Sustainable Supply Chain Management in the European Union Steel Industry.

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Abstract

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This master's dissertation examines the implementation of sustainable supply chain management (SSCM) practices within the steel industry, a sector critical to the European Union's climate targets due to its high carbon footprint. The research focuses on how major steel producers incorporate sustainability into their supply chains and what challenges they face in this ongoing process. Using the multiple case study design, qualitative data were collected through interviews with representatives from four prominent steel companies operating across Europe. The data were manually coded and analysed thematically to identify key sustainable practices and challenges. To enhance validity and provide additional context, secondary data were also reviewed and compared with the primary findings using a triangulation approach. The results indicate that firms are adopting a combination of decarbonization efforts, circular economy practices, social sustainability and digitalization as sustainable development strategies. These green efforts often require significant restructuring of supply chain management practices. Financial barriers were identified as the most common challenge across cases. While regulations urge steel companies to transition quicker and more transparently, they also act as constraints in their current form. The dissertation concludes with the recommendations for improving SSCM practices, emphasizing the role of innovation, collaboration and supportive practices in fostering sustainability within the steel sector.

Esta dissertação de mestrado analisa a implementação de práticas de gestão sustentável da cadeia de abastecimento (SSCM) na indústria siderúrgica, um sector crítico para o cumprimento das metas climáticas da União Europeia devido á sue elevada pegada de carbono. A pesquisa concentra-se em como os principais produtores de aço incorporam a sustentabilidade nas suas cadeias de abastecimento e nos desafios que enfrentam nesse

processo. Utilizando o desenho de estudo de caso múltiplo, os dados qualitativos forem recolhidos através de entrevistas com representantes de quatro empresas siderúrgicas proeminentes que operam em toda a Europa. Os dados foram codificados e analisados manualmente de forma temática para identificas as principais práticas e desafios de sustentabilidade. Para aumentar a validade e fornecer contexto adicional, os dados secundários foram revistos e comparados com as conclusões primárias, utilizando uma abordagem de triangulação. Os resultados indicam que as empresas estão a adotar uma combinação de esforços de descarbonização, práticas de economia circular, sustentabilidade social e digitalização como estratégias de desenvolvimento sustentável. Esses esforços verdes frequentemente exigem uma reestruturação significativa das práticas de gestão das cadeias de abastecimento. As barreiras financeiras foram identificadas como o desafio mais comum entre os casos analisados. Embora as regulamentações exijam que as empresas siderúrgicas façam a transição da forma mais rápida e transparente, elas atuam como constrangimentos na sua forma atual. A dissertação conclui com recomendações para melhorar as práticas de SSCM, enfatizando o papel da inovação, da colaboração e de práticas de apoio no fomento da sustentabilidade no setor siderúrgico.

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1. Introduction

Background

The target of the European Union to meet a reduction of emissions of 55% by 2030, in relation to 1990 levels, can be achieved only when energy-intensive manufactures especially in steel industry will take actions to become more sustainable by implementing new strategies that enable growth, with planet wellbeing in mind (European Union, 2020). I have chosen the steel industry as a subject of this research not only for that reason. One of most fascinating aspects of sustainability in steel production is the material's high recycling potential. Steel may be recycled endlessly and still retain its unique attributes and quality (Tata Steel Nederland, n.d.-a), making it an extremely sustainable material if managed correctly. This potential indicates that, with the right sustainable management practices, steel can help reduce environmental footprint (Nidheesh, Kumar, 2019). The steel industry is also a key player in heavy industrial sector and is characterized by its large-scale production processes. These processes, however come with environmental challenges, primarily due to high energy consumption and substantial greenhouse gas emissions (Nidheesh, Kumar, 2019). Studying how to manage these environmental concerns is important, as the industry's impact on climate change is visible for instance in tonnes of CO2 made per tonne of steel (SteelWatch, 2025).

Research focus

This study concentrates on the sustainable development strategies and supply chain management practices adopted by major steel manufactures in Europe. Given the industry's challenging and ever-changing business environment, firms are increasingly implementing sustainability-oriented strategies to reduce their environmental impact while maintaining competitiveness (Marcus, Villa, 2020; Janberg, 2024). This research examines how big companies in European Union try to implement sustainability within their supply activities, the challenges they encounter on the way as well as the effect of these strategies on supply chain management practices.

Research aims and objectives

This dissertation explores the sustainable development strategies and actions related to supply chain implemented by several firms in steel industry, to identify and present practices that are perceived as effective by well-established companies in the steel industry. By examining the in-depth interviews with representatives of four big steel firms including: Marcegaglia, Salzgitter, SSAB, TATA Steel Nederland, that operates across different European countries, this research aims to uncover valuable insights. It will address question such as what is the impact of sustainable strategies on their supply chain management. Additionally, it will explore what does the development of these entails for companies with a focus on challenges they face. Then a multiple case study will be introduced and the gained data will be analyzed using qualitative analysis to subjectively interpret the content by facilitating codes as a mean to recognize the patterns and repetitions in transcriptions. This study will also be enriched by conducted industry overview and will conclude with the set of context-specific recommendations that aim to promote sustainable development in the steel industry as well as liabilities that can affect the applicability of the results of this study.

Value of the research

The conducted study adds to the existing research on the sustainable supply chain management in the steel industry by offering an overview of current practices and their implications. Building upon the suggestions from the study of Batista and Francisco (2018), which recognized the need for analyzing organizational sustainability practices not withing only one country but in the wider scope this paper is examining firms in European context to provide more adequate and broader managerial implications. By obtaining insights from the major steel companies on current sustainable supply chain management practices, a comprehensive picture of SSCM within investigated sector can emerge enabling a meaningful comparison between theory and real-world applications. The study also responds to the vital need for and importance of decarbonizing the European steel industry to meet the sustainable goals of European Union (Skoczkowski et al., 2020) by examining sustainable supply chain strategies that support emissions reduction, resource efficiency and long-term environmental resilience.

2. Literature review

Introduction

To analyze the role of sustainable supply chain management (SSCM) in the European steel industry, it is crucial to first define the foundational concepts of sustainability and sustainable development. These concepts serve as the theoretical basis for understanding the pressures for changes faced by firms from resource-intensive industries like steel. The beginning of this literature review presents the dimensions of sustainability, focusing especially on the triple bottom line framework. Then, given the steel industry´s high carbon footprint and emerging regulatory challenges the sustainability strategies are presented. These include decarbonization efforts, circular economy principles and integration of innovative strategies. To further better understand these strategies the research introduces the Natural Resource-Based View theory, which explains how companies can gain a competitive edge by adopting sustainable practices. Additionally, sustainability standards are examined to understand their role in guiding and limiting the corporate environmental activities.

Recognizing that supply chains play a critical role in sustainable development the review transitions in chapter number two and three into supply chain management theories. This includes the dynamic capabilities framework which emphasize agility, adaptability and resilience in maintaining sustainability in complex global supply network. Additionally, different supply chain structures are analyzed to address their impact on sustainable performance and resources of companies. The last chapter of the literature review presents the theory about the sustainable supply chain management that is needed to correctly analyze the topic of this study. Next, the review ends with research gap and clear summarization of all concepts presented before.

2.1 SUSTAINABILITY

Defining sustainability

The definition of this term is clearly presented in James B. Sauer's article, where the author analyzes the discourse surrounding its meaning. Sauer draws on descriptions provided by the scholars such as Boulding, Jacobs, Brown and others, demonstrating that sustainability

encompasses both ethical and economic values. It reflects the conditions that result from a continuous flow of actions and decisions by its participants, with its meaning varying based on the context (Sauer, 1996). Another author showcases that sustainability has six distinct conceptual roots, contributing to a great number of this word's descriptions. At its core, this term can be understood as the proactive upholding of the planet's conditions and resources, with a focus on the evolving processes (Portney, 2015). As shown in this and many more articles, sustainability does not have one universally established meaning within the literature. Such a lack of consensus, which is criticized by scholars, creates opportunities for people to misuse the term, unintentionally or premeditatedly in the form of dishonest sustainable reports that can mislead stakeholders (Moneva et al., 2006; Ali, Fukofuka, Narayan, 2023).

Sustainable Development Theory

Sustainable development (SD) occurs when the needs that are met at the present, do not limit or prevent the needs of the future (Brundtland, 1987). This concept has gained growing importance recently, occurring more and more in different organizational areas due to the fast economic development that resulted in new regulations and goals aimed at safeguarding our planet's well-being. This thematic first prominent appearance can be seen in Report of the World Commission on Environment from 1979. Today, firms from all over the world can examine their actions by delving into the Sustainable Development Goals (SDGs). These goals illustrate the link and balance that should be obtained between three, significant for whole society elements: economic growth, environmental protection and social inclusion. Enterprises are an important factor to make SD possible as they have major impact on all these dimensions of life (Kuźniarska, Mania, Jedynak, 2024), that are collectively referred to as the triple bottom line of sustainability (Arowoshegbe, Emmanuel, Gina, 2016).

The author of the triple bottom line (TBL) term, John Elkington explained:

> "Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity. That companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line" (Elkington, 1998, p.397).

The TBL concept is used as an accounting tool by not only businesses but also by governments, non-profits and enables them to make additional flexible reports about their performance in the three areas: people, profit and planet (Slaper, Hall, 2011; Jackson, Boswell, Davis, 2011). However, twenty-five years after developing this concept, Elkington highlighted that the TBL should not be treated only as some accounting tool. Isted, he emphasized the need for it to

encourage additional reflection about capitalism´s future and its potential for transformation (Elkington, 2018). This perspective brings attention to the urgency for changes in the business models that will entail significant long-term results rather than the short- term gains (Arowoshegbe, Emmanuel, Gina, 2016). By the implementation of new strategies, operations, suppliers or materials companies can experience a new competitive edge and enhance its reputation (Teece, 2007). Thus, the TBL provides a holistic approach to sustainability, aligning business practices with greater environmental, economic and social objectives.

At the heart of the TBL framework lies the economic dimension. This dimension encompasses sustainable practices and maximal optimization of shareholder wealth (Adams, Thornton, Sepehri, 2012). The research about the effect that the sustainability activities have on financial performance of companies revealed that the majority of articles demonstrate a positive correlation between those variables (Alshehhi,, Nobanee, Khare, 2018) adding to the reasons why investing, researching and constantly improving sustainability within businesses is important. Other researchers presented that commitment to economic sustainability fosters long-term profitability for companies and presents with time economic benefits such as reduced employee turnover or an extended consumer base (Laurell, Karlsson, Lindgren, Andersson, Svensson, 2019; Pyster, 2021). This demonstrates how the economic dimension of TBL is important and ultimately strongly linked with social and environmental objectives.

Building on the economic dimension, the environmental element of TBL emphasizes protection of nature within companies' actions. The environmental line of TBL implies organizational practices such as reduction of emissions, efficient usage of materials or development of green resources that ensure the preservation of environmental resources for future generations (Alhaddi, 2015). Incorporating such vision into practice is complex and requires knowledge to result in profitable outcomes not only for the company itself but also on a larger societal scale (Pyster, 2021; Miller, 2020).

The broader perspective aligns with the final element of TBL, which emphasizes the company's need to generate value for every stakeholder (Miller, 2020). This social dimension of the triple bottom line is a part of the wide concept of corporate social responsibility (CSR) and is influenced by human perceptions and values (González-Rodríguez, Díaz-Fernández, Simonetti, 2015). CSR serves as an initial step towards achieving sustainability that connects it with values and communication with stakeholders (Sánchez-Teba, Benítez-Márquez, Bermúdez-González, Luna-Pereira, 2021). However, as literature shows, despite the positive

impact of reporting CSR activities on companies' profit, they in many cases struggle to do it effectively (Belas, Zvarikova, 2021).

While the TBL provides a comprehensive sustainability framework for companies, alternative models have emerged to further expand its principles. A different concept similar to the triple bottom line is presented in Borland's work about global strategic sustainability and is called the quadruple top line. What distinguishes this is that it allows organizations to recognize separately four dimensions: social, ecological, financial and planetary ensuring that planetary and environmental concerns receive equal attention (Borland, 2009). Another concept that is said to emerge from TBL as well as from that presented before CSR is ESG (Jacobs, 2024). ESG is a multifaceted concept that integrates not only environmental and social aspects but also the crucial governance dimension of sustainability. This approach is reflected in various sustainability standards such as GRI, ESG ratings or ISO 26000. Therefore, the focus is shifting towards not just what to sustain but how companies can implement sustainable principles, highlighting the importance of tools that can measure the introduction of sustainable development within organizations (Cantele, Landi & Vernizzi, 2024).

Sustainable Development in Europe

Sustainable development is also a key legal and strategic concept of the European Union, forming the foundation of its social, economic and environmental policies. According to the Treaty of European Union (TEU) sustainable development involves striving for the economic growth, overcoming social exclusion and preservation of the nature (European Union, 2012). To encourage such development, the EU designed multiple measures such as policies and projects.

> " These include the European Green Deal, the European semester, the circular economy action plan, the environment action programme, the better regulation agenda, the EU cohesion policy and the European Pillar of Social Rights action plan." (European Union, 2023, para. 2).

According to the literature, the Amsterdam Treaty first incorporated the concept of sustainable development into EU law, integrating social and economic progress and environmental needs. The concept was further expanded upon and presented in various treaties, including the famous Lisbon Treaty, which explicitly referred to the sustainable development of not only Europe but as well the planet (Kenig-Witkowska, 2017). Key milestones regarding this term also include the approval of the" Declaration on the Guiding Principles for Sustainable Development" by the European Council in 2005, which consisted of ten principles with one of

four key objectives being environmental protection. This document also puts sustainable development on the pedestal by establishing it as a core aim of all European Community policies (Council of the European Union, 2005).

As the European Union's ambitious goal of achieving carbon neutrality for manufacturers by 2030 gives a pressing need for sustainable practices in lots of industries, managers are compelled to confront the challenges and opportunities within their organizations and supply chains (Tolettini, Di Maria, 2023). One of those industries that is predicted to grow is the steel one, known for its large energy consumption and responsibility for 7% of all CO_2 emissions (Holappa, 2020).

Sustainable Development in NRBV

Sustainable development is also one of the three strategies belonging to the other theory called a natural-resource-based view (NRBV). According to the definition provided by Stuart L. Hart (1995, p. 986), the NRB view is "a theory of competitive advantage based upon the firm's relationship to the natural environment". Such understanding entails another important for this work concept such as competitive advantage. This special ability that companies should nurture is interpreted as unique resources and capabilities that are gained or developed and give an advantage over competition (Liang, 2013). The natural-resource-based view entails three strategic capabilities that facilitate this success within competition. To them we include the pollution preservation, described as a foundation for proactive sustainable management. It tells us about the need to remove avoidable pollution and waste. Importantly, a literature about this view suggests a path dependence in the order of these strategies, indicating that addressing the issue of pollution first is crucial, because otherwise it can be very difficult to tackle two other areas of the NRB view. For instance, in industries such as steel manufacturing, sustainable development goals depend heavily on their capabilities in both product stewardship and pollution prevention (Hart, 1995). This proactive approach is not only proven to have a positive impact on the profitability of companies (Graham & McAdam, 2016; Hart, 1995; Schwens & Wagner, 2019) but as well can facilitate the adoption of internal firm sustainability standards that are investigated in the next section of the thesis (Schwens & Wagner, 2019).

