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

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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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D. Stroud et al. (eds.), *Industry 4.0 and the Road to Sustainable Steelmaking in Europe*, Topics in Mining, Metallurgy and Materials Engineering,
https://doi.org/10.1007/978-3-031-35479-3_1

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 wriggle 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 CO_2 output of the sector by around 40%, which is nowhere near enough to reach the sector aim of above 80% CO_2 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 CO_2 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 conceptional 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.