A COMPARISON BETWEEN CIRCULAR ECONOMY AND PRODUCTION MANAGEMENT IN THE METALLURGICAL INDUSTRIES OF THE EUROPEAN UNION AND CHINA

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Abstract

The Circular Economy concept aims to minimize waste, increase material efficiency, and reduce primary resource consumption. This paper compares circular economy and production management strategies in the metallurgical industries of the European Union and China. The metallurgical sector faces global challenges such as environmental degradation, unsustainable development, and resource depletion. This study analyzes how the EU and China address these issues through different policy and industrial models. After reviewing available sources and extracting the key points, the findings reveal that China applies a top-down, government-driven approach focused on resource security and large-scale industrial restructuring under the 14th Five-Year Plan. However, it struggles with overcapacity and high emissions. China is improving production management through smart manufacturing and increased scrap utilization. In contrast, the EU employs market-based instruments and supranational policies, including carbon pricing, emphasizing high recycling rates, effective waste management, and low-carbon technologies such as electric arc furnaces (EAF) to reduce CO2 emissions. The main contribution of this paper is a structured comparative analysis of two distinct circular economy models in the metallurgical industry. The results show that while both regions are moving toward sustainability, their political and economic pathways differ significantly. Each model has advantages and limitations. The paper concludes that enhanced international cooperation and knowledge sharing are essential for a more sustainable global metallurgical sector.

Keywords: Metallurgical industry, circular economy, production management, European Union, China

1. INTRODUCTION

The metallurgical industry and steel sector are foundations of economic development worldwide [1]. Steel is widely used in automotive, oil and gas, petrochemical, construction, machinery, electronics, packaging, and renewable energy industries. This sector is one of the most resource- and energy-intensive sectors, contributing significantly to greenhouse gas emissions. The metallurgy and steel sectors account for 7% of the energy industry's CO2 emissions, making them responsible for helping address climate change challenges [1].

Climate change, geopolitical competition, wars, and resource scarcity have pressured countries to rethink circular economy and production management policies. The traditional linear “take-make-dispose” model is no longer considered environmentally or economically sustainable, especially given unstable resource prices. The circular economy centers on separating economic growth from resource use by reducing waste, optimizing resource efficiency, and ensuring that products and materials remain in use at their highest possible value for as long as feasible [2]. In parallel, production management aims to optimize manufacturing processes to increase productivity, efficiency, and quality.

This article focuses on the metallurgical industries of the two largest economies: the European Union (EU) and China. The EU has a strong regulatory framework and has implemented the principles of the circular economy for years. China, as the world's largest steel producer and consumer, has to overcome issues, such as industrial overcapacity, severe environmental pollution, and rapid modernization. These challenges shape how each economy implements circular economy principles and improves production management. The strategies adopted by the EU and China illustrate their different paths towards a sustainable metallurgical industry.

Given this context, the main research question guiding this study is: How do the governance frameworks, policy instruments, and industrial strategies of the EU and China shape their respective approaches to circular economy and production management in the metallurgical industry? And what are the implications of these differences for global sustainability? Accordingly, the specific objectives of this paper are: (1) to critically compare the circular economy and production management policies of the EU and China in their metallurgical industries; (2) to identify the key strengths and limitations of each model; and (3) to draw conclusions regarding the potential for cooperation and mutual learning between the two regions, thereby contributing to a deeper understanding of how global sustainability in the steel sector can be advanced.

2. METHODOLOGY

This study is presented as a narrative literature review due to the broad and interdisciplinary nature of the topic and the aim to provide a comprehensive comparative overview of the current state of circular economy and production management in the EU and China. The review draws on reliable, publicly available sources, including peer-reviewed academic articles, theses, sustainability reports of reputable companies, and official documents from the European Commission, Chinese ministries, and industrial organizations. Sources were selected based on their relevance, credibility of the issuing institutions, and timeliness, with preference given to peer-reviewed academic literature and official policy documents published within the last ten years. Keywords used in the literature search included: "circular economy," "linear economy," "environmental degradation," "metallurgical industry and economy of EU member states and China," "processes and production management in the EU and China," "resource depletion," "electric arc furnaces," "scrap steel," and "steel industry development in the EU and China." Through a structured thematic review and using comparative analysis, all sources were examined and organized around key thematic areas. This approach enabled the clarification of the similarities and differences between the EU and China regarding their circular economy strategies and production management practices. Given the narrative and qualitative nature of this review, the paper aims to identify major patterns, policy synergies, and practical divergences between the two regions.

