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Industry 4.0 and the Road to Sustainable Steelmaking in Europe

Recasting the Future

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Introduction: The Historic Importance and Continued Relevance of Steel-Making in Europe



Martin Weinel , Luca Antonazzo , Dean Stroud , Clara Behrend ,
Valentina Colla , Aitor Goti, and Antonius Johannes Schröder 

1 Introduction

In some sense, the European steel industry is the most European of industries as it has been inextricably intertwined with the conception, establishment and development of a political, social, cultural and economic entity that is known today as the European Union (EU). Indeed, the emerging European project started out as the European Coal and Steel Community (ECSC) in 1952 (European Commission 2023a).

One of the key reasons for the prominence of steel and the steel industry in the emergence of the European project is its strategic importance. Since the late 1800s, steel has become one of the critical ingredients of most large-scale infrastructure developments, whether this concerns the rapid urbanisation where steel plays an

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important role in construction projects or the development of transport networks where steel is for example used to build railway lines or bridges. In the post-war era, however, steel was recognised as one of the critical resources that can fuel and decide wars as the material plays such an important role in the manufacturing of weapons of all kinds. One of the key purposes of the ECSC was to prevent yet another European war by creating a unified and jointly regulated market for coal and steel which was supposed to create economic growth, increase employment opportunities and improve living standards across the 6 original signatory states.

While the relative economic and political importance of the steel industry for the European project has decreased over subsequent decades, its absolute importance is still high, and as some would say (e.g. WindEurope and Eurofer 2023), critical for the future success of the European project (see also Chap. 2). Steel remains the most important engineering and construction material and in recent years, thousands of new types and grades have been innovated to expand the range of applications in many sectors such as construction, automotive and mechanical engineering. Moreover, steel is durable, reusable and recyclable and is therefore an ideal material for the circular economy (Eurofer 2023). Within Europe, steel is still produced and processed in over 500 sites in 21 EU member states as well as in the United Kingdom and the steel industry employs more than 300,000 people directly and is supporting more than 2.25 million jobs indirectly in other sectors (Eurofer 2023).

But the continued survival of the European steel industry itself is under threat and to survive the sector has to face and overcome two technological challenges at the same time: on the one hand, it needs to embrace digitalisation and Industry 4.0 to remain competitive but also to deal with expected skills and labour shortages that become ever more noticeable. On the other hand, the sector needs to radically decarbonise its production systems and supply chains to remain viable and operational beyond 2050 when European states and the EU itself are legally bound to reach Net-Zero, which effectively means a state or group of states such as the EU will not be adding to the amount of greenhouse gases that is already in the atmosphere (European Commission 2023b).

2 Facing a Technological Twin Challenge: Industry 4.0 and the Decarbonisation of Steel

The present collection of essays is concerned with a twin challenge that is facing almost all European industries, but which seems to be particularly daunting for the European steel industry. The two challenges can be described and analysed separately, but they are to some extent intertwined and both have to be successfully met for the industry to have a long-term future on the European continent.

One challenge is to adapt to an already ongoing technological ‘revolution’, which is commonly referred to as the ‘Fourth Industrial Revolution’ or Industry 4.0 (e.g. Kagermann et al. 2011, 2013; Reischauer 2018; Enrique et al. 2022; see also Chaps. 3 and 4 for more extensive descriptions of Industry 4.0).¹ The name implies three previous industrial revolutions (Davies 2015). The first and best known industrial revolution, emerging in the second half of the eighteenth century, saw the emergence of mechanical manufacturing processes that were largely powered by water or steam and which started to replace hand production methods. The second industrial revolution, which began in the late nineteenth century was characterised by the emergence of electric-powered mass production systems that were based on the division of labour. ‘Assembly lines’ are probably the most iconic imagery of this period. The third industrial revolution is said to have emerged in the 1970s and is typified by the automation of complex tasks based on breakthroughs in electronics and information technology.