Product stewardship is the second capability that is a part of the NRB view. This strategy is externally oriented and highly connected to the topic of this thesis, as it is defined in the literature summary conducted in 2019 as activities that prioritize the conservation of the environment through the whole supply chain of the product which entails the stakeholders

(internal and external) integration (McDougall, Wagner & MacBryde, 2019; Graham & McAdam, 2016). Product stewardship also incorporates the environmental importance into product design. The start-ups can find it attractive to implement such ideas into their business model. It can as well serve as a differentiation strategy or as a foundation to gain reputation and position such a company as a pioneer in an emerging sustainable market segment, offering the opportunity to secure a market-leading position by means of strategic preemption (Hart, 1995; Hart, Dowell, 2011).

Sustainable development is positioned in NRBV as a mix of presented before concepts, which is said to be the most advanced one. Literature presents this capacity as the one that goes beyond environmental concerns but also addresses social and economic challenges while at the same time requiring broad changes in supply chain or corporate culture (Kim, Woo, Balven & Hoetker, 2020). This strategy shifts the focus from planet damage limitation to proactive future-oriented production (Hart, Dowell, 2011). Sustainable development plays a crucial role in financial performance (Kim, Woo, Balven & Hoetker, 2020). This construct is defined in the literature as clean technology and base of the pyramid. Clean technology in NRBV includes innovative technologies and processes that position companies for long-term competitive advantage by reducing consumption of materials and energy. On the other hand, Bop emphasizes catering to the unmet needs of a vast amount of the population that is underserved. These can be accomplished by embedded innovation and bring companies the advantage of long-term growth (Hart, Dowell, 2011). Together these elements mark the nature of NRBV, which not only seeks to minimize environmental harm but also leverages sustainability as a driver for innovation.

Sustainability standards

Sustainability standards pose as the guidance for corporations that aims to enhance their efficiency in 3 areas: environmental, economic and social. Reporting on sustainability brings value to an organization in multiple ways, such as giving the possibility to grow by enhancing processes and systems, lowering compliance costs, building trust among shareholders and customers as well as creating an environment for long-term success within competition (Mehul, 2017). These and many other factors have led to the widespread of various kinds of sustainability reporting frameworks to meet the growing demand for transparency and accountability in corporate sustainability practices (Global Reporting Initiative and World Benchmarking Alliance, 2024).

There has been an increase in sustainability reporting standards worldwide. These standards, which can be either mandatory or voluntary, require or encourage organizations to disclose their performance, especially their usage of resources. Voluntary sustainability standards (VSS) reporting includes firm initiatives, public/private partnerships, management systems, certifications or industry associations. It is important to know that various actors, particularly the private entities, public institutions and civil society, participate in creating, controlling and implementing these standards. These actors, who can be both within and outside the companies' supply chains (Mehul, 2017; Lambin, Thorlakson, 2018), play a critical role in shaping the effectiveness of sustainability standards.

However, sustainability standards face difficulties in enforcement, implementation and market impact. They aim to drive a positive change, but there is a risk of loopholes and weak oversight that can limit their effectiveness. For sustainability standards to deliver tangible results, literature notes that they require strong economic and instructional support. Their structure varies: public non-market-based standards usually come from regulatory bodies, while public market-based standards emerge from national or international standards setting-agencies. Private standards, on the other hand, can be industry-driven like ISO standards or market driven (Russo, Sansone, Colamatteo, Pagnanelli, 2023). Unlike direct governmental regulations, sustainability standards are often voluntary and over time, can become mandatory overtime due to market pressures, creating challenges in legal enforcement and accountability that way. In voluntary schemes the strictest consequence for non-compliance is usually exclusion. It unfortunately does little to compensate affected stakeholders or hold firms accountable. (Russo, Sansone, Colamatteo, Pagnanelli, 2023). Another challenge is making sure that sustainability requirements match with what firm is able to gain. High standards may result in low adoption rates or exclusion of smaller or less efficient businesses. Compliance costs can weaken competitiveness in the market. Mandatory standards help enforce sustainability but also can be costly, sometimes forcing companies to shut down. These standards may limit the level that product differentiate and lead to competition shifting towards price, which is detrimental for producers. Voluntary standards benefit firms that already operate efficiently and can afford various certifications (Russo, Sansone, Colamatteo, Pagnanelli, 2023; Negi, Pérez-Pineda, Blankenbach, 2020). As pointed out in this paragraph, sustainability standards are important, but they must be carefully designed to be effective, fair and practical for companies.

Sustainable strategies withing the steel industry

In the developing landscape of the steel industry, companies are increasingly compelled to innovate and adopt new strategies to stay competitive in the market. Literature proves that such commitment in response to changing market conditions can positively affect in sustainable competitive advantage in the market (Teece, Pisano, Shuen, 1997). The driving forces behind these changes are multifaced including regulatory pressures, market dynamics and a growing emphasis on sustainability. A significant factor that pushes companies to such actions is the commitment to achieving the United Nations' Agenda for Sustainable Development, which outlines 17 Sustainable Development Goals (SDGs) that concentrate on supporting economic, social and environmental sustainability (Andreotti et al., 2023). Companies recognize that adhering to these goals, for example, through changes in the strategy, not only matches with global sustainability efforts but also enhances their corporate image and can result in stronger relationships with stakeholders (Sen, Bhattacharya and Korschun, 2006).

A key aspect of these sustainability efforts is decarbonization, which remains a central strategy in the steel sector. Companies are usually exploring two primary routes to achieve significant reductions in the CO_2 emissions. They either try to store or reuse carbon that they produce or cut emissions by switching to hydrogen and electricity (Andreotti et al., 2023). Technological advancements, such as those enabled by Industry 4.0, play a crucial role in these efforts. Smart manufacturing systems optimize the production processes in steel companies, enhancing energy efficiency and enabling the use of innovative energy sources like mentioned before hydrogen or wind and solar power (Tolettini, Di Maria, 2023). The Big Data and IoT can particularly enhance not only product quality but also be helpful when it comes to optimizing emissions, production, material or energy usage (Enyoghasi, Badurdeen, 2021).

Another sustainable strategy within the steel industry is the use of steel scrap. This valuable material is used in the secondary steel making route and entails large benefits but as well hurdles for the companies interested in this sustainable strategy. Such scrap can become available in three main ways and vary in terms of the time since it can be used again in mills. We can identify home, new or prompt and old scrap. Unfortunately, as literature presents, there are few main obstacles to this recyclable idea. The main one is the limited availability, as many steel products remain in use for decades before becoming available for reuse. The reuse of steel

end-of-life wastes entails quality concerns for companies because such a byproduct often requires significant preparation. Many of the processes regarding scrap also entail costs due to their complexity when it comes to the sorting process, contamination issues and collection challenges. Beyond the environmental benefits, support for the circular economy and conservation of iron ore resources, companies may also be motivated to use scrap due to its potential for energy savings, economic value and versatility in usage (Yellishetty, Mudd, Ranjih, Tharumarajah, 2011).

Beyond scrap metal, companies are implementing various sustainable strategies to tackle other environmental concerns, among which are: reuse of waste generated or waste, the heat recovery and energy reduction (Nidheesh, Kumar, 2019).For instance the article from 2010 includes the case study with one of the solutions for the water-related concerns in the steel industry being a simple optimized water network, that in this instance, resulted in an almost 95% decrease in sewage emissions per ton of steel (Gao et al., 2011). Water management's overall task in the steel industry is the reduction of freshwater intake and emission (Colla et al., 2017). In order for water to meet industrial needs in the steel sector, there are few advanced water treatment technologies such as reverse osmosis, multimedia filters, ceramic ultrafiltration membranes and hollow fibre ultrafiltration membranes. There are also alternative water sources with backwash and river water being the most useful because, after treatment, it can replace fresh water in cooling and process operations (Fernández–AMIII, 2018).

The global steel industry's sustainability strategies are visible in China, the world's largest steel producer. In 2024, 1 881 394 thousand tonnes of crude steel was produced with the major producing country being China with 1 005 090 thousand tonnes produced (World Steel Association, 2025). A major strategy that can be seen in Chinese steel industry sustainable strategies is the transition from traditional coal-based blast furnaces to electric arc ones called EAFs, which utilize scrap metal and emit less pollution. In the first half of 2024, this country approved only new EAF project, signaling with that a commitment to cleaner steel production methods (Reuters, 2024). China is rapidly expanding the capacity for this kind of furnaces aiming to increase the share of steel produced with this technology from ten percent to fifteen percent by 2050 (Hasanbeigi, Lu, Zhou, Intelligence, 2023). This strategy could reduce emissions by even 70 percent compared to traditional practices (Ashcroft, 2024). Such a promising number remains insufficient, as findings from Zhang, Jiao, Zhang and Guo indicate that CO2 emissions should be decreased by 90 percent to reach the carbon neutrality goal

established by General Secretary Xi Jinping in 2020, wanting to fully offset emissions by 2060. To make this happen, the Chinese steel companies are investing as well in hydrogen metallurgy. The example is JISCO's scientific institute, which research the benefits and innovative technologies connected to hydrogen in the steel industry (Zhang, Jiao, Zhang & Guo, 2021).

2.2. SUPPLY CHAIN

Defining supply chain

A supply chain is identified as an organized system or logistic network of actions that typically spans from early-stage suppliers to the end user. The basic structure contains three participants: suppliers, the company and customers. The supply chain literature emphasizes three essential functions of such a network: monitoring, integrating and aligning the movement of materials, information and financial resources (Jaipur National University, 2013; Hugos, 2024). Over time, supply chains have undergone substantial transformation from fragmented operations to complex ecosystems. More recently the integration of AI and real-time data analytics has further changed known before supply chain operations (Van Herzele, 2024). These continuous advancements present the changing nature of supply chains that require managers to proactively analyze emerging trends to maintain their competitiveness (Susitha, Jayarathna, Herath, 2024).

According to the ASCM association, in 2025 there are 10 main trends associated with the supply chain. The adoption of AI can be seen as the number one trend transforming supply chain operations and decision-making processes by enabling optimized supplier selection, streamlined inventory management as well as smarter logistical planning. Tools that are powered by AI, like for example robotics, computer vision or augmented reality (AR), can be used to automate repetitive jobs, enhance efficiency across warehousing or improve safety. Companies may better control their costs, lower risks or even respond more effectively to demand fluctuations by using predictive analytics and autonomous technology (Association for Supply Chain Management, 2025). The Santosh Shrivastava's research (2023) recognizes artificial intelligence as a significant contemporary trend while also pointing out the growing importance of circular and sustainable supply chains. It is of high importance for companies to recognize such emerging trends to stay crisis resistant (Shrivastava, 2023).

Supply Chain Management (SCM) Theory

Supply chain management (SCM) describes an integrated approach that aims to streamline the distribution and production processes from the raw materials to the end consumer (Mentzer et al., 2001). This involves managing the flow of goods, finances as well as information across the entire supply chain (Prasad, 2018). According to Mentzer and others (2001), SCM mixes various activities, including manufacturing, procurement, distribution and logistics, all of which are coordinated to improve efficiency and customer satisfaction. SCM seeks to enhance performance by creating seamless processes that connect suppliers, producers and customers through a network of interconnected activities (Mentzer et al., 2001).

Building on this foundation, affective supply chain management focuses on relationship management and collaboration among different stakeholders, emphasizing the importance of collaboration. This involves not only fostering strong partnerships with suppliers and distributors to create value and achieve a competitive advantage but as well optimizing internal operations. Integrating such activities presents businesses with various advantages, such as the possibility to reduce costs, increase responsiveness to the market changes or improve the overall quality of their products/services (Wisner, Tan, Leong, 2021). To achieve desired supply chain capabilities, literature suggests prioritizing deliberate decisions across five performance driving areas: inventory, production, location, transportation and information (Hugos, 2024). Incorporating these efforts can help companies build strong supply chains that support their long-term success.

Different types of supply chains

There are three types of supply chains that are discussed in literature, to those we include: linear, closed loop and circular supply chain. The literature depicts the linear supply chain as the kind that often results in financial losses for firms, especially as they struggle with unstable raw material costs (Rasi, Ismail, Shahbaz & Kaliani Sundram, 2023). This type follows the simple sequence of actions: take, make and dispose (Weetman, 2016), where raw materials are extracted, processed and after use discarded as waste. It was established during the early stages of industrialization and leads to significant resource losses, environmental harm as well as inefficiencies (Ellen MacArthur Foundation, 2013).

Another type is called Closed Loop Supply Chain. Guide and Van Wassenhove (2009, p.10) provided an explanation of how those chains are managed, capturing this term as: ”the design, control, and operation of a system to maximize value creation over the entire life cycle of a product

with dynamic recovery of value from different types and volumes of returns over time". This SC involves environmental and economic dimensions of sustainability but omits the social part (Farooque, Zhang, Thürer & Huisingh, 2019). Additionally, CLSC is a step forward from the traditional supply chain design, but it requires extensive planning to execute such transformation, which is usually linked to high initial financial commitments (MahmoumGonbadi, Genovese & Sgalambro, 2021). Although these supply chains can help companies minimize waste, it is important to notice that their effectiveness is limited, as it is often impractical or not possible to recycle each unneeded element through the same chain (Weetman, 2016).

A different approach can be seen in the third type called circular supply chain (CSC) which emphasizes reuse at the product, component and material levels, which results in reduction of harmful materials and resource consumption and fosters restorative and regenerative practices. It addresses the challenges of finite resources and growing consumer demands by aligning with the TBL approach, which integrates into supply chain activities: environmental stewardship, economic sustainability and social responsibility to ensure sustainable development (Rasi, Ismail, Shahbaz & Kaliani Sundram, 2023). Implementing CSC entails several challenges across various domains. Those include primary financial barriers such as high investments and product costs that discourage businesses from adopting circular supply chain practices. Governmental hurdles despite initiatives like the EU's Circular Economy Action Plan and Circular Economy Executive Order in the United States include insufficient laws, conflicting visions between central and local authorities and lack of overall support for sustainable operations (European Parliament, 2020; Rasi, Ismail, Shahbaz, Kaliani Sundram, 2023). Limited knowledge sharing and inadequate awareness along with insufficient training about smart waste management pose as technological obstacles. Additionally, leadership commitment to such a new supply chain idea is frequently lacking and ineffective frameworks make the challenge worse (Rasi, Ismail, Shahbaz & Kaliani Sundram, 2023).