3. RESULTS

3.1. The European Union

3.1.1. Circular economy in the EU metallurgical industry

The application of circular economy principles in the EU is underpinned by strict environmental laws and regulations, aiming to transition the steel and metal industry toward a more sustainable future. It is crucial for the EU steel sector to reduce import dependence and accelerate sustainable development by lowering environmental impacts [3].

The European Union has prioritized increasing its production circularity rate. Currently, more than half of the steel produced in the EU is made from recycled scrap. Europe is the world's largest exporter of this material, sending roughly 20% of what it produces to destinations outside the EU. At the same time, there is growing

pressure to retain high-quality scrap metal within the EU [4]. To achieve this, the European metallurgical industry is investing in improved sorting and processing methods, more transparent classification systems for scrap metal, and more efficient use of scrap [5]. The EU hopes to unlock 20 to 40 million tonnes of high-quality scrap annually [5]. This would allow member states to use more domestic resources and ensure that recycled steel meets higher standards for advanced manufacturing, particularly in quality-sensitive industries such as automotive.

The findings indicate that increased scrap use in the EU reflects a significant shift from blast furnaces to electric arc furnaces (EAFs). Old blast furnaces are coal-fired and highly carbon-intensive, while EAFs emit approximately three times less greenhouse gases per tonne of steel [1, 5]. To support this shift, policy measures include early-warning systems to detect supply shortages, quality grading of scrap metal to enhance market transparency, and the use of green public procurement to boost demand for high-quality recycled steel [5]. These circular economy efforts could reduce between 64 and 81 million tonnes of CO_2 per year, making a significant step towards the EU's sustainable development and climate goals [3].

3.1.2. Production management in the EU metallurgical industry

The European Union metallurgy industry plays a key role in economic growth, employment, and innovation [6]. It produces more than 177 million tonnes of steel annually, approximately 11% of global production, making the EU the world's second largest steel producer after China [6]. However, the industry faces challenges such as raw materials and energy costs, strict environmental regulations, and competition from non-EU producers [6]. The EU steel production has declined by more than 30 million tonnes since 2018, with nearly 30,000 jobs lost [4].

To mitigate these challenges, the European Commission has implemented a comprehensive action plan. EU funds and policy instruments such as Horizon 2020, Structural Funds, and the Research Fund for Coal and Steel help reduce social costs and maintain skills for the future competitiveness of the industry. EU legislation provides an essential regulatory framework for sustainable development, internal market functioning, investor confidence, and a level playing field for the steel industry [6]. Steel demand depends on key consuming sectors like construction and automotive. To ensure growth and recovery in these sectors, the EU promotes growth-oriented policies, sustainability measures, and efficiency improvements [6]. Internationally, the EU participates in trade liberalization under the World Trade Organization (WTO) and through bilateral Free Trade Agreements (FTAs) to ensure fair competition [6].

The coal-based oxygen blast furnace (BF-BOF) still accounts for more than half of EU steel production [5], but the EU is a leader in innovation for net-zero emission steelmaking, including large-scale hydrogen-based Direct Reduced Iron (DRI) projects [7, 8]. Digital transformation, including the Internet of Things (IoT) and artificial intelligence, is playing a key role in improving efficiency and competitiveness in the European steel industry [9].

3.2. China

3.2.1. Circular economy in China metallurgical industry

China's steel industry has the world's largest production capacity. While this is an advantage, China also faces internal and external challenges, including overcapacity and high greenhouse gas emissions. Overcapacity is worsened by several important factors, such as weakened domestic consumption, intensifying price pressure in international markets, and trade conflicts with other major steel-exporting nations [10]. In response to these challenges, China has developed a strategic plan outlined in the 14th Five-Year Plan or 14FYP [11] for the Circular Economy (2021-2025). This plan provides an effective policy framework to significantly improve resource efficiency in industrial sectors, including iron and steel [10]. The operational and implementation support for this framework is provided by key policies such as the Special Action Plan for Energy Conservation

and Carbon Reduction in the Steel Industry and the national Trade-in Program [10], which Chinese government released in late May 2024. These measures are implemented through strengthening capacity regulation and output management and transitioning to Electric Arc Furnaces (EAFs) [10]. China aims to increase EAF steel production from the current 10% to 15%, as these furnaces are crucial for decarbonization of China's industries. This goal depends heavily on securing sufficient supply of scrap steel [10, 12].