The fourth industrial revolution originates in the early 2000s and represents a further step-change in industrial production technologies. Industry 4.0 is underpinned by a range of new technological developments:

- The application of information and communication technology (ICT) to digitise information and integrate systems at all stages of product creation and use (including logistics and supply), both inside companies and across company boundaries;
- Cyber-physical systems that use ICTs to monitor and control physical processes and systems. These may involve embedded sensors, intelligent robots that can configure themselves to suit the immediate product to be created, or additive manufacturing (3D printing) devices;
- Network communications including wireless and internet technologies that serve to link machines, work products, systems and people, both within the manufacturing plant, and with suppliers and distributors;
- Simulation, modelling and virtualisation in the design of products and the establishment of manufacturing processes;
- Collection of vast quantities of data, and their analysis and exploitation, either immediately on the factory floor, or through big data analysis and cloud computing;
- Greater ICT-based support for human workers, including robots, augmented reality and intelligent tools (Davies 2015).

In short, Industry 4.0 offers new technological opportunities and means to organise, monitor and continuously adapt and improve industrial production systems. Industry 4.0 is expected to lead to significant efficiency gains while at the same time

¹ The term Industry 4.0 can be traced back to an initiative coordinated and driven by representatives from politics, economy and science called ‘Industrie 4.0’ that went public during the ‘Hannover Messe’ (Hannover Fair). The term was used to link to previous technological paradigm shifts and to signify the revolutionary character of the current technological transformation (Kagermann et al. 2011).

allowing for more customisation of products. While the steel industry has not necessarily always been at the forefront of technological developments and industrial transformations, there is little doubt that the sector needs to embrace Industry 4.0 to retain its relevance within the European industrial landscape.

The steel sector is, however, not particularly well set up to face the challenges presented by Industry 4.0. Technological change tends to be relatively slow in the sector due to the capital-intensity of production technologies, which, once in place, disincentivise change as technological upgrades are costly. The fierce competition in the sector, underpinned by continuous global overproduction reduces the financial wiggle room for companies to fund investments in cutting-edge technologies. The industry also struggles to attract the right talent, be that skilled workers or engineers and technologists without whom the technological transformation of the industry cannot succeed.

Industry 4.0 is not the only technological challenge facing the sector at this juncture. An even bigger technological challenge comes with the need—due to legal commitments made by European nations and by the EU under the Paris Climate Accord—to radically decarbonise steel production. Steel production, not just in Europe, is responsible for significant Greenhouse Gas (GHG) emissions that if left unchecked threaten the continued existence of modern societies and indeed the survival of many organisms and species, including humans. Even if current steel production routes—mainly the blast furnace route that requires vast amounts of coking coal—were technologically optimised to the absolute maximum, the resulting reduction of GHG emissions would not be enough to fulfil the legal obligations emanating from the Paris Climate Accord.² Without a technological revolution, the steel sector in Europe faces an existential threat by the middle of this century as states would be legally obliged to shut down steel production facilities to reach their national emission targets.

There are some encouraging signs that this second challenge has been recognised as critically important by the industry as well by the EU and individual states. The presentation of the European Green Deal in 2019 has signalled a long-term policy and regulatory commitment to decarbonise the whole EU economy and decouple growth from unsustainable resource use.³ It builds on and complements other green initiatives such as the European Emissions Trading Scheme (ETS), and now the Carbon Border Adjustment Mechanism (CBAM) to address carbon leakage. From the perspective of the steel industry, the most important aspect concerning the greening of the sector is a switch to energy sources for steel production that drastically, if not entirely, reduce the release of GHG. For electric arc furnaces, this means ensuring that

² The EU-funded LowCarbonFutures project estimates that exhausting all efficiency gains of currently available steel making technologies (including all uneconomic measures but excluding Carbon Capture and Storage (CCS)) might reduce the CO₂ output of the sector by around 40%, which is nowhere near enough to reach the sector aim of above 80% CO₂ reductions (Stubbe 2019).