The concept of a circular supply chain is connected to circular economy (De Angelis, Howard & Miemczyk, 2018). In the handbook from 2016, the author (Weetman, 2016) explains that there are few principles of this approach. The main ones describe this approach as aiming to prolong the lifespan of materials whenever possible through practices such as a product redesign, reuse and disassembly. Companies should than try to copy natural way of being where waste becomes input for other processes. That way they can reduce resource dependency and their environmental impact. Embracing circular thinking also enhances operational resilience, supports the use of renewable energy and encourages collaboration across system. Additionally,

this framework aligns economic and environmental activities, enabling companies to thrive, while contributing to long-term environmental well-being (Weetman, 2016).

Triple-A Supply Chain

Within the evolution of the supply chains emerged the Hau L. Lee's work with a recipe for 'right' approach to the supply chain in the companies. In his study, Lee highlighted that having the most efficient supply chain is not a good strategy because those supply chains that overly focused on cost savings and speed tend to decline in the performance over time. Research on over 60 companies, reveals that the ones that prioritize rapid delivery and minimal expenses often experience inefficiencies and lower customer satisfaction. Despite significant investments in advanced technologies, collaborative initiatives to streamline processes and top-tier talent these supply chains failed to achieve lasting competitive advantages. Instead, they were unable to adapt to market changes leading to excess inventory and price cuts. Such situations resulted in reduced profits, disappointed customers and weakened brand value. In response to these challenges. This work stresses the importance of the triple-a supply chain concept as implementing one enables companies to outperform their competition in the long run (Lee, 2004). Additionally, utilizing this kind of logistic network boosts supply chain performance for companies, which led to enhanced overall organizational performance (Whitten, Green, Zelbst, 2012). To do so, firms aiming to be as successful, as those presented in the study, such as Seven-Eleven Japan or Zara, need to focus on agility, adaptability and alignment. The most crucial of these is cultivating agility, which is the capability to efficiently and correctly manage external disruptions by rapidly and cost-effectively adapting to shifts in supply or demand (Lee, 2004).

Recent research from 2021 (Erhun, Kraft, Wijnsma) supports and extends Lee's framework by integrating sustainability especially the environmental and social elements of it into the triple-a supply chain framework. It does so by giving new definitions to the agility, adaptability and alignment in ways that can be more useful for firms navigating modern supply chains complexities. This redesign incorporates meeting broader stakeholder needs by innovating supply chain control, influencing trends and aligning across all tiers with a customer focus, so actions that firms should take to overcome today's sustainability challenges. Another article that analyses the triple-a SC practices also shows that this framework is connected to sustainability-related performance outcomes for companies. It exhibits the important role of

enablers that have ability to enhance this relationship: top manager commitment, technology adoption and market competition (Jia, Li, Zhang, Chen, 2024). Thus, firms with sustainability goal that are reforming or creating their supply chains should take into consideration the triple-a supply chain or its management.

Dynamic Supply Chain Capabilities

The true transformation of supply chain is possible with the use of high-level dynamic capabilities (Teece, 2023). The capabilities represent the competence to effectively employ companies' resources to provide intended outcomes (Desfray, Raymond, 2014). Literature acknowledges the connection between dynamic capabilities and supply chain. Kareem and Kummitha (2020) presented that in order for companies to survive in the dynamic environment that is difficult to assess and predict they need to possess supply chain dynamic capabilities, that were presented with the use of four dimensions: collaboration capability, agility capability, integration capability, responsiveness capability. They highlighted that raising uncertainty is one of the factors in nowadays environment which requires adoption of such supply chains.

For companies to be ready for any disturbances in their environment such as shifts in demand and supply, preferences of targeted groups, market structure, they need to work on their supply chain capabilities that can be built by enhancing practices connected to resources, information and competences (Kareem and Kummitha 2020; Ju, Park, Kim, 2016). Other areas to consider for improvement connected to the presented above dimensions are relationship with partners, level of agility of supply chain, level of responsiveness as them not only can better prepare firm for possible changes but also have proven positive impact on operational performance (Kareem and Kummitha, 2020). Such actions are needed not only to sense threats and act accordingly but also possessing adequate dynamic capabilities gives companies extra opportunity to capitalize on the changes and gain that way superior advantage on market (Teece et al., 1997). Studies about dynamic supply chain capabilities (DSCCs) also present the power of constant learning and that it is associated with positive impact on such capabilities which can be useful for managers of industries characterized as dynamic as for example automotive one (Aslam, Haris; Azhar, Tashfeen, 2018; Siems, Land, Seuring, 2021).

2.3. SUSTAINABLE SUPPLY CHAINS

Sustainable supply chain

Nowadays supply chains are a key focus and major driver of sustainability with a growing number of companies are making effort to set sustainability goals (Barbosa-Póvoa, da Silva, Carvalho, 2018; Alves, Steinberg, 2022). However, many still struggles to take effective actions due to unclear understanding and the the complexity of sustainable supply chains. The SSC integrates economic, environmental and social principles into the management of linked processes across value chain. (Barbosa-Póvoa et al., 2018). This term is associated with increased transparency, collaboration and can be used by big firms, especially those at upstream end of the chain, to influence sustainability practices through the entire network (Forest Stewardship Council, 2024). A clear and properly applied understanding of the SSC is thus important for companies aiming to drive sustainability in today's increasingly uncertain and complex environments (Barbosa-Póvoa et al., 2018).

Sustainable supply chain management

Industrial revolution brought a rapid economic development but also led to excessive resource consumption and environmental degradation due to the negative effects caused by production processes. (Shen, Li, Wang, Liao, 2020). Over the last few decades, environmental pollution resulted in worldwide concerns from customers and governments (Li et al., 2021). Such a growing awareness of the situation made companies and individuals willing to pursue practices that contribute to environmental sustainability (Reche, Junior, Estorilio, Rudek, 2020). Business sector in response to this is undergoing constant changes. Such dynamic changes are influenced by ecology, technology, politics, culture and other factors that are also shifting more and more (de Oliveira, Lemos, Canedo, de Abreu, 2022). Within this context, the concept of sustainable supply chain management (SSCM) has emerged that integrates economic, social and environmental elements into the traditional supply chain management practices (Seuring, Sarkis, Müller, Rao, 2008).

The steel industry exemplifies the application of SSCM principles due to its resource-intensive nature as well as high levels of produced emissions (de Oliveira et al., 2022). The SSCM is a type of management that is supported by four key factors described in the literature as strategic alignment, ethical organizational culture, supply chain transparency and strategic alignment (Carter, Rogers, 2008; Carter, Liane Easton, 2011). One prominent SSCM strategy in the steel industry is the adoption of circular economy and industrial symbiosis (IS) principles. It is done by maximizing the circulation of materials and by-products among various actors in the value chain (Branca et al., 2020) and it is connected to the idea of exchange of other resources such as energy waste, between different sectors that can mutually benefit from this

operation (Fichera, Arfò, Huang, Matarazzo, Bertino, 2020). Here companies can also use the digital technologies boost supply collaboration, promoting at the same time resource reuse and waste reduction. These technologies help firms develop closed-loop systems for Circular Economy (CE) practices including the reuse or mentioned before industrial symbiosis, by facilitating information sharing and tracking. (Schroeder, Anggraeni, Weber, 2019; Tolettini, Di Maria, 2023).

Building on the shift toward going green, the green supply chain management (GSCM) has become a vital mechanism for connecting environmental activities with supply chain operations (de Oliveira et al., 2022). The GSCM involves a range of activities including green purchasing, reverse logistic and product's lifecycle management (Ribeiro, De Oliveira, da Silva César, Aprigliano Fernandes, 2021). By following this new concept, companies can experience higher costs related to green products or development of new technologies and equipment (Li, Rao, Goh, Yang, 2021). Despite that, the GSCM is proven to help improve customer services (Guide, 2003). However, researchers point out that this new kind of management differs significantly from the ordinary SCM (de Oliveira et al., 2022), as it is not as broad and does not incorporate social focus, omitting that way one significant dimension of sustainability (Ahi, Searcy, 2013).

2.4. SUMMARY AND RESEARCH GAP

The issue of sustainability has received growing interest from both the academic and corporate worlds (Seuring, 2008). This increasing trend, which was emphasized even by governments or the European Union, has led many organizations to adopt green practices across their production stages. The pressure for change has been and continues to be, driven by stakeholders and public opinion increasingly prioritizing environmental sustainability (de Oliveira et al., 2022). However, the articles indicate that there is still a need for case studies of companies and other supply chain participants' initiatives that focus on integrating sustainability aspects into the supply chain (Seuring, 2008).

SSCM is a type of management that emerged from the changes in the supply chain that caught the focus of managers and researchers. They noticed a shift in focus areas in this field of studies that started to move to topics such as the selection of the material, disposal of the end product and how employees, customers and other actors are treated in supply chain (Prasad, 2018). That is when the concept of SSCM developed, integrating traditional practices with the new ones incorporating three dimensions of sustainability (TBL) (Prasad, 2018; Seuring et al.,

2008). This study intends to fill gaps within the literature about SSCM by conducting multiple case study with in-depth interviews involving representatives from four big steel companies in various European countries. The collected information is explored to provide answers and examples of the possible research that can be found in few articles. The article from 2023 (Xu, Yu, Hou) addresses the demand for qualitative research using in-depth interviews for the better understanding of the impacts of the steel industry's sustainable development. In the same work we can find that, in the literature there is a lack of information about the uncertainties faced by the steel industry's sustainable development that I also wish to analyze in my study (Xu, Yu, Hou, 2023). Another article recommended to examine the green management of other supply chains in steel industry and the functioning of their sustainable management (de Oliveira et al., 2022).

A common theme in the literature on sustainable strategies is the decarbonization of the steel industry, which is being driven by the implementation of Industry 4.0 technologies. These technologies help lower emissions and support energy efficiency by making use of special smart manufacturing systems (Tolettini and Di Maria, 2023; Enyoghasi and Badurdeen, 2021). Despite these breakthroughs that help to make a positive change, companies encounter significant costs of developing new technologies. Nevertheless, implementation SSCM can lead to considerable benefits such as cost reduction or better corporate image and relationships with stakeholders (Carter and Easton, 2011; Sen, Bhattacharya and Korschun, 2006). Understanding how companies in the increasingly regulated yet still insufficient decarbonization landscape (Climate Action Tracker, n.d.) weight the benefits and challenges is important for encouraging more sustainable practices in the steel industry and with this research I would like to address this issue.

3. Methodology

Introduction

This research has a few objectives set within the context of steel industry in Europe:

1. Identify the sustainable development strategies adopted by European companies in the steel industry.
2. Explore those four European companies' views related to the impact of chosen sustainable development strategies on their supply chain management practices.
3. Investigate the challenges and barriers these companies encountered in implementing sustainable development strategies.

To address these objectives the research employs a qualitative multiple case study design, which allows for in-depth examination of sustainability approaches in different contexts. The chapter is than structured as follow. First the research questions guiding this study are presented. Next the research strategy is discussed including the rationale for selecting a case study design and the selection criteria for case companies. The following part shows the date collection methods and how they were chosen. It will provide more insights for the choice of semi-structured interviews as primary data and company's publicly available information along with documents as secondary data. Then the case study itself will be presented to inform about not only historical background but also current trends, key players, regulations and economic impact of steel industry in Europe. Following this, the framework for data analysis is explained, displaying the combination of deductive and inductive approaches. The chapter is finished by addressing the limitations and potential challenges of the study with all the measures taken to ensure the reliability of the findings.

3.1. Research questions

Base on presented above research gap and literature review I pose two research questions:

1. What are the sustainable development strategies adopted by European Union companies in the steel industry, and how do these strategies influence their supply chain management practices?

2. What are the main challenges of sustainable development in the European Union steel companies?

3.2. Research Strategy

The qualitative research serves as the foundation of this thesis. That type of research can be understood as "a synonym for any data collection method (such as an interview) or data analysis procedure (such as categorizing data) that generates or uses non-numerical data" (Saunders et al., 2003, p.151). It was based on the research strategy of multiple case study, utilizing primary data sources. As this study tried to unravel phenomenon of sustainable development strategies having impact on supply chain management practices in the European context with the base of various companies, it than meets the criteria presented in the Yin (2017), to utilize multiple case study. Additionally, to give multiple sources of evidence and deeper findings the triangulation took place (Stavros, Westberg, 2009).

The research is focused on brining in-depth and qualitative insights into sustainable development strategies issues. The existing literature presents gap in understanding the challenges the steel industry faces in implementing such strategies and calls for additional in-depth analyses. The evidence of this can be seen in the studies from 2023 (Xu, Yu, Hou) as well as 2022 (de Oliviera et al.). Therefore, this study wants to address these gaps and show usable recommendations to improve the effective implementation of sustainable development strategies in the European steel industry. Such research strategy aims to contribute valuate insights to both academia and industry stakeholders.

Participants in this study were sampled in two ways. The main goal was to get access to knowledgeable individuals from presented companies and gain new scientific data through comparison and contrast of emerging patterns visible through the online interviews. To do so, purposeful sampling with the snowball strategy was implied. It took a form of leveraging the referrals from the initial contacts made with specialized in the topic of this thesis departments to gain the designated number of interviews (4 to 5) with each of the preselected companies in the steel industry (Palinkas et al., 2015).

Convenience type of sampling was also used due to easy access to research subjects, in this case, European steel companies. The description of this non-random form of sampling is consistent with this study. It is convenient as the researcher is associated with a big company in this industry. While this approach allowed for efficient data collection, it as well restricted the potential generalization of the outcomes, as the sample might not accurately portray the

broader population of European steel firms. To properly select the companies from a large pool of potential candidates to whom the researcher has access, three criteria were formed, which are presented below (Biggam, 2008).

The companies' criteria for selection of this study will be as follows:

- Sustainability actions – each company has demonstrated significant efforts/actions connected to the implementation of sustainable development strategies that are evident in their company reports.
- Companies size – selected firms need to be defined as big companies, which, according to the European Commission (2003), means that their number of employees needs to be greater than 250. Such size makes their practices influential for instance on government (Macher, Mayo, Schiffer, 2011).
- Geographical Diversity- all companies need to be operating in different European countries to enable this study to capture the big picture of practices and difficulties that can occur.

The research object encompasses a group of big steel companies in Europe that are meeting presented above criteria. To the selected companies I am hoping to include TATA Steel Netherlands, Marcegaglia (Italy), Salzgitter (Germany) and SSAB (Sweden) that are presented below.

Tata Steel Nederland is a big company (92 000 employees in Tata Steel Ijmuiden) dedicated to becoming the leading sustainable steel business in Europe (Tata Steel Nederland, n.d. -b). This ambition shapes their vision for the steel industry and is reflecting in their multiple actions regarding sustainability (Tata Steel Europe, n.d.-a). For instance, this company has special Packaging Recycling team who collaborated with organizations to promote recycling and reduce landfill waste (Tata Steel Europe, n.d. -d). In the Netherlands, the company is committed to reduce CO2 emissions by 40% by 2030 and become carbon neutral by 2045. Currently, Tata Steel Nederland ranks high across the most technologically progressive companies in the country. Several projects support this transition toward the carbon-neutral steel production, including the energy shift to hydrogen, usage of Direct Reduced Iron DRI technology, focusing on new solutions like Zeremis® either Recycled, Carbon Lite or Delivered, Electric arc furnace (EAF) steelmaking technology out of scrap used in their circular economy (Tata Steel Nederland, 2023 -c, Tata Steel Nederland, n.d.-j).

