iron obtained from DRI. Scrap is also added to this process as well as pig iron from the BF process (Syndex and the Material Processing Institute 2021).

transitions. There remains high uncertainty regarding the technologies and routes that will provide the best opportunities for companies, as well as uncertainties at the policy level. But, it is crucial to be proactive in anticipation of change, particularly on skills development:

> We talk a lot about anticipation of change […] what's going to happen? Not tomorrow, what's gonna happen in five years, 10 years, 20 years? What skills do we need now, what skills do we need in the future? Because remember that steel is an ageing workforce […] if you have a huge amount of people, and they're late 50s, early 60s who retire, you may also need people have the good old-fashioned skills like welding(Community Research: Steel Industry HR Manager)

With the green transition being a major change and a critical target for companies throughout Europe, data from the ESSA project identifies 'green skill' needs at the sector level, including skills related to environmental awareness, energy efficiency, water conservation, waste reduction and waste management, and resource use and recycling. Although the idea of skills that are inherently 'green' can be criticised and calls for some reflection, it still makes sense in the context of this chapter to use this as an encompassing label while addressing the relationship between required skills and the process of greening the industry. In some indication of the readiness for the green transition, a survey of one-hundred steelworker UK Community members reported that whilst 92% of the current steel workforce view the transition as necessary only half view themselves as possessing the necessary skills to support the transition and 41% feel threatened by it. Another 79% have not been consulted on the necessary changes, with 78% expecting the transition to involve radical and disruptive technological change. But 'readiness' for the transition will differ by firm and/or country: evidence from the ESSA project suggests that a more holistic approach to vocational education and training in some countries e.g. Germany is likely to facilitate a much smoother 'green skills' transition, than for their counterparts elsewhere, e.g. United Kingdom.

## *Industry 4.0: Digitalising Steelwork*

This section draws on data from the ESSA project to discuss Industry 4.0 technologies in the steel industry and what the innovations mean for steelwork and steelworkers i.e. the 'social innovation' that goes hand in hand with technological innovation (see Chap. 3). Beyond the ESSA project, a wide array of evidence suggests that the steel industry is experiencing Industry 4.0 transformation. For example, with regard to the use of Internet of Things models, sensors and big data analytics to improve energy efficiency and resource management (and thus contribute to greening the industry), as well as quality monitoring and defects detection (Branca et al. 2020; Stroud et al. 2020). Robot-assisted production is increasingly/potentially allowing workers to supervise, instead of perform, dangerous and labour-intensive processes and tasks, e.g. drones (Stroud and Weinel 2020), and extensive generation, storage and analysis of data means that steel companies can now improve processes and plan recurring intervention on machinery based on sensor data and computer simulations, and signals moreover the potential effects of digitalisation and automation on jobs and skills in the sector (Murri et al. 2021).

However, stakeholders at the European level describe the sector as still uneven in technological terms:

> [When it comes to Industry 4.0] you're going to get different answers, depending on who you ask. Because you might have one company that they've already made a lot of changes [...] You might have others who've done no digitalization, and they're not prepared, and maybe they're not going to do it in the best way... The feedback we've got from a lot of our steel experts is the sector has already been digitized quite a lot already' (ESSA: Trade Union Representative, Europe).

Where Industry 4.0 has penetrated the sector, of particular note is the volume of data generated and the need for increased capacity for its analysis. More advanced sensors and measuring technologies mean that many more data sources are now embedded in the various processes and a vast amount of data becomes available for real time, as well as historical, analysis:

> Data collecting systems…vibro-acoustic (analyse the noise and with AI identify problems) Data collecting in general analysis with AI of all of these data. There is an algorithm that reach conclusions with AI and support the decision-making process. Before the most important variables were the target. Now the priority is to collect as many variables (data) as possible (ESSA: Rolling Mill Manager, Spain).

Thanks to these new developments, companies have many more opportunities to act and improve their processes:

> We have experienced years or better decades of technological change [...] we have now data, we can collect them, analyse them, act on the data [implement changes] and that is the great advantage we have now (ESSA: Head of Training Centre, Germany.)

Data generation and capturing are also used to improve the reliability of systems, also offering the opportunity to implement predictive maintenance models, which reduce the risk of system failures.