³ The presentation of the European Green Deal has subsequently been accompanied by a wide range of initiatives such sectoral strategies, a ‘Climate Pact’, a ‘Circular Economy Action Plan’, a ‘Just Transition Mechanism’ and so on. For details, please see the time line here: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

the utilised energy is not based on any fossil fuels but on renewable energy sources. The greening of the European electricity network is under way and the European Union has exceeded its own strategic targets concerning energy consumption from renewable sources as the 27 EU states reached 22% in 2020 while it was aiming for 20%. The real technological challenge for the steel industry is, however, related to its main steel production route using blast furnace—basic oxygen furnaces (BF-BOF)—responsible for just under 60% of all steel produced in Europe—which requires vast amounts of coking coal to generate the required energy to make steel and therefore releases significant amounts of carbon dioxide into the atmosphere. The European steel industry will not reach the emissions targets set by the EU and by individual European states without a technological revolution that allows it to produce steel without using any fossil fuel (e.g. Eurofer 2019).

The green transformation of the steel industry is under way even though it has just begun. At the European level, ESTEP, the European Steel Technology Platform, is particularly active in this regard and leads on initiatives and projects such as the ‘Clean Steel Partnership’ and ‘Green Steel for Europe’² which try to support the technological developments needed to achieve net-zero steel making. Almost all large steel producing companies have drawn up their own plans for decarbonising steel production and more than 60 concrete projects are under way across the continent. In this respect, the industry is embracing hydrogen which can replace fossil fuels such as coal and gas that are currently used in steel making processes. This approach is known as Carbon Direct Avoidance (CDA) and numerous projects of this nature are under way or are planned in the near future. The Swedish Hybrit (Hydrogen Breakthrough Ironmaking Technology) system made headlines around the world in 2021 by being the first to deliver its first batch of fossil fuel-free steel to customers. Another approach is referred to as Smart Carbon Usage (SCU) which aims to reduce the release of GHG in steelmaking processes by either reusing waste gases within their own production systems or to make them available to other companies as a resource which can then be used to create other products. Whichever approach or combination of approaches are taken by the industry, it is clear that business-as-usual is not a viable option (see also Chap. 2 for more on this). Moreover, any approach to reduce GHG needs to be part of a wider economic and societal transformation towards a circular economy that reduces ‘waste’ of any kind as much as possible. Steel is highly durable and thus reusable but also fully and infinitely recyclable: steel is the quintessential material of the circular economy (Eurofer 2019).⁴

There is also an inherent connection between Industry 4.0 and the decarbonisation of the steel making processes. Industry estimates suggest that the economically viable technical improvements of current steel making processes could reduce CO₂ emissions by 15%. While this is insufficient in itself and a more radical technological revolution in steel making is required to meet the legally binding emission target in 2050, it is also clear that the optimisation of currently utilised processes can still meaningfully contribute to reaching net-zero steel production in a few decades. It is

⁴ Of course, as pointed out above, steel production would need to switch to entirely renewable and green energy sources to be truly sustainable.

in this area where current Industry 4.0 and digitalisation trends have an important role to play. There is, for example, scope to further optimise the inputs required in EAF-based steel making in a bid to ultimately reduce GHG emissions (see Chap. 4 for a more extensive analysis of the link between Industry 4.0 and decarbonisation).

3 Responding to the Twin Challenge

There seems to be hardly any doubt among European steel industry stakeholders that the transformative challenges of adopting Industry 4.0 technologies as well as decarbonising the production of steel are genuine challenges that cannot be left unaddressed. The big question, which this edited collection begins to address and answer, is how best to respond to these challenges to safeguard the future of the European steel industry.

The first section of the book, *The EU steel industry: a social and technological transformation* grapples explicitly with this question on a theoretical and conceptual level. The broad consensus among the diverse set of authors is that technological challenges require more than ‘technological responses’. This approach is informed by social scientific research over the last few decades which has convincingly shown that technologies not only have social effects and consequences, but that they are also themselves shaped by wider social forces (e.g., Salento 2018; Bijker et al. 1987; Winner 1980). This perspective, when taken seriously, has profound implications for the design, development and deployment of technologies. Instead of regarding technology as ‘neutral’, ‘inevitable’ or even ‘natural’, recognising the socially shaped and constructed nature of technology opens up avenues to shape technology in such a way that is aligned with desirable societal values and objectives.