The Trade-in Program serves two important roles. First, it boosts scrap steel recycling through trade-ins of old equipment and consumer goods such as vehicles and household appliances. Second, it stimulates demand for new, more sustainable products and provides a market for excess steel [10]. This program helps secure scrap supply for expanding electric arc furnaces capacity. Moreover, external pressures, particularly the European Union's Carbon Border Adjustment Mechanism (CBAM), are forcing China to accelerate its decarbonization efforts. Thus, expanding domestic scrap production and significantly increasing its use for secondary steelmaking are critical priorities for China [10, 13].

3.2.2. Production management in China metallurgical industry

As noted, China's metallurgical industry consistently faces the challenge of overcapacity, rooted in massive government incentive programs that led to significant production gluts [10].

China's steel industry also struggles with other issues, including high labor costs, substantial carbon emissions, a low level of automation, poor production efficiency, and inconsistent quality control [14]. As domestic demand, especially in real estate and infrastructure sectors, has declined, overcapacity has forced Chinese steel producers to continuously increase steel exports, at lower prices, exacerbating trade tensions with other steel-producing countries [10]. Heavy reliance on traditional blast furnaces makes the steel industry China's second largest carbon emitter and a major barrier to its decarbonization goals [10].

In response, China has launched several large-scale intelligent manufacturing initiatives. These initiatives are strategically designed to enhance production efficiency, improve product quality, reduce manual labor demands, lower production costs, shorten product development cycles, and optimize overall working conditions for employees [14]. These initiatives integrate manufacturing with "modern information technologies, including 5G, digitalization, networking, and artificial intelligence (AI)" [14]. China aims to transform its traditional mass production model into one that is more customized, adaptable, and responsive to customer needs [14]. It has also defined the Steel Industry Work Plan (2025-2026), which sets out strategies to stabilize raw material and fuel supplies, accelerate key technology projects, and support low-emission capacity development, aiming to reduce overall steel production and systematically reduce overcapacity [10]. Together, these measures reflect China's efforts to modernize and optimize its production management across the entire value chain toward a more sustainable and high-quality development path.

4. COMPARATIVE ANALYSIS AND DISCUSSION

This section moves beyond description to offer an analytical comparison. The main contribution of this paper is to identify not only what each region does, but why their approaches differ and what that implies for global sustainability. The core similarities between the EU and China are that both are pursuing a transition toward a more circular metallurgical industry, both are prioritizing increased scrap utilization and EAF adoption, and both are leveraging digital technologies for production optimization. However, the key differences lie in their governance models, policy instruments, and the pace of change. These are not merely variations in degree but fundamentally different logics of governance and industrial transformation: a regulatory-market system (EU) versus a state-capacity system (China). **Table 1** summarizes the core comparative findings:

Table 1 Comparative findings between European Union and China

Analytical dimension	European Union	China
Key driver	climate leadership, market creation	resource security, pollution control
Governance framework	supranational regulation, market incentives	top-down governmental planning, direct mandates
Key policy instrument	carbon pricing, circular economy action plan	five-year plans, ultra-low emissions standards
Scrap metal and recycling	high-quality market, high EAF share	rapidly growing domestic scrap reserve, rapidly expanding EAF share
Key strengths	Predictable regulations, high-quality innovation, mature recycling markets	speed of implementation, high rate of investment
Key challenges	high transition cost, global competitiveness under carbon costs	coal-based infrastructure, balancing economic growth with environmental goals, data transparency

Analytical insight: The EU follows a market-driven approach, using regulations to generate demand for green steel. In contrast, China adopts a government-led model, where the state allocates resources and imposes transformation. The EU benefits from well-established institutions, while China capitalizes on administrative efficiency and large-scale execution. Neither model is superior; rather, their effectiveness depends on local economic and political situations, and industrial maturity. The EU has chosen a regulatory framework that uses environmental policies to create a market for green products, trying to implement an independent circular economy model. China employs a top-down government approach to mobilize all resources and implement rapid, large-scale industrial changes. This fundamental distinction has practical implications: the EU's approach is more suitable for incremental, innovation-driven improvements in a stable institutional environment, whereas China's model enables rapid, structural shifts but risks inefficiencies and environmental trade-offs in the short term. This difference is exemplified by the EU's reliance on carbon pricing and market signals to steer investment, whereas China uses direct state mandates and national plans to enforce change. These contrasting logics also shape their respective challenges: the EU struggles with high transition costs and global competitiveness, while China faces the legacy of heavy coal-based infrastructure and the tension between economic growth and environmental goals. Mutual cooperation between the EU and China is important, but currently underutilized. The EU CBAM pressures Chinese exporters to reduce their carbon footprint, while China’s production scale can significantly lower global costs of green technologies such as electric arc furnaces. A key finding of this paper is that these two approaches are not in conflict, but potentially complementary: the EU provides demand-side incentives and technological standards, while China provides large-scale supply capabilities and rapid implementation.

