



Impact Analysis of Differentiated Electricity Pricing on Production Costs and Competitiveness in Steel Enterprises

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Abstract. In the early 21st century, China approached the final phase of its heavy and chemical industrialization, marked by excessive blind investments in energy-intensive industries and redundant, low-efficiency projects. These practices triggered a surge in energy consumption and exacerbated environmental pollution. Against this backdrop, the differentiated electricity pricing policy emerged as a critical instrument to drive industrial restructuring through price leverage, balancing economic growth with ecological protection. By examining electricity expenditure and production technology adaptations across steel companies, tracking the evolution of China's differentiated electricity pricing policy, and analyzing strategies adopted by global steel industry leaders to address similar policies, this study synthesizes the impacts of differentiated electricity pricing on steel enterprises. It provides actionable recommendations for their sustainable development.

Keywords: Differential Power Prices, Steel Production Cost, Waste Heat Utilization, Production Process, Energy Saving, Green Transformation

1 Introduction

China is the world's largest steel-producing country, with its total steel production output being substantial, as illustrated in Figure 1. However, the Chinese steel industry faces severe challenges in energy consumption and environmental pollution. The energy structure of China's steel industry is dominated by coal and coke, resulting in significantly higher energy consumption per ton of steel and carbon emission intensity per ton of steel compared to international levels [1].

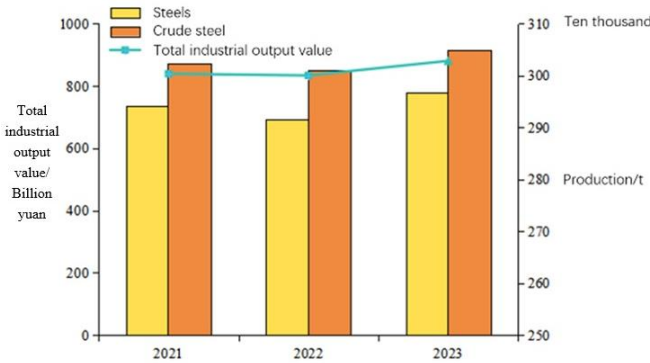


Fig. 1. Gross Domestic Product and Production of China's Steel Industry from 2021 to 2023
Source: Created by the author

In June 2004, the Chinese government first implemented a differentiated electricity pricing policy to curb the unchecked expansion of high-energy-consuming and high-pollution steel industries. The core elements of China's differentiated electricity pricing policy include classification standards, surcharge mechanisms, and implementation scope. The differentiated electricity pricing policies in some developed countries differ from China's in pricing mechanisms and primary objectives, as illustrated in Table 1. However, such policies across nations share common features, such as leveraging market-oriented tools, adopting combinations of time-of-use, seasonal, and tiered electricity pricing, and aligning closely with power market reforms.

Table 1. Comparison of differential electricity pricing policies among the United States, Japan, Germany, and Sweden Source: Created by the author

Country	Pricing Mechanism	Main Goal
America	Four types of electricity prices: 1. time of use electricity price, 2. seasonal electricity price, 3. user category electricity price, 4. socially oriented electricity price	Transfer 24% of summer peak load through peak valley price difference to optimize power grid operation
Japan	Three levels of electricity consumption: 1.0-120 kWh, 2.121-300 kWh, 3.>300 kWh	Regulating electricity consumption behavior and optimizing energy efficiency
Germany	Yellow electricity price, green electricity price	Reduce peak demand
Sweden	The dual dimensional price difference between day/night and summer/winter	Promote staggered production

Steel production costs primarily consist of raw materials, energy, and labor. Among these, raw material costs account for the highest proportion (over 60%), followed by energy (15–30%), while labor costs vary significantly depending on a country's development level. Additionally, international research often employs comprehensive indicators to assess the competitiveness of steel enterprises, such as asset scale, operational efficiency, technological innovation, and environmental performance [2].

Existing research has several shortcomings. First, methodological limitations: current studies predominantly rely on static analyses and historical data, lacking predictive models for dynamic factors. The second shortcoming is uneven data coverage and short time spans. The third is neglecting emerging competitive elements, such as green competitiveness, which has not been sufficiently integrated into evaluation frameworks.

This study reviews extensive literature and data, analyzing relevant cases. It begins by delineating the intent and purpose of differentiated electricity pricing, then examines its impact on steel enterprises, and finally provides strategies and recommendations for the sustainable development of the steel industry.