In some cases, this is entirely obvious and already widely accepted: as pointed out above, using blast furnaces to make steel is a possible technological route that the industry has relied on for many decades, but this is no longer compatible with societal needs which require a radical decarbonisation of steel production. Hence, the broad consensus to develop alternatives, even though many different challenges—funding the development of new hydrogen-based steel making technologies, creating the infrastructure to produce green hydrogen at acceptable prices, drawing up appropriate regulatory regimes, reskilling the workforce and so on—will have to be overcome to replace one working technology with an alternative that fits changing societal needs.

Often, however, the way in which technologies are designed and how they are intended to function is not sufficiently questioned and challenged (Edwards and Ramirez 2016), resulting in suboptimal outcomes. In some cases, this will take the form of workers actively resisting or rejecting technologies when these are perceived as threatening or undermining. In other cases, technologies are allowed to shape workplace experiences that devalue the contribution of workers or create dull and boring working environments where workers are stripped of any autonomy. It thus

makes sense for all relevant stakeholders involved in addressing technological challenges to always consider whether proposed technologies and technological developments can be shaped in such a way that they will be widely accepted when deployed and that they do not create any undesirable consequences. Instead of imposing technological change, it might be far more beneficial to actively shape technological change to increase benefits and minimise negative consequences (see in particular Chap. 3).

4 The European Steel Skills Agenda (ESSA)

Over recent decades, much has changed in the theory and the practice of how to deal with technological change. A narrow focus on technology as a means to increase efficiency and productivity has given way to more holistic perspectives that are capable of pursuing and reconciling a broader set of goals such as sustainability, dignity, resilience and social justice beyond narrow economic concerns (Rip, Misa and Schot 1995; European Commission 2021).⁵

The Erasmus+ funded European Steel Skills Agenda (ESSA) project that (directly or indirectly) binds all the contributors to this edited collection together embodies this holistic approach to technological change. The ESSA project aims to draw up a developmental blueprint for the European steel sector that maps out a holistic response to the pressures arising out of the rapid technological change described above that is already beginning to affect the industry. Identifying available technologies, or designing, developing and/or implementing entirely new technologies appropriate and relevant for the sector, is just one aspect forming part of a wider, holistic response. As technologies require an appropriately qualified workforce, the ESSA project also analysed current and future skill needs and competence gaps with regard to job profiles and occupational qualification programmes, which can then inform the design of new or additional training instruments to prepare the workforce to be able to cope with the ongoing technological transformation. Recommendations concerning the adjustment of vocational education and training also consider the need to ‘train the trainers’.

While the holistic blueprint for the transformation of the steel industry represents a European approach, the industry tends to be embedded in regional industrial networks as steel plants tend to cluster in geographical areas that historically provide relatively easy and reliable access to traditional steel making resources such as coal or abundant electrical energy and/ or iron ore. Thus, regionalised responses have been identified as the most promising approach to create localised ‘Communities of Practice’ consisting of stakeholders from the industry including employer associations and trade unions, but also those from academia, civil society, governmental and non-governmental organisations, etc., that can not only organise and coordinate technological innovation

⁵ Social Innovation; Industry 5.0

but also complement these with appropriate social innovations (training regimes, organisational changes to accommodate technological change).

As suggested above, almost all contributors to this collection are in some ways associated with the ESSA project. The project has brought together a highly diverse set of steel sector stakeholders including representatives from all large European steel companies, regional, national and European steel associations, trade unions, policy-makers, Vocational Education and Training (VET) providers administrators as well as researchers and academics. The ESSA project has also created fruitful links and connections with a range of other collaborative European research projects. Moreover, most of the contributions in this collection are at least partly, if not fully informed, by research conducted as part of the ESSA project (as well as other research projects, too).

5 This Edited Collection

This edited collection consists of three sections. The first section *The EU steel industry: a social and technological transformation* consists of four chapters that look in some detail at the case for the transformation of the sector as well as at theoretically informed accounts of how the transformation ought to be organised.

Chapter 2 by sociologists of work Dean Stroud, Luca Antonazzo and Martin Weinel takes a more in-depth look at the twin challenges of adopting Industry 4.0 technologies and decarbonising steel production.⁶ By adopting a historic perspective, the chapter reveals how wider, non-technological factors such as ownership structures, attitudes and approaches to skills and competence development and relationships between social partners are crucial in shaping the consequences of technology use and the trajectory of the European steel industry on the whole. Their findings lend further support to the approach advocated in this book, which suggests that a successful transformation of the European steel industry has to be grounded in a holistic approach that pays attention to not only to the economic but also the social, political and environmental implications of technology use. In doing so, they set the scene for the next chapter which provides more detail on how best to respond to the challenges facing the sector.