Marcegaglia is an Italian steel manufacturer actively involved in sustainability initiatives. The company is organized into several specialized entities, such as Marcegaglia Buildtech or Marcegaglia Stainless Sheffield and many more. Each of them targets different type of product or market. This structure gives this company possibility to control every stage of production chain up until finished product and gives Marcegaglia a chance to implement various sustainability practices across its operations, as detailed in their sustainability report from 2023 (Marcegalia, 2024 - a). As a member of the First Movers Coalition an initiative aimed at decarbonizing industrial sector, Marcegaglia is committed to pioneering sustainable practices, starting from the supply chain (Marcegaglia, 2023- a). Based on the information on their website this worldwide leading industrial group employs 7,000 people and has a turnover of 9 billion euros, which makes it a big enterprise (Marcegaglia Poland, n.d.). This company has been recognized among Italy's sustainability leaders for three consecutive years by II Sole 24 Ore and Statista, pointing out its proactive approach to the climate change management and integration of sustainable practices into its supply chain (Marcegalia, 2024 - b). Moreover, they have been a member of first global multi-shareholder initiative called ResponsibleSteel™ since 2022, which focuses on addressing the growing need for sustainable production of steel (Marcegalia, 2023- b).

The Salzgitter AG is a globally positioned, German steel manufacturer with approximately twenty-five thousand employees (Salzgitter, n.d.-e). This company is working hard to meet their Salzgitter AG 2030 strategy that main aim is "Industry Rethought" as well as to become leaders of circular economy and technological solutions on the market through partnership with other sectors (Salzgitter AG, 2025- a). The company in 2015, created special program called SALCOS consistent of 3 projects, which objective is to produce steel virtually that will enable them to lower emissions almost entirely. Within this idea, Salzgitter is determined to already reduce their carbon footprint by 30 % by next year (Salzgitter AG, n.d.-d). This company is so committed to climate protection that was awarded the highest score by CDP, placing it among the top 2% of over 22 000 assessed companies worldwide (Salzgitter, 2025- c). This company has diversified portfolio including even engineering services and has processing plants across Europe (Salzgitter, n.d.- e). Salzgitter's 2030 strategy has a goal to cut scope 1 and 2 CO2 emissions by over half and increase annual scrap recycling to more than 3 milion tons. Additionally, beginning in 2026 company plans to supply low-carbon steel to major clients for example BMW's manufacturing facilities (Association for Iron & Steel Technology, 2022).

SSAB is a global steel company from Sweden that has 14 500 employees (SSAB, n.d.-b). Their published documents (SSAB, 2020) and testimonies from clients (SSAB, n.d. -c) the company is dedicated to sustainability. This company's vision is to create a more sustainable world and is recognized as a leader in high-strength steels and decarbonized steel solutions. SSAB has commitment to eliminating carbon dioxide emissions from its operations, aiming to be the first fossil free steel on the market with the fastest transition to carbon/free production (SSAB, 2024). This transformation is supported by significant investments including almost 5 billion euro in new steel mill and installation of EAFs, which will let company use the fossil/free sponge iron and recycled scrap (SSAB, 2025- a). Their sustainability strategy focuses also on helping customers achieve up to ten million tonnes of annual CO2 savings with their lighter and more efficient products (SSAB, 2017).

3.3. Data collection methods

Primary sources include in-depth semi-structured interviews with representatives from approximately 4 steel companies operating in different countries across Europe giving in total 4 interviews each with different company. As states Bryman (2016) the semi-structured interview is the one that helps researcher gather greater amount of rich data on specific topic. It is a combination of structured and unstructured way of interviewing that results in pre-planned questions but gives the respondent and interviewer flexibility to elaborate more on specific open-ended questions (Bryman, 2016; Alsaawi, 2014). This method was chosen due to the potential of this method to give the interviewees more space and increase the likelihood of developing the best possible recommendations in this study. Such approach enabled this thesis to illustrate the impact of strategies the companies are using to solve the complex problem that is the sustainability of steel industry. Sources were used to identify their actions, challenges and plans related to posed research questions. This comprehensive data collection method provided a foundation for analyzing the sustainable development strategies and their implications on supply chain management within the European steel industry.

The questions asked by the researcher included the ones that inquiry about the sustainable supply chain management in the specific company with the interest in adaptation, challenges/risks, causes of implementation. Those topics were discussed during the online interview. With the participants' permission, the study was audio-recorded their interviews and transcribed them word-for-word so that the data can be analyzed more precisely with more accurate conclusions. Although this might introduce some bias/influence by the researcher, it

allowed them to become more familiarized with the data and thus help them gain a richer and contextualized understanding (Gibbs, 2007). Moreover, this seems sensible given the number of interviews and scope of the study.

This study entailed triangulation of data collection methods, as the publicly available documents and information about firms were used as well. The reasoning behind this choice is that it can reveal in-depth motivational aspects that might otherwise be omitted and show greater context for choices made by organizations in question. Similar reasoning was presented in an article on the use of triangulation and multiple case studies, where author showcased that these techniques, when used correctly, may make research stronger and more reliable. This can add more variance and overall strengthen the research (Stavros, Westberg, 2009).

3.4. Data Analysis

A flexible research approach grounded in the literature was adopted to guide data analysis, supporting both deductive and inductive analytical strategies. This approach facilitated not only the assessment of data against established themes and theories but also the discovery of new themes as they emerged. The deductive approach involved examining how closely the collected data matched concepts identified in prior research, while the inductive one focused on extracting new insights directly from data itself (Saunders et al., 2019). Grounded theory was also applied, giving the researched the ability to adapt the research process as patterns and themes developed, thereby ensuring a responsible and through investigation (Glaser and Strauss, 1967).

The primary data from the interviews will be analyzed with the use of Matrix Analysis. Such kind of collected information examination was chosen as it is recommended to be used in multiple case studies with for instance several organizations as it is in this research. This will allow the reader to acknowledge differences between the firms as well as researcher to contrast them to prepare adequate conclusions and recommendations. Additionally, presenting gathered data as a summary all in one table can be seen as organized and easier to comprehend (King & Brooks, 2018). Overall, data from interviews was analyzed via themes as explained in the book of Biggam (2008), as the themes present objectives and aim of this research. Such themes are interrelated and serve as a help during the interview process as well as during the transcripts analysis.

The qualitative data coding was done manually, following a hybrid approach that includes both deductive and inductive coding, as recommended by Fereday and Muir-Cochrane (2006).

First, a set of codes was developed based on literature review and objectives of the research, which provided a structured starting point for examining four interview transcripts. As the analysis progressed, new codes were allowed to emerge directly from the data, ensuring that the unexpected insights could be captured. Stage four of the recommended analysis was adapted to manual coding without the use of any qualitative data software. Manual coding has been recognized for its ability to foster in-depth understanding of the data (Linkedin, n.d.). The primary data were than synthesized and sorted through Matrix Analysis, enabling clear presentation (King & Brooks, 2018) and second verification of text to identify inductive codes. At this stage, to ensure validity and contextual understanding, secondary data were subsequently analyzed using these predefined codes while also searching for new ones. (Bowen, 2009; Fereday, Muir-Cochrane, 2006). Then the analysis was concluded by connecting codes to discover patterns/themes which are presented in the finding and discussion section. Finally, themes were refined to assure they are coherent with secondary and primary data and distinctive following the procedure described in article from 2006 (Fereday, Muir-Cochrane).

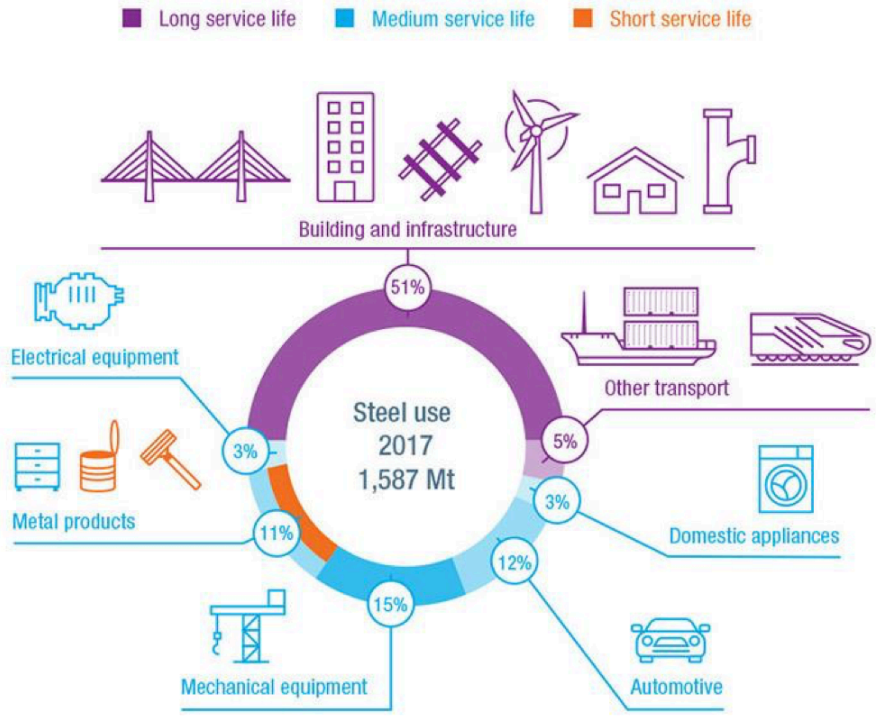
3.5. Case Study: Steel industry in Europe

Historical Background

Steel is one of the most essential materials worldwide for hundreds of years already. The presence of this alloy of iron is noticeable in almost every field of life from everyday items like cans of food to specialized mechanical or military equipment and many others (Pinto, 2019) that are presented on the Figure 1. Furthermore, steel is linked with economic growth and is special because it is a permanent material on our planet (Gajdzik, Wolniak, Grebski, 2023; World Steel Association, n.d. - a). This resource is wholly recyclable without the impact on its quality as well as is very durable what enabled it to be a part of human's life since even twelfth century BC (World Steel Association, n.d. - b). Before that, it was the Iron Age, the time when thanks to the tribes that spread the knowledge of smelting iron across Asia and Europe it was then when early smith must have come across steel for the first time by accident and noticed its superpowers. Back in 3th century the quality and result were in the individual steel worker hands as the ingredients and chemistry connected to the steel making process were unknown to people. The unordinary skills of people from India and China contributed to the beginning of global steel industry as we know it today. One of the legendary breakthroughs for the steel industry in Europe that allowed departure from the long/used steel producing method using the cementation process, was the invention of crucible technique in England by Benjamin

Huntsman during Industrial Revolution in 1740. It took a lot of inventions during that time to make steel as mainstream used on a global scale as it is nowadays. As the 20-century approached steel finally began to be treated as dominant metal meeting the military demand as well as customer demand for everyday appliances (World Steel Association, n.d.-b).

Figure 1: ”Steel in society”

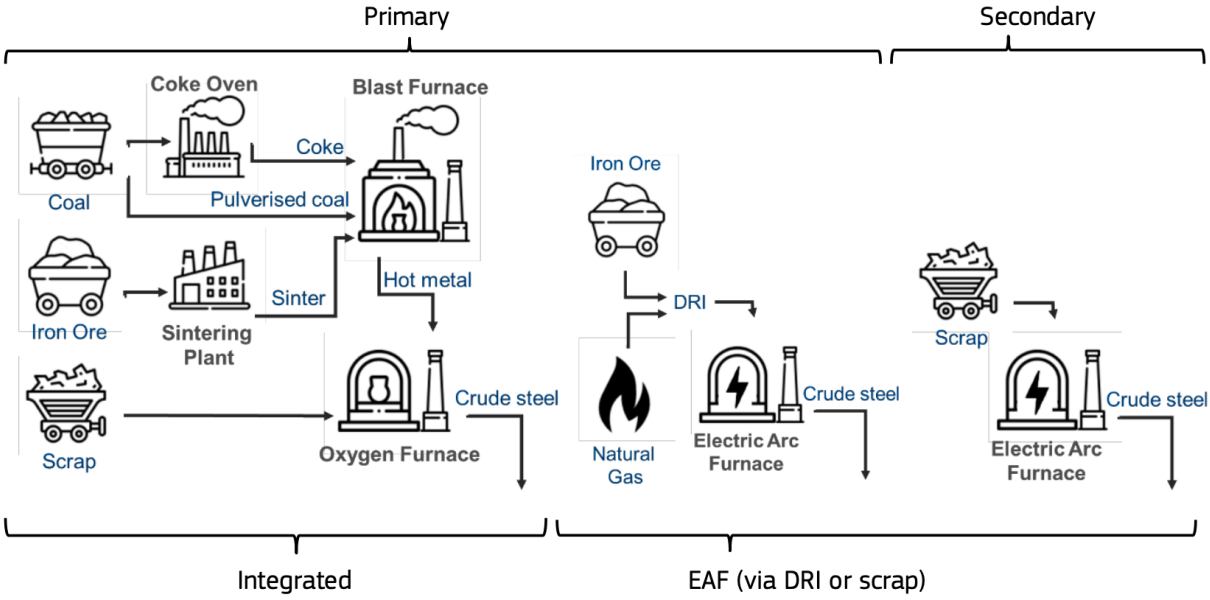


Note. These diagrams were produced by World Steel in 2017 accessed from publication of Pinto, J. (2019). *Sustainable resource management in european steel supply chains* (Doctoral dissertation, Université Clermont Auvergne [2017-2020]; Háskóli Islands).

Steel that is mainly produced now is classified into four categories according to AISI/SAE system. Such differences in the grades of steel are the result of small changes in the ingredients. We can identify with this system carbon steel, alloy steels or tool steels (Pinto, 2019). The main kind of steel produced in Europe is carbon steel non alloy. Europe is the second major crude steel producing region in the world. Steel production today remains as a major factor of global industry but faces growing pressure to decarbonize and modernize. Therefore, it is so important to understand how the steel is produced to full judge the sustainable actions of companies in this industry. Nowadays majority of the steel is produced using BF/BOF route, which is explain on the Figure 2 and means blast furnace that uses coal, scrap or iron ore and generates

significant CO2 emissions. In Europe over two-thirds of primary steel is made using this traditional method, with only a small share coming from Electric Arc Furnaces EAF that are feeded iron ore or scrap (EUROFEAR, 2024- a; World Steel Association, n.d.-c). Furthermore, steel can be produced either primary or secondary route as depicted on Figure 2. The primary steelmaking route uses virgin raw materials processes in the BF-BOF system where oxygen is incorporated through molten iron to create steel. In contrast, the secondary route focuses on recycled scrap steel that is melted down in EAF (World Steel Association, n.d.-c). Many steel producers are transitioning and using this new electric method due to because it enables resource efficiency and lower carbon footprint. The cost of secondary steelmaking is generally lower than primary because it uses recycled materials and consumer less energy. As the steel industry continues to transform it now enters new era with the emerge of green steel, which is produced using innovative, low carbon techniques such as renewable energy, aiming to drastically reduce the sector's impact on environment while maintaining the important role of steel in society (Fortune Business Insights, 2025).