2 Overview of Differential Electricity Pricing Policies

2.1 The concept and categories of differential electricity pricing policies

As an energy-intensive industry, steel production consumes substantial resources and generates significant pollution, posing threats to sustainable economic development. China categorizes steel enterprises into three classifications—obsolete, restricted, and excess capacity—based on their energy consumption levels and environmental compliance. These designated categories are subject to electricity rates exceeding standard tariffs. The core objectives of implementing differential electricity pricing include phasing out outdated production capacity, promoting technological upgrading, and alleviating energy supply-demand imbalances while achieving energy conservation, emission reduction, and enhanced industrial concentration [3].

The Chinese government categorizes its differential electricity pricing policies into three primary types based on distinct policy objectives and technical pathways.

Type 1: Energy Consumption-Based Pricing

This policy enforces electricity surcharges to compel technological upgrades or market exit in energy-intensive industries. Enterprises employing nationally prohibited obsolete technologies/equipment, or those with excess capacity and substandard energy efficiency are classified as "obsolete" or "restricted" categories, facing substantial tariff increases [4]. As of 2024:

- Obsolete category: Surcharges of 0.3-0.8 CNY/kWh
- Restricted category: Surcharges of 0.1-0.5 CNY/kWh

Enterprises exceeding energy consumption limits are subject to tiered pricing with penalty tariffs—those surpassing limits by over 100% are charged at obsolete category rates. Conversely, enterprises compliant with national industrial

policies and energy efficiency standards are designated as "permitted" or "encouraged" categories, eligible for standard tariffs or subsidies.

Type 2: Environmental Performance-Based Pricing [5]

To reduce hazardous emissions, steel enterprises implementing environmental protection measures receive preferential rates—e.g., 0.015 CNY/kWh desulfurization electricity subsidies. Those achieving ultra-low emission standards ($\leq 10 \text{ mg/m}^3$ particulate matter) obtain tariff incentives. Conversely, enterprises with low resource efficiency ($< 60\%$ material utilization rate) or in high-pollution industries face canceled subsidies and enhanced surcharges (up to $1.2\times$ base rates).

Type 3: Time-Differentiated Pricing

China implements a four-tier temporal segmentation:

- Peak: $3.8\times$ off-peak rates (e.g., 1.52 CNY/kWh vs 0.40 CNY/kWh)
- High-demand: $2.1\times$ off-peak rates
- Normal: Base rate
- Off-peak: Reference rate [6]

This time-of-use pricing balances grid load (reducing peak demand by 12-18%), enhances renewable energy integration (increasing utilization by 8-15%), and optimizes energy consumption patterns [7]. Seasonal pricing adjusts rates by $\pm 20\%$ based on regional climate variations, while real-time pricing reflects hourly market fluctuations ($\pm 30\%$ from baseline). The implementation of the time-of-use electricity pricing policy has led to significant shifts in electricity consumption patterns within steel enterprises, as depicted in Figure 2.

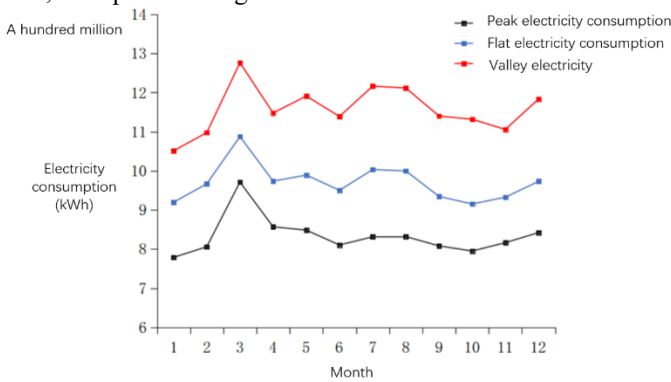


Fig. 2. Changes in annual electricity consumption of steel enterprises under time of use electricity pricing Source: Created by the author

2.2 Current implementation landscape of differential electricity pricing policies in china

China initiated a trial of the differentiated electricity pricing policy in 2004, followed by continuous refinement and expansion from 2006 to 2020. Since 2021, the policy has matured and aligned with carbon neutrality goals. Its current scope now extends beyond

traditional energy-intensive industries like steel to include high-pollution sectors such as ceramics and glass, alongside a more rational and effective dynamic adjustment mechanism.

Significant electricity surcharges have sharply raised production costs for elimination-category and restriction-category enterprises, accelerating the exit of outdated small and medium-sized (SME) capacities. Funds generated from the policy are earmarked to support energy-saving and carbon-reduction projects. Governments offer substantial incentives to enterprises completing ultra-low emission retrofits, promoting advanced low-emission technologies like short-process electric arc furnace steelmaking. For instance, Hebei Province allocated differentiated electricity pricing revenue to support ultra-low emission upgrades in 2024, raising the retrofit rate from less than 30% in 2017 to over 80% by 2023. Simultaneously, the policy has eroded the viability of private SMEs, while large state-owned enterprises (SOEs) have demonstrated greater cost resilience due to economies of scale and technological advantages, leading to production capacity concentration among industry leaders. With local government support, steel enterprises are relocating to resource-rich coastal industrial clusters, optimizing regional capacity distribution.