Chapter 3 by Dortmund-based German sociologists Antonius Johannes Schröder, Mathias Cuypers and Adrian Götting takes up the themes developed in Chap. 2 and offers a coherent and holistic, forward-looking theoretically informed framework referred to as Industry 5.0. Slightly counter-intuitively, the term *Industry 5.0* does not refer to the next technological revolution. Instead, it denotes a complementary

⁶ All three authors worked together at Cardiff University in Wales on the ESSA project. While Stroud and Weinel are still at Cardiff, Antonazzo is now an external researcher at the Centre for Workplace Research at the Prague University of Economics and Business in the Czech Republic and he is also located at the Department of Human and Social Sciences, University of Salento, Lecce, Italy.

conceptual framework designed to guide stakeholders through dealing with the adaptation and implementation of Industry 4.0. The suggested Industry 5.0 framework at the heart of the chapter posits that the industry has to not only undergo the technological revolution, i.e. Industry 4.0, but also—and at the same time—a complementary social, cultural and environmental transformation to make the technologies work effectively and to thus survive and thrive in the long run. The suggested Industry 5.0 framework recognises that technologies do not exist in a (societal) vacuum: their particular form and functionality, but also their consequences for companies, communities and society as a whole is the result of many different choices. Schröder and colleagues argue that the Industry 5.0 framework offers a more holistic approach to technology development and implementation as it centralises environmental and societal concerns, which are often overlooked in favour of a narrow focus on efficiency and costs.

In Chap. 4, Italian researchers Teresa Branca, Valentina Colla and Maria Murri in collaboration with Antonius Johannes Schröder take a closer look at the connections between the technological, social and environmental transformation in support of the argument that a holistic approach is required to deal with the technological challenges facing the steel industry. Their particular focus is on the complementing effects of digital technologies for the wide-ranging transformation of the industry. As the authors convincingly show, digital technologies are not only critical in achieving desirable environmental outcomes, for example by helping to reduce energy and resources needed to produce steel. They are also crucial in supporting the required social transformations, for example by aiding the delivery of training or through simplifying communication between different actors involved in steel production.

Chapter 5 by Italian researchers Marco Vannucci, Ruben Matino, Maria Murri and Roberto Piancaldini, in collaboration with Antonius Johannes Schröder and Dean Stroud, focuses on technological responses by describing the current technological state-of-the-art of Industry 4.0 applications and by analysing how two specific technologies—robots and unmanned aerial vehicles (drones)—can be applied in steel plants and what their potential for the modernisation of steel plants is. While the authors focus is on technologies, social and organisational aspects are also considered as the way in which technology is experienced by workers has important effects on the acceptability and ultimately the usability of technologies in particular work settings.

The second section, *Industry Perspectives on Industry 4.0 and Workplace Change*, changes perspective from academic and theory-informed accounts towards the view of actors operating within the industry. The focus is thereby mainly on the consequences of technological change on workplaces in the industry. The section includes chapters from HR managers, trade unionists and representatives of industry associations. While some chapters take a historic perspective to trace how technological change has led to changing workplaces, other authors reflect on their own experiences gathered while working in the steel industry to highlight practical steps companies can take to respond to rapidly changing circumstances without jeopardising recruitment and talent retention.

Chapter 6 by Anna Mowbray, a former research and policy officer for the British trade union Community, traces the long and at times tumultuous history of the relationship between steel companies and trade unions in the United Kingdom. The United Kingdom, while no longer a member of the EU, remains an interesting case study. It had the first industrialised steel sector in the world and used to be the world's biggest producer of pig iron and crude steel in the second half of the nineteenth century. Like steel sectors in other European countries, the industry's fortunes were cyclically changing over the decades until the 1970s industrialisation of steel making fundamentally changed the workforce organisation and labour relations. Highlighting a range of critical junctures in the history of the British steel industry, Mowbray shows that periods of prosperity in the sector tended to be accompanied by good and cooperative relationships between employers and employees, while the numerous periods of crisis the sector has experienced over the last century were usually accompanied by strained and at times hostile labour relations. In light of this historic analysis of industrial relations, Mowbray argues for the importance of good working relationships between employers, employees and state to ensure the well-being of the sector in a challenging context while also protecting and preserving jobs and communities dependent on the sector. This is an especially important lesson in light of the required transition to net-zero that must balance environmental, economic and societal needs and is likely to fail if the main stakeholders cannot successfully and productively work together to safeguard the future of the British steel industry.