Figure 2: "Steelmaking production routes"



Note. These models were produced by JRC. From *Greenhouse gas intensities of the EU steel industry and its trading partners* (p. X), by D. Koolen & D. Vidovic, 2022, Publications Office of the European Union. Copyright 2022 by Publications Office of the European Union.

Current Trends

With the evolution of steelmaking techniques, so too have the ideas around the resource prevention and planetary health advanced within the European steel industry. It does not come as a surprise that this biggest energy user sector among the industrial ones, that demands high energy consumption, has a considerable effect on the environment. The main areas where the key sustainability trends emerged related to this material are carbon footprint and green steel (Conejo, Birat & Dutta, 2020). Due to its large scale of production, this industry accounts for around 7 % of global and 5% of the European Union (EU) carbon dioxide emissions (Rodríguez Diez et al., 2023). Experts indicate that changes in this relatively old industry to make it more carbon neutral will require a huge investment. Achieving the goals of Net Zero Emissions by 2050 for steel and iron industry will involve even $1.4T as the Wood Mckenzie analysts estimated for Financial Times. Carbon footprint cut, that is desired by the industry nowadays to obey the European law or companies' own sustainability standards, can be achieved by combination of electric arc furnaces and hydrogen to eliminate the emissions of carbon dioxide (Financial Times, 2023). Examples of that practice can be found in the two case studies examined in the article titled: "Decarbonization Pathways, Strategies, and Use Cases to Achieve Net-Zero CO2 Emissions in the Steelmaking Industry" (Rodríguez Diez et al., 2023). This study presents new low energy technology pathways that fit decarbonization goal such as iron electrolysis, Direct Reduced Iron (DRI) with green or blue hydrogen or Carbon capture storage and storage (CCS/U), utilizing smart carbon as well as incorporating CCS into BF (Rodríguez Diez et al., 2023).

There are also intermediate solutions that companies introduce nowadays more often to fight this problem. One of them is use of the recycled steel in the blast furnace (Financial Times, 2023). Usage of these steel scrap possess challenges such as limited availability to meet market demand and restrictions on using more that 30 percent in blast furnace process (BOF) route (EUROMETAL, 2023). To other trending developments used by steel companies' literature includes the focus on energy efficiency. Manufacturers, by investing in modern equipment that needs little energy input and optimizing production processes, hope to cut their energy usage. They do that by capturing and reusing heat produced during the steelmaking process (Jacobsen and Jones, 2024).

All presented trends associated with sustainability are challenging to implement due to the high cost and long time, new clean energy infrastructure and huge investments they require to make it a reality for the steel industry to adopt this energy sources (Rodríguez Diez et al., 2023; ArcelorMittal, 2019). Additionally, there are other challenges such as technology maturity and skills, end-customer market with low motivation to pay higher price for green steel, lack of green hydrogen needed for such changes and many more limiting the transition of steel industry (Deloitte, 2023- a).

Key Players and Their Roles

To the major European players mentioned on sustainable transformation tracking website include ArcelorMittal, Thyssenkrupp, Voestalpine, Erdemir Group, Salzgitter, SSAB, Erdemir Group, Severstal, NLMK, Metinvest Holding LLC, MMK and Evraz. Within them SSAB and Salzgitter stand out as this both companies are planning to become carbon neutral even before 2050 (LeadIT, 2024), with Salzgitter aiming for net zero by 2050 at the latest and SSAB targeting net zero by 2045. Both align their strategies with the Science Based Targets initiative (SSAB, 2020-b; Salzgitter AG, 2024). The main focus of today's European steel industry is on designing the best green steel, which involves replacing traditional carbon-intensive processes with cleanser alternatives (Ahmed, 2024). By 2030, many of these companies aim to commercialize green steel, making it viable option for industries like automotive and construction (Choo, 2021). Interestingly, in 2024, Voestalpine company was the first steel one to issue the green bond in Europe which is a pioneering move in this industry, signaling a commitment to innovative financing for sustainable transformation (Voestalpine, 2024).

These leading firms not only set ambitious internal targets but also with them shape the broader industry's sustainable patch. They create benchmarks in their climate strategies for others to follow and foster a culture of transparency mixed with accountability (Torres-Morales, 2024). Some of this big companies encourage also collaboration across their supply chain and provide practical solutions for other steelmakers but also suppliers or firms from different segments (Deloitte, 2023- b). To make the transition possible these companies are investing also billions of euros in innovative technologies such as EAFs, with ArcelorMittal alone committing almost two billion euros to decarbonization project in France (Kolisnichenko, 2025). Such impactful actions of major players are essential to push industry wide progress by leading through example.

Regulatory Environment

The regulatory environment within which the European steel industry operates is shaped by growing and dynamic set of laws and policies that aim for climate neutrality in the future, strategic autonomy and protection of industrial competitiveness (European Commission, 2025-a). According to the data, European steel industry is one of the global leaders in sustainability. Given an impressive fifty percent decrease in energy usage and carbon dioxide emissions per tonne of steel since the 1960s (EUROFEAR, 2016). This industry's commitment to minimising its negative ecological influence is also demonstrated today by its objectives specified under the European Climate Law the European Green Deal. These frameworks together require that the EU achieve so called climate neutrality in next twenty-five years (European Commission, n.d.- a). To reach this target, literature shows that it requires a combination of coordinated investments, cross-sector collaborations and a stable energy policy that could ensure access to renewable and affordable energy (Hudson, 2022). The European Union has an important role in this transformation, implementing and working on a new set of regulatory frameworks that support the steel industry´s journey toward a low-carbon future, while reinforcing Europe's position as well as a pioneer in sustainable steel production (EUROFER, 2013). This presents the European Union's strategic intension to make the decarbonization of steel a priority in its green transition.

Currently the foundation of European Union regulatory landscape for the steel sector is the Steel and Metals Plan. It lays out priority actions for decarbonization, investment and trade protection and calls for introduction of a voluntary carbon intensity label for steel products (EUROFEAR, 2024- b). Another important aspect of today EU´s regulatory approach is also the Emissions Targeting System (EU ETS), a so-called cap and trade mechanism operating since 2005. Its purpose is to limit greenhouse gas emissions by capping CO2 allowances and promoting necessary investments in low-emissions technologies (European Commission, n.d.-b). Recent reforms under the "Fit for 55" package are slowly removing free allowances and by 2034 the steel industry will have to buy all its permits through auctions (Strege, 2024). At the same time, the Carbon Boarder Adjustment Mechanism (CBAM) is entering new phase and will begin applying carbon costs to imports of steel from 2026 (Naidoo, Ellis, 2024). The CBAM regulation protects European industries from competition with countries that have much less rigorous environmental policies and aims to stop carbon leakage outside the EU (Deloitte, 2024; European Commission, 2025-b). Additionally, the updated Industrial Emissions

Directive enforces stricter emissions limits, circular practices and best available technologies (BATs). These instruments are legally binding and require steel producers as well as importers to submit emissions data and eventually pay for carbon intensity (European Commission, n.d.-c).

Beyond enforced pollution control, the steel sector in Europe is increasingly focused on the social aspects of the Sustainable Development Goals, by strongly emphasizing the value of social responsibility and improved workplace conditions (NTF, 2024). Literature shows that large companies are today more willing to disclose their ESG performance, which is important factor in determining their standing among investors (Segal, 2024). The steel sector's key social priorities include enhanced safety, contribution to the local communities and responsible supply chain management. Many companies from this sector acknowledge the importance of transparency for stakeholders and therefore comply with these global recognized standards and publish comprehensive ESG reports. Such dedication not only enhances accountability but also allows for performance evaluations across industry (Banerjee, Gada, 2023). This aligns with EU's strategy called Action Plan for a sustainable but also competitive industry in the future as the President of the European Commission stated:

> The steel industry has always been a core engine for European prosperity. Next-generation, clean steel should therefore continue to be manufactured in Europe. (…) To make sure they remain competitive, we must reduce energy costs and help them introduce innovative, low-carbon technologies to the market. (European Commission, 2025- c, para.3).

Economic Impact

The steel industry plays a vital role in creating value and boosting economic output around the world. Such statement can be proven by the founding's of World Steel Association report made by Oxford Economics. Based on the global data this industry accounted to 3,8 percent of global GDP few years ago, equal to nearly US$2,9 trillion. Industry impact goes far beyond the steel production as they support various sectors like in the case of for example Salzgitter is energy and automative one (World Steel Association, 2019; Salzgitter AG, n.d.-c). Furthermore, the employment statistics shows that it not only supported 259 million jobs worldwide considering the important role of steel in seven major segments but also the productivity per worker in steel industry is three times higher than the average global number of other sectors (World Steel Association, 2019). Additionally, Steel is more cost-efficiently compared to other wildly used materials. Steel degrades slowly making it a material that does not require frequent costly repairs nor maintenance, simultaneously being the most widely reused metal globally (Lux Metal Group, 2025). In summary, this material's unique

combination of economic significance, durability and recyclability influenced its position as an indispensable material in modern society.

To fully assess this industry substantial contribution to the economy it is important to acknowledge the European steel industry´s impact as well. Statistics from Eurostat suggests that there were recently some small changes in export and import of steel comparing numbers from 2022 to those of 2023. The export of iron and steel felt slightly when the import at that period increased by 0,4 percentage point (European Commission, 2024- a). EU is one of the leading global producers of steel with the primary markets for export being United States and UK. Germany is the first major steel producing country in European Union, being ranked number 7 in the world and it is experiencing the highest steel production costs. Such a situation is also faced by the third biggest steel making country, which is Italy where the big influence on production costs from 2021 been the increasing energy related and raw material prices (Ben M'barek, Hasanbeigi & Gray, 2022; World Steel Association, 2024). These changes, combined with geographical tensions and supply chain disruptions have major negative impact on steel demand. That can be seen in the decrease of 1,3 percent in consumption in 2024 that shows the continuity of negative trend (EUROFER, 2024). Overall, these factors present the significant economic challenges that this influential industry is currently facing.

3.6. Limitations and ethical concerns

A key limitation in this research is that the findings are context-specific, given the inherent nature of qualitative research and the choice of organizational setting. This reduces the external validity of the findings and makes it harder to synthesize/integrate these with another research (Creswell, Poth, 2016). Although the findings are not broadly generalizable to all companies in the steel industry in Europe, they are still potentially transferable to other enterprises of similar size from the same sector (Treharne, Riggs, 2015), given their similar operations, raw materials, and impact on environment. Moreover, this study does not aim to obtain a final grasp of the topic, but rather to contribute to the literature and encourage further research. This is particularly important as the regulatory environment affecting European steelmakers is still evolving, resulting in mixed reactions to tightening policies, especially with the 2030 goal of lower emission by half is approaching (EUROMETAL, 2025; European Union, 2020).

A second weakness is that the research design was limited by feasibility constraints for instance time. This reduces the scope of the study and means that the sample size is relatively

small compared to other studies mentioned in the literature review. This undermines the reliability and validity of the research findings and its perceived trustworthiness by other researchers (Andrade, 2018). Nevertheless, the chosen data collection methods allow for a deeper, more contextualized understanding of the research phenomenon (Alvesson, Ashcraft, 2012).

The time specific and geographical aspect of this study limits its practicality. The dynamic nature of climate policy and market shifts that affect the steel industry may affect the relevance of present findings. Additionally, this research relies partially on secondary data such as official reports or European policy documents. While these materials provide adequate and important insights about the industry, they might not fully capture the internal strategic deliberations or operational realities that companies face.

A final potential issue may concern a limited engagement from participants in the in-depth interviews which would reduce the quantity/quality of data collected (Tietze, 2012). This is likely due to their busy schedules, the nature of the topic, and the researcher's own positionality as a student, which may reduce their willingness to divulge authentic responses. To overcome this, additional data analysis will be used to provide more information about the companies' actions and to triangulate the findings from the interviews. Triangulation enhances the validity and confirmability of the results by identifying commonalities and minimizing the role of differences among disparate data collection methods (Flick, 2004).

4. Findings

Introduction

This section presents the findings that were obtained according to illustrated earlier methodology. The results are based on semi-structured interviews that lasted on average 40 minutes per interview and secondary data from publicly available company reports, official documents and other relevant sources of information. Primary and secondary data are organized according to three themes that were used during the interview process. The questions, divided according to these same themes are provided in Appendix 1. Each section starts with a table showing the use of Matrix Analysis, which enables rigor and cross-case comparison of primary data. The responses from participants are summarized in tables to showcase patterns, key insights and differences across the four case companies. Where responses were particularly detailed or illustrative, direct quotations are provided to show the participants' perspective in their own words. These tables are followed by a detailed analysis that includes direct, important quotes from interviews and is further supported by relevant secondary data.

Table 1: "The overview of case companies in this research."

	CASE I	CASE II	CASE III	CASE IV
Name	Tata Steel Netherlands	Marcegaglia Steel S.p.A.	Salzgitter AG	SSAB AB
Country	Netherlands	Italy	Germany	Sweden

Note: Table created by the author.

4.1. Sustainable Development Strategies in the steel industry

Table 2: "Summary of the responses from company's representatives to the first question."

	CASE I	CASE II	CASE III	CASE IV
Has your company introduced any sustainable strategies? If so, which ones?	- Introduced low carbon steel products, Zeremis Carbon Lite, offers 90% reduction in carbon footprint, through mass balancing -Increased use of scrap-based steel	- Health and safety in the workplace to protect personnel -On-going staff training and certification according to the SA8000 standard	-Building Electric Arc Furnace and using Direct Reduced Iron instead of coal-based input -Transition to use of scrap steel as feedstock in EAF, considered a zero-	-Introduction of low emission product offer SSAB Zero -Transformation of production technology to eliminate fossil fuels by use of hydrogen to make fossil-free steel and lower

	-Transitioning to Direct Reduced Iron and Electric Arc Furnace configuration -Implemented measures to reduce energy consumption: optimizing use of natural gas and electricity -Developed advanced coating for painted products to increase lifespan and frequent replacements	-The energy management system based on ISO 50001 and push towards energy efficiency -Reducing direct GHG emissions (Scope 1) and indirect emissions (Scope 2) -Numerous and diverse projects for the use of renewable energy, like installation of photovoltaic systems for self-consumption and other contractual instruments such as PPAs, GO and EACs	emission input due to its recycled nature -Introduction of green hydrogen as a reduction agent in DRI process -On-site facility being built to produce green hydrogen -Participation in Germany's upcoming hydrogen backbone network -Utilization of renewable energy to power the current EAF in Peine - Group-wide sustainability integration to eliminate unnecessary plastic waste	emissions by using EAFs instead of blast furnaces -Taking part in projects like HYBRIT -Elimination of toxic substances from production (i.e. PFAS)

Note: Table created by the author.