3 Cost Impact and Market Response

3.1 Effects of differential electricity pricing policies on manufacturing costs of steel enterprises

Electricity costs constitute a significant portion of steel production expenses, typically accounting for approximately 30% of total costs according to multiple studies. With the refinement of classification criteria and increased surcharge rates under China's differential electricity pricing policy, steel enterprises face progressively rising electricity expenditures, directly driving up overall production costs [8]. This has heightened cost sensitivity per ton of steel across the industry. Medium and small-scale steel mills, characterized by high grid dependency (approximately 72% purchased electricity) and lacking captive power plants, exhibit even greater cost vulnerability. These enterprises experience sharper declines in per-ton profit margins, compelling their gradual market exit and generating a marginal displacement effect on outdated production capacities [9].

Steel enterprises are classified by scale: those with an annual output exceeding 1 million tons are categorized as large enterprises, while those below 1 million tons are classified as small and medium-sized enterprises (SMEs). Large steel enterprises typically have self-owned power plants or secure electricity prices through long-term agreements, with electricity costs accounting for 8%-10% of total expenses. When an elimination-class surcharge of 0.5 yuan/kWh is imposed, the cost per ton of steel increases by approximately 50 yuan (based on 466 kWh of electricity consumption per ton). However, SMEs rely heavily on external electricity purchases, with electricity costs reaching 15%-30% of total expenses. The elimination-class surcharge raises their cost per ton by 120-232 yuan, increasing the cost proportion by over 9%. SMEs that fail to complete environmental upgrades also face punitive electricity prices of 0.1-0.5

yuan/kWh, leading to additional cost increases of 43-215 yuan per ton. Consequently, SMEs experience greater declines in profit margins and higher risks of losses. By production process, steel enterprises are divided into long-process and short-process categories. The blast furnace-converter route, widely used in long-process enterprises, consumes 450-470 kWh per ton of steel, resulting in a cost increase of around 50 yuan/ton under the surcharge. Short-process enterprises, which rely on electric arc furnaces (EAFs), consume 500-700 kWh per ton, leading to cost increases of 90-120 yuan/ton. Medium-frequency furnace enterprises are hit hardest, with cost surges of up to 20%, forcing many to exit the market.

The differentiated electricity pricing policy imposes tiered surcharges to directly raise power costs for high-energy-consuming and inefficient capacities, creating significant cost pressures. This forces enterprises into a dilemma: exit the market or adopt technological upgrades and energy-saving measures to reduce consumption and avoid high tariffs. Funds generated from higher tariffs are primarily used to support steel enterprises in implementing energy-saving retrofits, incentivizing technological advancements to lower energy use, reduce electricity expenses, and enhance economic efficiency, as illustrated in Figure 3. By targeting production costs, this policy drives supply-side structural reform and high-quality development in the industry, promoting greener and low-carbon practices.

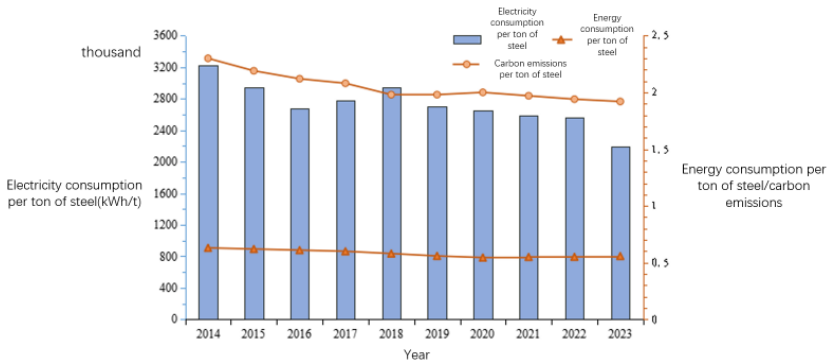


Fig. 3. Energy consumption of China's steel industry from 2014 to 2023 Source: Created by the author