Chapter 7 is another contribution using a historic lens to understand the challenges and opportunities that come with the advent of adopting Industry 4.0 technology in the steel industry. Written by Roman Ďurčo, Marcel Pieleš and Dana Sakařová from the Czech union OS KOVO, the chapter reflects on the changing fortunes of the Moravian steel region around the city of Ostrava in the Czech Republic and its intricate relationship to other industries. Having operated for 40 years or so in the protected environment of a socialist production regime, the steel industry in the Ostrava region suffered a significant downturn in the wake of the political change sweeping through Eastern Europe at the end of the 1980s and in the early 1990s. The loss of industrial jobs on a large scale in conjunction with an ageing population has left Ostrava in a marginal and potentially perilous position that has also been experienced by many other former industrial regions across Europe. Yet the authors also emphasise the potential importance of Industry 4.0 as well as the drive to decarbonise human activities can have in the economic renewal of the Ostrava region. Looking at other examples of industrial renewal, the authors suggest that in a context where regional stakeholders work together strategically and use available resources to create an innovative and dynamic environment for companies and communities to thrive, the economic decline of a region traditionally associated with steel and coal is not inevitable. In the case of Ostrava, metallurgy and steel-making continue to play a vital role in attracting investment and skilled workers and thus helping to shape the economic, social and cultural future of the city and the region.

In Chap. 8, José Ignacio Alonso Osambela, who works as Human Resource Manager for the Celsa Group, provides fascinating insights into the changing practices of recruitment and training in a steel company as a consequence of increasing

digitalisation of processes. Digitalisation affects HR practices in at least two different ways: on the one hand, the digitalisation of steel plants increases the pace of change that affects an increasing number of jobs, which means HR professionals have to change their practices. At the same time, digitalisation also directly changes HR practices as hiring processes are no longer paper-based, new opportunities to rethink the provision of training open up and social media offer new avenues for recruitment of talent. Consequently, the chapter describes and analyses in detail how certain key HR practices, such as finding and hiring new staff or training new and existing staff, have changed due to the increased digitalisation of steel companies.

In Chap. 9, Nicole Rudolph and Martin Kunkel, who both represent the *European Federation of the National Associations of Cold Rolled Narrow Steel Strip Producers and Companies* (the associations acronym is CIELFFA, which stands for *Comité International d'Étude du Laminage à Froid du Feuillard d'Acier*) puts the challenges facing the European cold rolling industry into the focus. An important downstream part of the European steel production community, the European cold rolling industry is presented with similar challenges that the industry as a whole is facing: fierce global competition as well as high pressure to adapt to technological change such as Industry 4.0 in order to stay competitive and innovative. The chapter focuses, however, on a problem that is common across the steel sector but acute in the Cold Rolling Industry: an ageing workforce that is facing more demanding and changing working conditions. The challenge for cold rolling companies in this context is to safeguard the employability and the innovative potential of their ageing workforces on inclusive and appropriate training and development initiatives. The chapter focuses on one particular sector-wide initiative, the so-called KaGiWi¹² project, that is designed to address the challenges of retaining and continuously training older employees by raising awareness and expertise among managers. The project applies a participatory framework that analyses at company level parameters such as the age structure of the work force, the skill requirements associated with a range of tasks and stress points that can have adverse effects on the health of employees. The project not only helps managers and employees to jointly understand how work is experienced, but also provides a range of practical advice and resources that improve working conditions and strengthen the organisational resilience of companies.