Presented findings clearly indicate companies' dedication to reduce and in some cases like Case III and Case IV eliminate emissions with their sustainable strategies. To do so all of them pointed out the use of Electric Arc Furnaces (EAFs). The Case III stated their reason for it is that: "Our blast furnaces have the advantage that it produces a very good quality steel but with disadvantages that the CO2 emission is very high". Such big ecological impact pushed all presented companies to decision on on-going building processes of furnaces that can be fed by scrap as Case I, Case III and Case IV mentioned. Case II does not fell behind as according to their Sustainability Report in 2023 during the acquisition they gained an electric furnace for special steels (Marcegaglia, 2024 - a). When it comes to becoming more CO2 neutral this company also elaborated:

> "Decarbonization strategies are the core of sustainability and transition plan starting from mapping the organization's carbon footprint, moving to the product carbon footprint and up to setting science-based targets."

Within this topic all representatives agreed on the importance of the steel going green. Example of that can be seen in the words of Case I that introduced low carbon steel product Zeremis Carbon Lite or in the Case IV that mentioned SSAB Zero. Case II also contributes to this change as of 2021 they announced to be an important industrial partner and one of the investors of H2GS's "green" steel plant that in 2024 got approval for $284 in funding from the EU (Marcegaglia, 2021; Hydrogen Europe, 2024).

Those investments lead to another key subject that contributes to emissions mitigation, which was frequently mentioned during the interviews, being hydrogen. This clean fuel enables Case IV to make fossil-free steel, will be used as reduction agent in DRI process by Case III, is paving the way for future advancements like first hydrogen powered ship (Case I) and plays important role in Italy's future decarbonization through the "Decarb Fast Track" program (Case II) (Tata Steel Netherland, 2023- a; Marcegaglia, 2024 – c). All the companies consider or are actively trying to produce their own green hydrogen that can make all this processes even more effective, but this hydrogen is as the Case III stated:

> "The energy is simply either very expensive or not yet there as there's no green hydrogen. If you want it or not. There's no green hydrogen."

While the secondary data indicated that there has been an increase in electrolyze production since 2022 to make the 10 million tons of green hydrogen annually in the EU by 2030 more realistic, there is still a significant shortage of this crucial energy source (Schwarz, 2025). This situation can take place also due to high cost of green hydrogen that is often even four times higher than fossil-based hydrogen because its production nowadays is also costly (European Union Agency for the Cooperation of Energy Regulators, 2024; Kotowicz, Baszczeńska, Niesporek, 2024). To conclude, as demonstrated by the findings and proven by several secondary data, all four companies are actively making the sustainable transformation possible with their shared commitment to getting rid of carbon emissions in few years. This transformation can be seen for instance on Green Steel Tracker platform that shows current state of actions made by the main companies in the steel sector not only in Europe but in the whole world (LeadIT, 2024).

Table 3: "Summary of the responses from the companies' representatives to the first question. Part 2."

	CASE I	CASE II	CASE III	CASE IV
How where these strategies selected?	-Twofold approach - "In short-term offer a variety of solutions to customers, allowing them to choose the best fit for their sustainability goals and maintain a customer-centric approach, ensuring flexibility" - "Long-term the company acknowledge the need for steel industry to drastically reduce CO2 emissions, recognize the significant investments required for transformations and carefully evaluate each strategy's potential impact and alignment with vision for sustainable future"	-Core focus when selecting on decarbonization (ISO 14064) -Adoption of ISO 14025 and ISO 14067 to evaluate the environmental impact of products -Sets targets based on the Science Based Targets Initiative -Strategic alignment ensured through membership in international initiatives including: United Nations Global Compact, First Movers Coalition, ResponsibleSteel, Energy Efficiency Movement, Decarb Fast Track	-Identifies its sustainability areas for improvement and places them into six areas of focus -Executive Board responsible for strategic decisions -Regular meetings and stakeholder engagement -Use of Science Based Targets Initiative Alignment for setting sustainable targets	-Structured process entailing stakeholder engagement, strong governance and science-based targets -SSAB's Board of Directors and Group Executive Committee approve such strategies -Interviews or surveys with stakeholders -Make sure to have Science Based Targets

Note: Table created by the author.

Having confirmed that all case studies introduced sustainable strategies, in this part the researcher wanted to gain further insights into how the selection process was conducted, using the follow up question presented in the table above. Based on the responses there are three different tactics that companies used. Case I presented that the company is primarily focused on catering their customer needs and is doing so by offering different options but at the same time carefully evaluate possible solutions in order to find the best fit with their abilities and environment. Case II on the other hand highlighted that their actions are led by available standards they want to meet and their involvement in the vast number of international initiatives in the steel industry. Similarly, also to Cases III and IV, this company make sure that its goals are science based, which is another factor that enables the selection of the most suitable and green strategy. Case III and IV described this process as a structured one that entails stakeholder engagement and internal governance. Although it was not mentioned during interviews the strategy selection is also formalized in all other cases like. For instance, in Case II that can be

observed in their Sustainability Report from 2024 that they obtain Sustainability Committee since 2020 that actively supports the decision-making process regarding environmental, social and corporate governance actions (Marcegaglia, 2024-c).

The significance of taking actions to decarbonize the industry was once again pointed out here in Case I and Case II. Representative of Case I stated that:

> "In the long-term the company acknowledge the need for steel industry to drastically reduce CO2 emissions, recognize the significant investments required for transformations and carefully evaluate each strategy's potential impact and alignment with vision for sustainable future."

However, this companies are not the only ones highlighting in their visions the dedication for sustainability. Based on secondary data all presented companies implemented the sustainability agenda in their business models or strategic directions (Marcegaglia, n.d.; SSAB, n.d.-d; Tata Steel Nederland, n.d. -c; Salzgitter AG, n.d.-a). As can be seen the companies even when having different approaches to selection of strategies, have in mind one mutual goal which is the sustainable development.

Table 4: "Summary of the responses from the companies' representatives to the first question. Part 3."

	CASE I	CASE II	CASE III	CASE IV
What sustainability problems do these strategies address?	-Primarily their strategies aim to reduce CO2 emissions -"Focusing on reducing overall energy consumption and enhancing energy efficiency across operations" -Commitment to responsible sourcing also addresses for example deforestation	- "Many issues such as decarbonisation, energy efficiency, human rights, injuries reduction and just transition"	-Strategies aspire to decarbonize the sector by leading as an example of future CO2 zero company -Adress the issue of transport related emissions and fossil fuel dependency but also plastic waste and packaging	- Addressing with their strategies the high carbon emissions from steel production as well as toxic substances in production -Want to fight also supply chain emissions and resource transparency

Note: Table created by the author.

Investigated companies were humble when describing their sustainable strategies. As evidenced on their official websites, all the firms conducted variety of initiatives that go well beyond the environmental changes that were mainly discussed and are presented in Table 4. On Case I company's page we can read that they are involved with the community through various partnerships supporting that way the social sustainability (Tata Steel Netherland, n.d.- c). They

do that also by actively changing their plants so that their activities are in fit with local community needs. The example of that is their Roadmap Plus programme with which they over the years: fight dust, odour, noise, light and PAHs and nitrogen emissions to make their presence less effective on communities. They also highlight their dedications to have their workplaces safe and inclusive for all employees. For instance, they implemented the Green Steel Social Contract that guarantee employment possibility even when the old plants will be closed (Tata Steel Netherland, 2023- b). Case III also is addressing social sustainability problems by promoting sustainable community actions, offering training and continuous development and being forward oriented company. On their website they wrote:

> Health and safety at work is a central priority in the Salzgitter Group. We want people to be able to work safely and healthily with us. We therefore rely on comprehensive occupational health and safety management and take measures to protect and sustain our employees' health. (Salzgitter AG, n.d. -b, para.5).

Similar measures are taken in the Case IV that has a set of social targets regarding safety, inclusion and diversity, just transition (SSAB, 2024). Only in the Case II the response included the company's efforts on the social aspect of sustainability. Thus, the gathered data suggest that the chosen strategies adopted across all cases tackle a wide range of sustainability challenges.

Table 5: "Summary of the responses from the companies' representatives to the second question."

	CASE I	CASE II	CASE III	CASE IV
Are there any sustainability strategies your company has implemented within its supply chain?	- "Integrated sustainability into supply chain by benchmarking our suppliers on various sustainability criteria" -The BES 6001 certification, reflects dedication to responsible sourcing and sustainable supply chain management - "Map entire supply chain to see what actions the most important and focus	-Partnered with STEGRA a Swedish producer of low-carbon steel using electricity and hydrogen instead of fossil fuels. That is 7-year supply contract signed in 2023 and contributes to reducing supply emissions by 90% -Extensive use of ferrous scrap in steel production with full internal scrap recovery and reuse the same for by-products	- Circular economy and resource efficiency with the closed loops -Offering services to customers and suppliers related to navigating CO2 emission certificates -Entering long-term agreements with new steel plants such as Greenfield projects, worldwide that are designed to produce CO2-free steel, ensuring future access to sustainable materials	- "Rethought supply chain from ground up" -Created a completely new production route that enables sourcing of low-emission raw materials, especially low-carbon iron and scrap - Started using electric-driven trucks for internal transportation between production units

	on transparency within supply chain” -Engaged in Metal Agreement to work together towards sustainable supply chain	-Company represents an example of virtuous model of circular economy -Strategic acquisition for sustainable integration of French mill in 2024 to modernize and decarbonize supply chain. -Efficient resource management with careful scrap selection to optimize material quality -Reuse of waste energy and minimization of emissions across processes	- “Establishing a dedicated department responsible for ESG matters to manage compliance, reporting and support for suppliers and customers”	- “Work closely with strategic suppliers to ensure that the entire sourcing and logistic system aligns with environmental targets”

Note: Table created by the author.

Responses for this question gathered during interviews are just the introduction to the acquired data about sustainable supply chains of this companies as in the later sections the actions regarding for example transportation will be discussed separately. All cases demonstrate a clear commitment to integrating sustainability principles into their supply chain strategies. The repeating similarity in the data is the shift toward responsible sourcing and long-term partnerships with low-carbon or circular suppliers. For instance, Case I shared that:

> “We integrated sustainability into supply chain by benchmarking our suppliers on various sustainability criteria. This includes evaluating their environmental practices, labour conditions and overall commitment to sustainable operations”.

Another example is the statement of representative in Case II that said:

> “Partnership with STEGRA is creating sustainable change in heavy industry for generations to come. By 2026 production will start with 2.5 million tons of low CO2 steel per year. In 2023 Marcegaglia closed a 7-year supply contract.”

Likewise, Case IV has redesigned its entire supply chain around low-emission raw materials and collaborates closely with strategic suppliers. Another shared strategy is the emphasis on circular economy principles. It can be seen in the Case II and III as them both integrate scrap recovery and reuse systems to minimize material waste. Circular steel making is the part of Case I as well. This company utilise their own and bought scrap metal and it even studying how to use it more frequently as a substitute for other materials to make their production even more circular (Tata Steel Nederland, n.d. -h). The data also suggests that both Case III and Case IV have or are planning to have the closed loop in their supply chain. In the press release of Case IV the interviewed Thomas Hörnfeldt said:

> "Since we will be using mostly recycled steel scrap as the raw material in Oxelösund, we will also be able to offer our customers closed loop solutions (…)". (SSAB, 2025- b, para.7).

Table 6: "Summary of the responses from the companies' representatives to the third question."

	CASE I	CASE II	CASE III	CASE IV
Does your company collaborate with suppliers to improve its sustainable strategies? If so, how?	- "We engage in continuous dialogue with our suppliers, sharing best practices and setting clear expectations regarding sustainability" - "If supplier fails to meet our sustainability standards and is unwilling to make necessary improvements, we reduce business with them"	-Main influence of suppliers concerns raw materials and CO2 content -Collaborate through being a part of the STEGRA project - "Acts as a lever by using a dedicated qualification portal to select suppliers across various areas, including legal compliance, certifications, safety, energy, environment and social responsibility"	- "Delivering CO2 reduced slips to our suppliers internationally so they can make reduced products" - "Talk with suppliers to explain what sustainable changes we are doing and convince them to follow us on that path" - "Interviewed many of suppliers worldwide and attend conferences to present company's idea about sustainability and ask about intentions and possibilities and how can company help with them" - "Convince suppliers to take part in transformation"	-"Our emission reduction goals extend beyond our direct operations; they also cover our suppliers' scope 1 and scope 2 emissions" -Organize workshops, provide technical guidance and in some cases, work on joint innovation projects to help suppliers transition towards more sustainable practices

Note: Table created by the author.

Companies' representatives all indicated that they already made changes in how they collaborate with suppliers and emphasized the significance of these relationships. As the Case I representative said:

> "Collaboration with our suppliers is key."

Indeed, collaboration and communication with suppliers can be seen as reoccurring response in all cases. This takes various forms such as dialogue, interviews, conferences, workshops or projects like the STEGRA one mentioned in Case II. In Case I, secondary data also shows collaboration with Meconet, a supplier of CO2-reduced steel, which supports the steel service center's sustainability efforts by enabling the use of low-emission materials (Tata Steel Nederland, n.d.-e). This example also illustrates a second key pattern in how companies engage with suppliers to improve its sustainable strategies. In all cases they influence and guide suppliers towards the changes. Case I does that by defining clear expectations and reducing businesses with non-compliant parties, while Cases III and IV support their suppliers in this process by for instance, through joint innovation projects. Case II, on the other hand, incorporates sustainability requirements into its Supplier Policy, enforcing compliance with company's values using formal qualification process (Marcegaglia, 2023-c). Last noticed similarity in responses is that all companies extend their sustainability goals beyond their own operations, aiming to create a greater impact. The response from Case IV:

> "Additionally with our customers we promote a shared philosophy around fossil-free materials. So, the impact continues along the entire supply chain."

and Case I:

> "Our goal is to have a supply chain where every participant is committed to sustainable practices."

are the evidence of that. In total, all these mostly similar approaches suggest that building close relationship with suppliers is necessary for reaching significant and lasting improvements in steel supply chain's sustainability.

Table 7: "Summary of the responses from the companies' representatives to the fourth question."

	CASE I	CASE II	CASE III	CASE IV
Has your company introduced any new technologies to support its sustainable strategies? If so, what kind of technologies?	- "One significant initiative is implementation of DRI-EAF technology to substantially reduce CO2 emissions" - "Exploring the use of green hydrogen as reducing agent in our DRI processes" -Adopting digital tools and data analytics	-Green DRI in Marcegaglia Fos sur Mer -Carbon Capture and Storage plant in Ravenna uses the KM CDR™ process - Green DRI in Ravenna Plant with I-Smelt system -MODIPLANT Project that aims to decarbonize reheat furnaces by combining electrification and gas combination -Smart Rolling uses Tensil-Pro technology with virtual sensors and advanced metallurgical models to optimize high-quality sheet production -DIGI-INOX as a part of Transition 4.0.	- "Building Electric Arc Furnace and using Direct Reduced Iron instead of coal-based input" -Introduction of green hydrogen as a reduction agent in DRI process -On-site facility being built to produce green hydrogen	- "Several. The biggest is transformation towards hydrogen-based reduction of iron ore instead of coal, HYBRIT initiative" -Replacing old oil-fueled equipment with electric alternatives -Move to EAF powered by renewable energy

Note: Table created by the author.