A deeper interpretation of the data reveals that the EU's higher EAF share (44.4% vs. 10.2% in China) is not solely a result of policy ambition but also reflects the EU's limited domestic iron ore reserves and historically higher labor and energy costs, which made scrap-based steelmaking economically attractive earlier. In contrast, China's vast domestic coal and iron ore resources, combined with rapid urbanization, created strong incentives for BF-BOF expansion. Thus, the observed differences are path-dependent and rooted in resource endowments and historical development trajectories, not just policy choices. This insight suggests that while China can learn from the EU's regulatory instruments, its transition pathway will necessarily differ due to its unique structural conditions. This complementarity suggests a pathway for international cooperation that could accelerate the global transition to a circular metallurgical industry. **Table 2** presents comparative statistics.

Table 2 Comparative statistics between European Union and China

Items	European Union	China
Share of steel production via EAFs (EAFs, %) [15]	44.4%	10.2%
Scrap utilization (million tonnes) [16]	56.3	142.2
CO2 emissions intensity (per tonne of steel) [17, 18]	1.6-2.0 tonnes	2.0-3.0 tonnes

Interpretation: Despite a lower EAFs share, China's total scrap utilization is much higher due to its massive production volume. However, its CO2 intensity remains higher, suggesting that both technology mix and process efficiency could be improved. The gap in EAF share (44.4% compared to 10.2%) is the most notable structural difference and accounts for a large portion of the gap in emissions. Nevertheless, this does not imply that the EU model is inherently superior; rather, it reflects different starting points and strategic priorities. China's rapid scaling of EAF capacity, albeit from a low base, demonstrates its capacity for fast technological catch-up. This structural gap highlights that China's transition will require not only technological upgrades but also a fundamental shift in its energy mix and industrial policy focus.

Another critical comparative finding is that while both regions aim for carbon neutrality, the EU prioritizes high-quality recycling to reduce import dependency, whereas China utilizes its massive industrial scale to lead in secondary steelmaking capacity expansion.

5. CONCLUSION

This comparative study contributes a clear analytical distinction between the EU and China. The research question—how governance frameworks, policy instruments, and industrial strategies shape each region's approach—has been addressed by demonstrating that the EU's regulatory-market system and China's state-capacity system lead to divergent but internally consistent pathways. The EU's circular economy model is characterized by a mature economic outlook and strong environmental governance rooted in an industrial policy framework [19]. Resource efficiency, high-quality recycling, and market-based incentives form the strategic basis of the EU's approach. A significant increase in the use of Electric Arc Furnace (EAF) technology and advanced scrap management are key success factors, supported by regulatory measures and investments. The EU emphasizes reducing its environmental footprint and strengthening strategic autonomy by reducing import dependence.

On the other hand, China, the world's largest steel producer, is undergoing a complex transition to curb overcapacity, reduce severe environmental pollution, and upgrade technology. These changes are driven by strong government policy initiatives. China's circular economy is directly linked to reducing greenhouse gas emissions while sustaining economic development. The main difference, as identified in this analysis, lies in governance logic: the European Union follows a gradual, market-driven, and regulation-based path for its circular economy, whereas China's transformation is defined by rapid, large-scale, top-down changes driven by government policy, such as electric arc furnaces adoption and smart manufacturing.

The paper's main contribution is to show that both the EU and China are moving toward a more sustainable, technologically advanced, circular metallurgical industry, but their strategic definitions, economic structures, and policy frameworks differ fundamentally. A novel finding is that these differences are not merely matters of degree but represent distinct system archetypes: a regulatory-market system versus a state-capacity system. This finding is significant because it suggests that policy transfer or emulation between the two regions would be challenging without accounting for deeper institutional and political contexts. For long-term success, both must balance economic profitability with environmental impact reduction and social justice. The findings further indicate that the EU's regulatory instruments, such as carbon pricing and green public procurement, could be adapted to the Chinese context, albeit with modifications to account for China's state-led governance structure.

Conversely, China's experience with rapid industrial policy implementation offers lessons for the EU in accelerating infrastructure investment and technology deployment. Therefore, enhanced international cooperation, sharing of best practices, and development of common standards for circularity and advanced production management are essential for a truly sustainable global metallurgical industry. Both the EU and China play critical and complementary roles in creating a circular future for steel production.

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