In Chap. 10, German Human Resource experts Veit Echterhoff, Peter Schelkle and Stefan Cassel continue to explore how steel companies can deal with workforce challenges such as recruitment, retention and training of staff.⁷ Their contribution provides answers to the question as to what steel companies can do to attract and retain highly qualified talent in a context of steel jobs that are seemingly less attractive than jobs in other sectors. Based on insights gained from European-level research projects that identify a range of internal and external factors that influence the success or failure of talent recruitment and talent retention, the Chapter develops a range of practical recommendations for steel companies but also for sector associations and

⁷ All three authors work or worked for Thyssen Krupp Steel Europe. Echterhoff and Cassel continue to do so, while Schelkle now works for another steel company, the Hüttenwerke Krupp Mannesmann GmbH.

organisations that, if followed up and implemented, promise to ease the recruitment challenge faced by European steel companies.

The third section *New skills requirements, training and recommendations* returns to a more academic and theoretically informed perspective on how to organise the twin transformation facing the European steel industry. All three chapters are directly based on empirical research conducted across Europe.

Chapter 11 by Luca Antonazzo, Dean Stroud and Martin Weinel discusses the implications of extensive automation and digitalisation for the European steel industry and the responses of national vocational education and training (VET) systems to emerging skill demands. Based on research conducted as part of the ESSA project, the authors shed light on the issue of emerging skills gaps in the industry. Their findings suggest that so-called transversal skills—skills that are considered as not specifically related to a particular job or task such as critical thinking, teamwork or problem-solving—become ever more important. The chapter then investigates the responses of national VET systems in Germany, Italy and the United Kingdom drawing on an institutionalist framework that pays particular attention to the role that VET institutions and organisations play in shaping national responses to continent-wide problems. By showing that national responses to common problems vary significantly, the chapter demonstrates the importance of institutions and organisations and their particular characteristics and capabilities in the ongoing transition of the European steel sector.

Chapter 12 by Spain-based steel industry experts Tugce Akyazi, Aitor Goti and Félix Báyon changes perspective from institutional VET context to concrete practices at sector and company level needed to manage the twin transition. As the European steel sector is undergoing constant and substantial changes due to the technological change and the need to decarbonise steel production, the majority of older workers in the steel sector do not have the technological, digital and social competences that changing technologies, business models and organisational structures require. To deal with the complex task of re- and up-skilling the existing workforce, the authors propose the creation of a sectoral occupational database as a practical tool that can help companies and sector organisations to continuously manage changing skills requirements. The chapter describes the method and the utilised data that inform the sectoral occupational database. Presenting some exemplary results and illustrations of the database output, Akyazi, Goti and Báyon highlight the added value of their dynamic and constantly evolving database compared to existing occupational databases such as the European Skills, Competence, Qualifications and Occupations (ESCO) database which is static and lacks the sector-specificity.

The last substantive contribution to Sect. 3, Chap. 13, has been written by German-based social researchers Adrian Götting, Clara Behrend and Michael Kohlgrüber. Starting with the premise that the digitalisation of work is accompanied by far-reaching processes of change, which also affects the jobs and skills of employees and managers, the chapter presents findings from the empirically oriented Beyond4.0 project on the future transversal skills demand due to increasing digitalisation. In particular, the results of a case study involving the steel industry located in the Rhine/Ruhr region in Germany are presented. The focus thereby rests on skills that

are gaining in importance across all occupations and at all qualification levels. Given the focus on the digital transformation of the steel industry, the assessment of future digital skill needs was an important part of the study. Interviews with regional stakeholders reveal that basic digital skills become a necessary requirement for all jobs, while higher-level digital skills requirements increase in line with skill levels of jobs, i.e. high-skilled jobs require advanced digital skills. One key insight of the study is that the digital transformation affects skills beyond those that might be narrowly classified as digital skills, which might include the use of digital devices, cybersecurity, the secure handling of data as well as the use of complex digital communication tools and so on. The study reveals that a wide range of transversal skills, including social, personal and methodological skills gain greatly in importance in conjunction with digital skills as the digital transformation takes place. While digital skills are important when it comes to the actual operation of digital devices and infrastructure, non-digital transversal skills are vital when it comes to designing, planning and implementing the use of digital technologies as well as when it comes to interpreting or acting upon digital data.

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