Another area in which Industry 4.0 technologies can be found in steel companies is that of quality assurance, for instance in the case of defects detection of rolled steel. Further, Industry 4.0 solutions are adopted in some sites directly in production, for instance in melting shops or in rolling mills:

> In some melting shops I saw really excellent installations not only to measure, to do some typical stuff, but even with some kind of Artificial Intelligence, with kind of sampling and some predictive methods, not only like a reaction to the problem but prediction…. But I would say we are at the beginning of that in the steel plants in Poland (ESSA: Steel industry expert, Poland).

Further, as indicated above, advanced robotics is an aspect of Industry 4.0 that is gradually being integrated into steel production:

> [Recently we have had] the introduction of ABB[12] robots [...] the labs have implemented quite a new automation system. So, automation is obviously a key thing within the works (ESSA: Company Training Advisor, United Kingdom).

[12] A Swedish-Swiss supplier of advanced electrical and robotic technologies.

What is evidenced here is that the European steel industry is progressively moving towards Industry 4.0, which requires a level of adaptation for the workforce or social innovation. The question is the extent to which workers can easily adapt to changed tasks and processes:

> That is why we already use robots extensively and this is not by accident […] there will be simplifications of work but at the same time there will be more complex and difficult tasks and the simple work will increasingly be automated because, slightly exaggerated, the simple and the complex tasks incur the same costs [when humans are involved] and this means that it makes economic sense to automatize the simple work as far as possible so that I do not have to pay the high costs associated with human staff […] but I believe that for us the advantage is that our people are much more holistically trained and are therefore far more flexible in their response to new developments and changes.' (ESSA: Head of Training Centre, Germany).

In accordance with such views, commentators such as Pfeiffer (2016) maintain that the qualitative role of workers has increased with automation, thus undermining the idea of technologically driven deskilling. Where simple tasks will be replaced by robots, or algorithms, new requirements will emerge, particularly in supervision, analysis and maintenance. The underlying question is not whether entire occupations will be replaced by technology (see Frey and Osborne 2017), but in what way the automation of specific tasks will reconfigure existing jobs (Arntz et al. 2017; Dengler and Matthes 2018).

Certainly, the ESSA data point more to the complementation of human workers and technologies, rather than a full replacement. On an empirical level, the relationship between task automation and substitution is of a non-linear type, and workers displacement should not be assumed on the mere basis of task automation. What was remarked upon several times by our (ESSA) interviewees was the importance of contextual understanding and practical experience directly associated with technological developments, with workers required to make sense of the data they are presented with by machines and digital devices and to project them onto real-work situation, and act upon them accordingly.

A related demand, and what analysis of the ESSA data point to, is the need for more holistically trained workers who can easily adapt to technological changes within the companies:

> We are working in the direction of a multiskilled workforce. So, in the production line they are involved in training programmes so that a worker will be able to work in lamination, but also in other parts of the production, and also be able to do some part of the maintenance process (ESSA: Human Resources Officer, Spain).

On this, the question that remains is the extent to which current patterns of work organisation and systems of vocational education and training, as well as training offered by steel firms, can meet the demand for new ways of working and the emerging skill needs deriving from the developments discussed. Evidence from the ESSA project suggests that like the uneven spread of technological advancement across the European industry (as for decarbonisation), some firms and countries seem better placed than others to support and make the transition (see Antonazzo et al. 2021b).

## 4 Conclusion

The steel industry was once characterised by limited cross-border cooperation between steel producers, with few mergers and acquisitions. But, from the mid-1990s things began to change significantly, reflected in churns in ownership and the establishment of huge multi-nationals, e.g. the merger of British Steel and Koninklijke Hoogovens to create Corus, which was then purchased by the Indian conglomerate Tata, as well as the creation of new global entities e.g. Liberty Steel. In the context of over-capacity and global competition it is perhaps that there will be further consolidation within the steel sector as producers position themselves in relation to changing market patterns, price volatility and fluctuation, and national and regional consolidation, with the European industry just one player on a global market (see Fairbrother et al. 2004).