One of the takeaways from the Table 7 is that all four companies are actively investing toward more green production with a strong focus on decarbonization through technological innovation. While they share common ambition, each case follows a different path, shaped for example by their resources or technological maturity. Common actions include here the use of Direct Reduced Iron, Electric Arc Furnaces and green hydrogen. Case III and Case IV stands here out as they already have EAF in Peine or are producing SSAB ZERO using this technology, based on findings from interviews. Case I according to the primary data has their

Green Steel within which is building EAF by 2030. Case II in 2023 acquired one EAF mill in United Kingdom and in 2024 the second in France, Fos sur Mer (Taylor, 2024). The adoption of EAF is a main major technological shift based on the data, with the potential to lower by as much as seven percent Sweden's total emissions. However, it is important to note that is also very costly as companies invest even around $643 million to make these changes happen (SSAB, n.d.-e).

Moreover, within the topic of newly introduced technologies cases I and II admitted adopting the data analytics and digital tools to support their sustainable strategies. The secondary data from Case I website confirms this, as the company has introduced a sustainable digitization solution called DataDrivenSteel that integrates Machine Learning, AI and dashboarding to support their green steel production (Tata Steel Nederland, n.d.- g). Nevertheless, the Case II also uses advanced digital tools like Machine Learning Applications, Advanced Roll Cluster Configurator and HMI to modernize their mill as a part of green transformation (Tenova, 2025). Plus is actively caring out digitally based projects called MADELEN, DIGI-INOX and Smart Hot Rolling (Marcegaglia, 2023- c). In the cases III and IV there are also examples of innovative technology for example SAS solutions or SAP S/4HANA (SAS, n.d., SAP, 2023). Similarities across all cases can be seen with the use of cloud computing for instance use of Microsoft Azure Cloud Services by Case I, SMS DataFactory of Case IV or WeAre4Cloud software of Case II (Apps Run the World, n.d.; SMS group, 2021; Marcegaglia, 2024- a). All of this demonstrate a strong commitment of analyzed steel companies to sustainability by technological transformation.

4.2. Impact of Sustainable Strategies on Supply Chain Management

Table 8: "Summary of the responses from the companies' representatives to the fifth question."

	CASE I	CASE II	CASE III	CASE IV
Have your company's sourcing or logistic decisions changed in response to sustainability efforts? If so, how?	- "Yes both. Company is BES 6001 certificated, which proves that we select suppliers based on fair labor conditions, deforestation" - "In logistic, optimizing our transportation methods to reduce	- "Sustainable procurement with recent acquisitions and involvement in STEGRA project" -Shift from road to trail transportation -Rail transport already used in multiple company's entities, which made	-Revised supplier selection criteria to prioritize partners who demonstrate compliance with environmental standards and commitment to reduction of CO2 -Sourcing raw material locally, when possible, to	- "Substantially. Company now selects suppliers not only based on cost and quality but also on their carbon footprint" - "Logistic-wise optimized transportation routes to favor lower-emission options

	CO2, including the use of biodiesel and exploring electric transport options” - “Consider multimodal transportation solutions to enhance efficiency and minimalize carbon footprint”	it possible to over years avoid over 67 000 tons of CO2 emissions -Signed agreement to in the future design and build new railway terminals and connections, manage new wagon fleet for broader group transport needs, construct a new 11 km railway to Gazoldo degli Ippoliti plant	minimize transportation - “Logistic department works more closely with low -emission transport providers or alternative vehicles” -Strategic investment in rail transport and adoption of green procurement policies -Digital tracking system to monitor carbon footprint of logistics and enhance supply chain transparency	like electric trucks and rail, whenever available”

Note: Table created by the author.

A frequent subject among the cases is the move to low-emission transportation options, particularly the rail. Cases II, III and IV concentrate investments or strategic transitions to rail transport aimed at reducing CO2 emissions with Case II measuring its effect exceedingly even 67 000 tonnes of CO2 prevented. The sustainable reasoning for such decision is explained in the Sustainable Report of Case II saying that:

> “The infrastructure work will reduce road traffic, with dual objective: the reduction of emissions into atmosphere from road transport and greater road safety, considering that a single train removes 30 trucks from the road.” (Marcegaglia, 2024- c, p.55).

Case III is unique for utilizing digital tracking tools to control logistic emissions and improve transparency. Additionally, in Case II the company is using high-tech satellite mapping of their equipment to locate and shorten distances (Marcegaglia, 2022). All four cases address the optimization of transport routes or the adoption of cleaner alternatives, such as electric trucks or biodiesel, indicating an overall acknowledgement of logistic as a significant sustainability tool.

In sourcing, each case has established new criteria that promote environmental performance. Case I and III applies BES 6001, the certificate for responsible sourcing, stressing

an ethical and environmental standpoint (Peiner Träger GmbH, n.d.). Case IV has their own Supplier Code of Conduct but also, they highlighted sustainability during interviews mentioning:

> "Low-emissions practices are a key part of our supplier selection" (SSAB, n.d.-f).

The similar approach takes Case II using their Supplier Policy (Marcegaglia, 2023-c). In these requirements for suppliers, the cases focus on environmental but also social and ethical requirements. The data of Case III and IV mentioned that they concentrate mainly on the carbon footprints of collaborating parties. In addition to that Case III referenced the application of more recycled steel and local materials, thereby linking procurement directly to reductions in pollution. At the same time, Case II connects its sustainable sourcing strategy with acquisitions, exhibiting more broad approach.

Table 9: "Summary of the responses from the companies' representatives to the sixth question."

	CASE I	**CASE II**	**CASE III**	**CASE IV**
Do your sustainability strategies affect production planning or operations?	- "It requires comprehensive planning and adjustments" - "Transitioning to involves significant changes in our production process, workforce training and infrastructure" - "Continuously seeking ways to improve energy efficiency and reduce waste in our operations, which necessitates ongoing evolution and adoption of our plans"	- "Intercompany interactions are those that will be most affected by the new agreements following the implementation of the interventions described before"	-Heavy investments into carbon-zero transformation - "Simultaneously constructing new facilities and employing over 1000 new workers for that" -Developing and marketing CO2-reduced materials -Training stuff and educating customers and suppliers -ESG department	- "It led to concrete shifts in production timing and capacity plans" -Accelerated its decarbonization schedule -The company will close old existing furnaces when new ones are ready -Future changes due to fossil-free steel mill makes company revise its production plan

Note: Table created by the author.

The incorporation of sustainability strategies into production planning and operations is evident in the cases and is transforming how steel firms approach technical advancement and

investment. Cases I and III illustrate once again that decarbonization is not a secondary effort but an essential redesign of production processes. As the case I representative stated:

> "Transitioning to involves significant changes in our production process, workforce training and infrastructure,"

stressing that way the extent and complex nature of these improvements. In the same manner, employee in Case III described the process as a:

> "We have a total changement of the process route. We have different use of pre-metal and different energy supplier."

This company also explained that the changes are big, as similarly to the rest of studied cases, they must manage two processes simultaneously. The cases need to carry out the work on old furnaces, while building the new ones. Gathered data reveals also that the impact extends to intercompany relations and internal coordination. For instance, in Case III, the organization pointed out that various departments are transforming due to sustainability priorities. Such new capital and workforce-intensive operations reflect the industry's awareness that reaching ecological goals calls for long-term, fundamental reconfiguration of essential production processes.

4.3. Challenges in implementing Sustainability Strategies

Table 10: "Summary of the responses from the companies' representatives to the seventh question."

	CASE I	CASE II	CASE III	CASE IV
What challenges, if any, does your company associate with transforming to more sustainable supply chains?	- "One significant risk is the competitive market environment" - "Many customers do not yet perceive the value of sustainability efforts and often clean production methods are more costly" - "Currently our margins are too low to fund these initiatives entirely on our own" - "Prioritize self-funding sustainability initiatives"	- "The main ones are rising awareness among operators and engaging them" -Technical limitations in applicable technologies - "The balance between technical constrains and market availability of materials coming from EAF instead of BOF"	-High cost and risk of new projects - "Energy costs, especially in Germany and that makes it nearly impossible at the moment to produce a steel which is at the price level where you can still earn money" -Customers accepting to pay higher prices for steel made with sustainable principles -Hiring a lot of new people for sustainable initiatives is very costly	-The financial investment required for new technologies and facility upgrades is significant - "Increased complexity as implementing new production methods increases the risk of initial quality issues or production disruptions" - "Availability of scrap material and renewable energy on the scale we need is a major long-term challenge"

Note: Table created by the author.

The gathered data reveals a distinct trend in challenges, which is the significant financial capital necessary for various new investments that all cases face to obtain sustainable supply chains. This most frequent barrier refers to financing innovative technologies, renewable energy, recycled materials or hiring of specialized staff. Firms frequently brought up the challenge of balancing these costs with market conditions including the facts that many customers are remaining hesitant or unconvinced to pay higher prices for sustainably produced steel and competitive market environment for recycled materials. Representative of Case IV mentioned that:

> "We overcome this by working on long-term supplier partnerships, investing in technology development and collaborating closely across industries."

Similarly, Case I stated:

> "To manage we focus on selecting options that offer value to end customers, such as the automotive industry, which is often willing to fund some of the extra costs associated with sustainable practices."

Indeed, secondary data reveals that this firm actively collaborates with different industries to address sustainability challenges by using its innovative Zeremis Carbon Lite steel. This solution not only supports supply chain decarbonization but also creates opportunities to secure funding and offer tailored solutions across various sectors. Case I funds CO2 reduction projects, verified by DNV and stores the resulting savings in their special "CO2 bank." Customers can than access this bank to acquire carbon lite declarations, supporting their own Scope 3 emission targets. Revenue from this declaration is than allocated again into Case I's carbon-lowering initiatives (Tata Steel Nederland, n.d.-f). This demonstrates that they use self-funding and collaboration to proactively address the pressing industry-wide challenge of financing the transition to more sustainable supply chains.

Table 11: "Summary of the responses from the companies' representatives to the eighth question."

	CASE I	CASE II	CASE III	CASE IV
Have government regulations or industry standards affected your company's sustainability efforts? If so, how and which?	- "Operate under tight licenses based on the best available technology in industry principle. This means we're required to adopt the most effective and advanced methods for reducing environmental impact, which drives us to continuously innovate"	- "The main regulations that have influenced the sector are the European directives ETS and IED, related to emissions from combustion and aspects concerning emissions matrices in the atmosphere and water, as well as alignment with the best available techniques for each sector" -Currently the most impacting are CBAM and CSRD with CSDDD directive and regulations concerning certain products associated with deforestation expected to be introduced in the coming years	- "From 2026 companies will have to pay for CO2 emissions per ton of steel produced, if their emissions exceed the European Union average for that product" -Trading system called ETS -new ESG department to address regulatory demands Offices have been established in Brussels and Berlin to maintain regular contact with government entities and politicians regarding support and regulatory developments	- "While sustainability has been embedded in company's long-term vision for years, regulations like EU's Carbon Border Adjustment Mechanism have accelerated our internal decision-making" - "They pushed green transition projects to completed faster and helped build stronger business cases for investment in sustainable technologies" - "Without regulatory pressure or strong demand, many suppliers are hesitant to invest in low-emission techniques"

			-Engaged in discussions with policymakers - "Government assistance is helpful but not sufficient"	

Note: Table created by the author.

All studied cases described during the interviews concrete European government regulations that that impacted their sustainable actions. Case I mentioned the Best Available Techniques (BAT) principle that is an element of the European-wide Industrial Emissions Directive (IED). This law affects industrial activities in terms of emissions they cause and as the company said:

> "This means we're required to adopt the most effective and advanced methods for reducing environmental impact, which drives us to continuously innovate."

Such a European mandatory directive is particularly interesting because it was refined last year and is now stricter, further affecting practices in the steel industry. Today, the new IED 2.0 is targeting exactly the companies included in this research (except the Case II) which are among the largest emitters (European Commission, 2024- b; Industry Tracker, 2021). Another example of policy was shared by representative of Case III, identifying changes in CBAM regulation and EU ETS. In this case, the company recently established a special department responsible for addressing current and upcoming regulatory changes, while also strategically locating their offices to actively engage in and influence policy discussions. They described the situation saying:

> "Government assistance is helpful but not sufficient."

A similar position was taken by the interviewee from Case IV, who also mentioned CBAM in their response and said:

> "Without regulatory pressure or strong demand, many suppliers are hesitant to invest in low-emission techniques."

This showcases that the need from the European steel industry for newer and more precise regulations in high, but at the same time the ones in place are clearly having an impact on their actions.

Case II also acknowledged the influence of key European directives on their sustainability efforts. According to the interviewed person:

> The main regulations that have influenced the sector are the European directives ETS and IED, related to emissions from combustion and aspects concerning emissions matrices in the atmosphere and water, as well as alignment with the best available techniques for each sector.

Additionally, they noted the Carbon Border Adjustment Mechanism and Corporate Sustainability Reporting Directive currently are having the most significant regulatory impact on their actions. That company, just like in the Case III, is preparing for upcoming legislations such as the Corporate Sustainability Due Diligence Directive (CSDDD) and other new product regulations.

5. Discussion

Introduction

Following chapter include interpretation of presented before findings on sustainable supply chain management (SSCM) in the European steel industry. Based on the results from in-depth interviews with representatives of steel firms and secondary data, this section links the insights from gathered information with theory and literature reviewed earlier. It presents how current practices of studies companies relate or question existing theories, offering that way answers to research questions. Moreover, the chapter explores the managerial implications formulated based on this research, considering the unique for the sector challenges in the context of the European Union's evolving sustainability goals. This part of research will also address the future research proposition.

Circular steel making

One of the key sustainable development strategies identified among the studied European steel companies is the adoption of circular economy principles, especially recycling and closed-loop production, which supports the findings of Branca et al. (2020). This addresses the first research question by showing that firms use steel's recyclability to reduce their environmental impact while at the same time improving supply chain efficiency. Founded among responses practices, align with the Triple Bottom Line theory (Elkington, 1998), as integrating more scrap into steelmaking processes helps reduce waste and lower carbon dioxide emissions, supporting the environmental dimension (Tata Steel Nederland, n.d. -h). Companies invest in new technologies like EAFs to use more scrap, creating that way more jobs, as in Case III, illustrating the social dimension of TBL. Additionally, the practice supports the economic dimension through the effective use of materials to cut the costs associated with by-products. Circular practices associated with scrap also reflect the Circular Economy theory pictured in the work of Weetman (2016), who emphasized reuse and redesign in sustainable production. Companies are doing exactly that, as shown in Table 1, they are making special steel from scrap, reusing the raw material as much as possible. In summary, these findings align with those from 2011 (Yellishetty Mudd Ranjih and Tharumarajah) and 2023 (Van Audenaerde and Gulgulia) and demonstrate that circular steelmaking based on scrap continues to be a frequently adopted sustainable development strategy in the steel industry today.

However, putting these strategies into practice is not without challenges. Several steel companies pointed out obstacles like availability and cost of scrap, as presented by Case IV in Table 10. These challenges are in line with those identified by Yellishetty et al. (2011), who proposed the solution of a "scrap stabilization fund" to help mitigate scrap market instability. Although such a fund does not exist in Europe to this day, the scrap market is being closely watched by the European Commission and the Circular Economy Act is planned to enter into force in 2026. This legislation is meant to enhance how the European scrap market functions (European Commission, 2025- d). Meanwhile, scrap-based strategies remain attractive because they align with the industry-wide transition to Electric Arc Furnaces (EAFs). Based on the data, all companies studied either have or are constructing EAFs that operate on scrap. An example being Case II, which acquired one last year (Taylor, 2024). Primary data shows that this shift impacts supply chain management by improving material flow and encouraging closer supplier collaboration. At the same time, the regulatory environment in the EU, especially the use of BAT that was mentioned by companies, creates strong reasons for today's steel firms to emphasize those strategies. These findings suggest that circular steelmaking is the dominant sustainable development strategy among the big European firms because it corresponds with regulatory expectations and key enabling technologies like EAFs.

Decarbonization initiatives

All the steel companies that took part in this study are working towards substantial limitation or overall cut of their emissions. They are primarily achieving this by making their production more energy-efficient and by use of more green energy like hydrogen. According to the interview this is primarily caused due to the imposed regulations and standards which include various targets they want to meet. In some cases, steel firms are even imposing their own using Science Based Targets as seen in Case III and IV. This motivation is also reflected in the interviews where companies recognize the environmental risks their processes are poising, and all officially expressed their commitment to change by placing this agenda in their strategic visions. The customer pressure is not there yet a major factor, as firms need to educate and persuade them to buy more costly green products. Additionally, the main driver behind implementing sustainable decarbonization strategies, according to the companies is and should continue to be the increased mandatory regulatory pressure. Literature agrees and calls for more adequate regulations for this sector in Europe as such mandatory standards help enforce desired level of sustainability (Climate Action Network Europe, 2025; Russo et al., 2023).

Operating in a competitive and complex environment, as described by the cases in Table 11 is connected to the natural resource-based view (Hart, 1995), which emphasized constant development of capabilities and efficient use of resources It all also simply resonates with Sustainable Development definition included in the Brundtland Report, which calls for protecting the needs of future generations (Brundtland, 1987). The drive for decarbonization, as incorporated in these companies' sustainability strategies is highly influenced by the EU policy ambitions, such as frequently highlighted in interview EU ETS. These decarbonizations actions are redesigning how companies manage their supply chains. They now pick suppliers who are meeting their environmental requirements and actively support them in lowering their carbon footprint according to Table 6. Steel companies are also investing in new technologies and partnering with specialists in them such as SMS group (2021) to provide DataFactory for Case IV. Decarbonization is becoming a way for companies to stand out and succeed in today's market (Wells, 2025). It is important to remember that these results mostly apply to big companies in EU as smaller might find it harder to follow the same strict mandatory regulations and achieve success (Russ et al, 2023). That is why getting more support from policymakers is so important if the whole industry is to move forward.

Social Sustainability

In addition to environmental strategies, the data suggest a growing although less frequently emphasized, attention to social sustainability among four analyzed firms. Interviewed companies described ongoing initiatives related to workforce upskilling, inclusion initiatives and development of safety standards, which are aligned with the social dimension of the Triple Bottom Line (Elkington, 1998). These initiatives are evident for example in Case I which showcases the important role of continuous stakeholder dialogue to understand their perspective to in maintaining legitimacy. According to its Sustainability Report, this company is adjusting to changing community expectations to keep its social license to run operations and continue sustainable mission (Tata Steel Nederland, 2023- a).

While the original natural resource-based view (Hart, 1995) focused primarily on environmental capabilities as sources of competitive advantage, later versions of this theory also recognize that social sustainability efforts. That is why actions of Case I, such as employee training, all stakeholder engagement, training employees and protecting community wellbeing (Tata Steel Nederland, 2023- a) can form unique, valuable and difficult for other companies to copy resources. These special capabilities support NRBV theory, especially when they go

beyond legal requirements and are integrated into company's core strategy, boosting resilience and adaptability in the face of stricter regulations and shifting social pressures (Hart, Milstein, 1999; Hart et al, 2016). Similarly, Case III's goal of becoming the safest company in the industry (Salzgitter, 2025-b), combined with its open communication and strong social responsibility targets, also demonstrates these capabilities. The Banerjee and Gada (2023), who pointed out community contribution and improved worker safety as key social sustainability strategies in the steel industry, also complement and explains these results. The inclusion of the social dimension can also be explained by practical needs of today's steel industry. As the interviews showed, companies face problems associated with funding, technological and workforce changes. Studies confirms that socially responsible firms are better positioned to attract new talent, build trust with investors and handle both technological and environmental tensions (González-Rodríguez et al, 2015).

Digitization and Smart Sustainability Management

Notable and evident finding across all cases is the growing integration of various digital tools to meet climate goals. According to the interviews and secondary data, they do so to enhance environmental performance and supply chain efficiency. Example of that is Case II that mentioned their Smar Hot Rolling project that introduces virtual sensors and advanced models to optimize production of high-quality sheet. It also entails Tensil-Pro technology to calculate the stress-strain distribution and predict the evolution of microstructure, improving their energy efficiency and reducing greenhouse gas emissions. Overall, all analyzed companies, based on publicly available information sources, are reported to use cloud computing for data management (Apps Run the World, n.d.; SMS group, 2021; Marcegaglia, 2024- a). These Industry 4.0 practices enable SSCM in the companies, this is evident in Case IV incorporation of PSImetals in their mini-EAF that gives them more sustainable supply chain management (PSI Software AG., 2024) and align with work from 2020 (Mastos et al.). Overall, this behavior matches the concept of Dynamic Capabilities (Teece, 2007), where firms continuously adapt and reconfigure resources in response to shifting landscape they operate in. In the highly regulated and changing environment of high uncertainty (EUROFEAR, 2025), digital tools such as SAS Analytics for LoT or other LoT solutions like in Case I help European steel companies quickly manage risks, adapt (SAS, n.d., Tata Steel Nederland, n.d.-i) and therefore demonstrating the core principles of dynamic capabilities among big companies. This improves their agility in decision they make and contribute to the Triple-A supply chain principles (Lee, 2004) by enhancing adaptability, agility and alignment. The important traits for

firms responding to such steel dynamic market. This shows that steel industry is using more often smart sustainability strategies.

Sustainability objectives transform SCM practices

Findings of this study show that sustainability strategies are having a strong impact on supply chain management practices in the European steel industry. This is consistent with the literature overall about companies, which finds that integrating environmental and social goals into supply chains makes companies change how they select suppliers (Hutchins, Sutherland, 2008). Moreover, data presents that introducing sustainability objectives leads companies to make significant changes in how they work with other companies. For example, all the cases reported that environmental goals required them to change communication and collaboration both within their own organizations and with their suppliers (Table 6). Just as the literature describes logistic becoming so called integrator (Jørsfeldt, Hvolby, Nguyen, 2016) my data showed that logistic teams now play a key role in managing different departments and coordinating efforts with external partners meet sustainable targets. Many efforts of analyzed companies can be described as sustainability-oriented supplier development initiatives as described in paper from 2022 (Jia, Stevenson, Hendry, 2021) because companies are not only choosing suppliers based on their environmental compliance but also work with them through knowledge sharing.

Gathered gata show that firms adopt recognized sustainability certificated like BES 6001 to ensure the environmental and ethical compliance of sourced materials (Peiner Träger GmbH, n.d.). This refers to the article describing growing tendency among firms to use voluntary standards to enhance environmental but also social practices in their supply chains (Lambin, Thorlakson, 2018). Regarding the supply chain management, analyzed companies mentioned investments in rail logistic and mixed transport options, which demonstrate a move away from carbon-intensive distribution methods. Summing up, these actions support the development of agile and environmentally aligned supply chains that resulted from green vision of companies, consistent with triple a supply chain framework (Lee, 2004) and show how sustainability is embedded not only in production by EAFs but through the whole chain of European steel firms. Changes can be seen from production, logistic, transport up to new departments signaling that sustainability strategies made companies redesign almost every activity of their supply chain management (Table 8 and 9)

Challenges

All companies consistently reported significant financial barriers to investing in new technologies, renewable energy and staff, as well as balancing these costs with tight market margins and limited customer demand for green products, as outlined in Table 10. Such financial challenge is consistent with the work from 2021 (Muslemani, Liang, Kaesehage, Ascui, Wilson), which mentions the high cost of sustainable steel production and insufficient customer demand for its which affects firms significantly. These findings, directly relate to the Dynamic Capabilities framework (Teece, 2007), which outlines that firms constantly adapt and reconfigure resources in order to remain competitive in turbulent environment. Similarly, the NRBV (Hart, 1995), explains how firms seek competitive advantage by efficiently developing resources. For instance, Case I's idea of reinvesting revenue from declarations into future sustainability initiatives show the steel companies dedication to sense, seize and transform according to opportunity their operations to maintain competitiveness and reach their sustainable goals. Overall, these finding reflect a proactive and strategic response to ongoing financial challenges associated with sustainability transitions in the European steel industry.

Additionally, the gathered data in this study suggests that governmental policies and regulations in the EU are not perceived by analysed companies as challenge to implement sustainability strategies. Instead, these regulations are often described as a motivating force that accelerates the adoption of sustainable practices and drives innovation, particularly through mechanism like BAT and CBAM that are mentioned in Table 11. This finding aligns with feedback gathered by European Commission, which suggests that CBAM influence innovation positively (European Commission, 2021). At the same time, most of the companies expressed during interviews desire for better prepared and precise regulations, showing the need for clearer guidance, support from government and fair rules on European steel market. This finding supports literature on sustainable development in EU, which recognised the mixed role of regulation as both push to positive change and an area where critical improvement is needed (European Environmental Bureau, 2025). Other study highlight that inconsistences of the regulatory environment pose a barrier against circular strategy (International Chamber of Commerce, 2024).

Recommendations and Managerial implications

Based on identified financial challenge in the research several practical recommendations emerge for managers in the European steel industry. Firms should look for

ways to work together with businesses from other industries and find innovative ways to pay for sustainability project and gain that way competitive advantage like in the Case I. Digital tools can help companies minimalize waste and cost and respond more quickly to market changes. To properly use regulatory environment companies should continue to invest in best technologies but also engage proactively in possible with policymakers to be prepare and influence upcoming regulations. Additionally, companies should invest in customer and suppliers' education which can boost compliance and willingness to pay. European steel companies that want to develop sustainably should include circularity, decarbonization, digitization and social dimension into their strategy. By using these recommendations, managers can overcome current barriers and become leaders in sustainable supply chain management.

Future research

Future research about the European steel sector could involve a longitudinal study on how steel producers in the region adjust their sustainability strategies over time, particularly regarding net-zero targets set for 2030 and 2050. Such research could analyze how firms react to missing their climate goals. It could also investigate the consequences of unmet targets on investment attractiveness and reputational risk. Future research could also include greater number of analyzed firms from different continents to provide even more adequate insights valuable for whole steel industry.

6. Conclusion

The intention of this research was to examine sustainable development strategies and supply chain management practices adopted by major steel manufacturers in the European Union. It specifically focused on identifying which approaches are most commonly used today, understanding the challenges companies encounter in implementing these strategies and evaluating the overall impact on supply chain operations. The importance of this study is described in several articles that called for qualitative research that would analyze challenges and practices across different supply chains within the steel sector (de Oliveira et al., 2022; Xu, Yu, Hou, 2023). While some studies address specific technologies (Khalili-Fard, Sabouhi, Bozorgi-Amiri, 2024) or individual firms (Roy, 2025), few studies provide a broad, sector-wide and up to date perspective (Pinto, 2020) across multiple companies and countries to illustrate the overall state of steel industry. The closest to this research study is from 2019 (Pinto) also examining European steel industry, but since than the industry experienced war associated and Covid-related disruptions, as well as noticeable regulatory changes suggesting importance and timeliness of this research. Moreover, as the Caitlin Swalec, Program Director for Heavy Industry at Global Energy Monitor noted:

> The biggest steel producers are also the biggest culprits in terms of emissions. They must swap out coal-based processes for cleaner ones. But it's impossible to score if you don't know where the goalposts are. Ambitious and transparent targets are crucial. (LeadIT, 2023, para. 7).

This shows how important it is to set clear sustainability goals and share strategies openly. By showing what sustainable development strategies leading companies are using, my study helps companies study the green activities on the market and accelerate industry-wide transformation.

This study used in-depth interviews with representants of Marcegaglia, Salzgitter, SSAB and Tata Steel Nederland, as well as comprehensive industry overview. The data revealed that despite the steel industry's barriers such as high material cost and significant carbon emissions, big European steel companies are making progress towards sustainability. The research identifies four major types of sustainable strategies used by companies: circular steel making, decarbonization, social sustainability and digitization with smart manufacturing. Moreover, the research suggests that such strategies and green efforts require companies to fundamentally change their entirely their supply chain management practices including their transportation, partnership, logistic and production methods. The most significant challenge mentioned across all cases in implementing sustainable strategies turned out to be financial.

Interestingly, the regulatory environment played a dual role, while it pushes companies to faster and more transparent transition, its current form can also serve as a barrier.

In summary this study contributes to both academic and managerial practice by offering a context specific understanding of sustainable supply chain management in the European steel industry. The insights gained present the importance of mixed approach that combines technological innovation, circular thinking, social aspect and emphasized decarbonization objective in sustainable strategies. For practitioners this research recommends prioritizing the development of standardized sustainability metrics, investing in digital solutions and fostering deeper collaboration across the supply chain. Ultimately, while the path to sustainability in the steel sector is complex and ongoing, the sector's proactive strategies and willingness to transform place it as a key player in advancing Europe's sustainability agenda and building more responsible industrial future.

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Appendix

Appendix 1.
The interview questions with themes.

THEME 1 – Sustainable Development Strategies in the steel industry

Q1. Has your company introduced and sustainable strategies? If so, which ones?

- How were these strategies selected?
- What sustainability problems do these strategies address?

Q2. Are there any sustainability strategies your company has implemented within its supply chain?

Q3. Does your company collaborate with suppliers to improve its sustainable strategies? If so, how?

Q4. Has your company introduced any new technologies to support its sustainable strategies? If so, what kind of technologies?

THEME 2 – Impact of Sustainable Strategies on Supply Chain Management

Q5. Have your company's sourcing or logistic decisions changed in response to sustainability efforts? If so, how?

Q6. Do your sustainability strategies affect production planning or operations?

THEME 3 – Challenges in Implementing Sustainability Strategies

Q7. What challenges, if any, does your company associate with transforming to more sustainable supply chains?

Q8. Have government regulations or industry standards affected your company's sustainability efforts? If so, how and which?