What is evident is that the transformation of the EU and European industry involves interrelated processes of globalisation, privatisation, rationalisation and restructuring, and it is these processes which provide the background for the industry's technological and social transformation, and the more specific twin challenges of digitalisation and decarbonisation. The twin challenges discussed in this chapter might be framed as an opportunity for a more efficient, competitive and sustainable industry, better able to meet global challenges. Often, however, there are also opportunity costs and in this chapter we are careful to reflect on the social transformations that accompany the industry's technological transformation, and their attendant social consequences.

The developments discussed have important implications for the organisation and control of labour in steelworks. In the context of competitive markets, between companies and between countries and regions, steel companies are beginning to integrate Industry 4.0 technologies and explore alternative forms of more sustainable and decarbonised production (Branca et al. 2020; Antonazzo et al. 2021a). Parallel to this are attempts to recompose steel workforces, to upskill and also recruit a more highly skilled workforce that is overall reduced in numbers. Some have (long) argued that some of the focus of such activity has been on creating a more malleable and compliant workforce (Fairbrother et al. 2004; Pfeiffer 2017) with the introduction of various forms of team work and high-performance work systems (Bacon and Blyton 2000; Appelbaum et al. 2000).

Others have focused on workers' levels of engagement with the technologies that change the nature of work in fundamental ways—including the skills necessary to work within new 'greener' and digitalised contexts (Antonazzo et al. 2021a, b). Certainly, against the backdrop of organisational and occupational restructuring, in line with the twin challenges, steel employers have looked to develop the skills profile of their workforces. The introduction of new knowledge intensive data led technology, for example, demands a more highly skilled workforce, with restructuring towards flatter, more functionally flexible working practices demanding workers with higher degrees of generic skills, which places a higher premium on education and training to develop the skills and competencies of workers (Fairbrother et al. 2004;

Antonazzo et al. 2021b). However, the contexts in which all of these developments take place raise distinct questions for the industry and those employed within it.

The first question is what are the implications for European producers and steelworkers of the increasing internationalisation and globalisation of steel production and consumption? What are the implications of moves by, for example, the US[13] and China to create a more innovative and competitive environment for investment in green steel? Clearly European producers face a new global reality which necessitates making a strong and green industrial base a strategic priority (Eurofer 2022b, 2023). And as a 'social consequence' it seems a likely concern that there will be a continued emphasis on the repositioning and reconstructing of workforces to meet the challenges of these developments (see Fairbrother et al. 2004; Eurofer 2023: 12).

Second, and related, what is the precise impact of Industry 4.0 and decarbonisation—with changing production processes involving increased automation and experiments with new processes? Certainly, it is likely that there will be pressures on firms and workers to adapt and change, i.e. social innovation to meet these new circumstances, and be more flexible and adaptable, which will carry consequences for the material realities of employment in the industry (see, for example, Stroud and Weinel 2020).

Third, to facilitate technological and social transformation what is the training offer? With the re-composition of the steel labour process (deriving, for example, from the twin challenges) there is likely to be pressure to ensure that steelworkers have the skills base to deal with the changes that are taking place—as we have indicated training and skills will come to acquire a different significance in such circumstances.

Fourth, will the range of developments discussed in this chapter lead to common patterns of development across the industry? We know that as the industry consolidated over recent decades it witnessed similar approaches to the way work is organised (e.g. team working) across firms and countries (albeit introduced at different speeds), but might we then expect, for example, similar approaches to skill development and training to emerge? At present there is some evidence to the contrary, particularly with regard to systems of vocational education and training, as well as patterns of digitalisation and decarbonisation (see Stroud 2012; Antonazzo et al. 2021a, b).

Finally, there is the question of what role trade unions and social dialogue might play in addressing these questions and the challenges we have discussed? Our view is that—as with vocational training arrangements—it is the national context and the strength or weakness of participative arrangements at this level that has long informed the protection of workers' interests, across the European sector. We thus expect the outcomes (or social consequences) for workers to differ in the same way, as the processes of digitalisation and decarbonisation unfold (see Stroud 2012; Stroud and Fairbrother 2011; Stroud et al. 2020; Antonazzo et al. 2021b *cf*. Bechter et al. 2012).

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[13] The US Inflation Reduction Act, for example, looks to provide in the region of USD 85 Billion of funding for steel production and upstream energy requirements (Eurofer 2023: 5).

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