Steel enterprises can implement four main pathways for technological upgrades and energy conservation. First, process optimization and equipment upgrades: Adopting short-process steelmaking (e.g., replacing blast furnaces with EAFs) reduces energy consumption by 50% and carbon emissions by 55% [10]. Compared to long-process steelmaking, short-process steelmaking demonstrates higher efficiency and superior environmental performance, as illustrated in Figure 4. Waste energy recovery technologies, such as dry coke quenching (saving 59.68 kg CO₂/ton and lowering costs by 261.9 yuan/ton) and converter gas power generation (unit emission reduction cost: 366.3 yuan), improve energy efficiency. Intelligent retrofits, including online energy monitoring systems and AI-driven process control, aim to achieve 80% digitalization of key processes by 2025. Second, energy structure optimization: Using coke oven gas

for hydrogen and LNG production reduces fossil fuel reliance while increasing self-generated power via waste heat recovery cuts external electricity costs. Third, standardized operations: For example, optimizing LF refining (e.g., precise alloy ratios) reduces refining costs by 11.37 yuan/ton. Fourth, circular economy: Recycling scrap steel (raising scrap ratios above 30%) lowers iron ore costs, and reusing hot slag as flux reduces auxiliary material consumption. These complementary measures ensure the effectiveness of differentiated pricing policies.

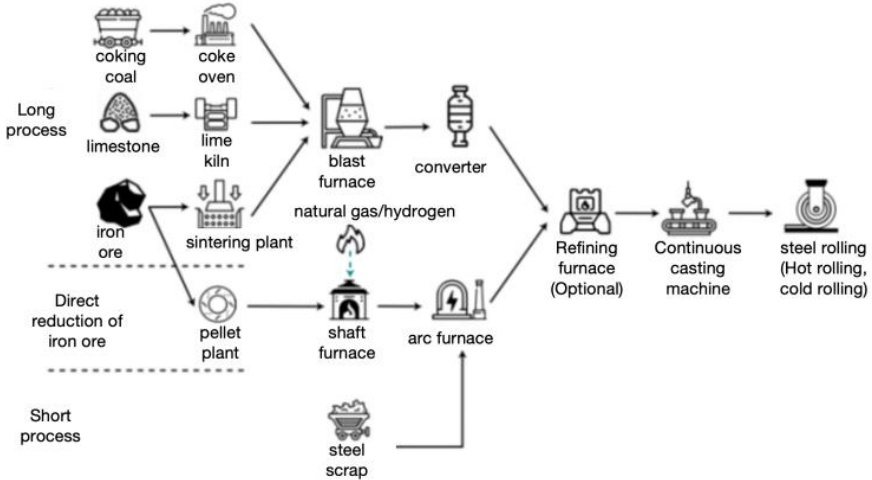


Fig. 4. Schematic diagram of long and short process production processes for steel Source: Created by the author

3.2 Effects of differential electricity pricing mechanisms on cost-driven competitive edge in the steel industry

The steel industry is a quintessential energy-intensive sector, with the proportion of electricity costs varying significantly across production processes, as shown in Table 2 [11]. For instance, the medium-frequency furnace process exhibits the highest electricity-cost ratio, which accelerates the elimination of obsolete production capacities. This demonstrates that differentiated electricity pricing policies impose direct cost pressures on steel enterprises, compressing the survival margins of low-profitability manufacturers. Consequently, this drives a structural realignment in the market landscape. Large-scale enterprises, particularly state-owned steel mills, leverage self-owned power plants and economies of scale to reduce average costs, thereby consolidating market share and reinforcing their competitive advantages. Conversely, numerous private small and medium-sized steel producers have exited the market due to prohibitive electricity expenses [12].

Table 2. Energy structure and proportion of electricity cost for different processes [11]
 Source: Mukherjee, A., Basu, S. N., & Saya, S. (2023). A Review on Energy Efficiency of Steel Plants in India. *Journal of Cleaner Production*, 135(3), 45-54.

Process Type	Characteristics of Energy Structure	Proportion of Electricity Cost
Electric Furnace—Converter	Mainly coal (coke accounts for 58.9%)	5%
Arc Furnace	Electricity accounts for 20% of energy input	7.97%

To enhance competitiveness, steel enterprises adopt four strategies: (1) developing high-value-added products (e.g., radiation-resistant steel) [13]; (2) deploying breakthrough technologies (e.g., FINEX); (3) establishing market-driven innovation mechanisms; and (4) transitioning to green materials (e.g., hydrogen-based steel).

3.3 Effects of differential electricity pricing regimes on the market competitiveness of steel industry products

Electricity cost fluctuations significantly affect steel product prices and quality. Rising tariffs increase production costs, which are passed downstream via price hikes. A German study found that a 5% electricity price increase led to a 16% demand drop and an 18% output reduction. Similarly, Chinese enterprises may resort to off-peak production or shutdowns to cut costs, but unstable power supply risks disrupting production continuity and product quality. Cost pressures also force firms to optimize processes, potentially phasing out energy-intensive methods and indirectly affecting quality.

Within the total carbon emissions from steel production, fossil fuel-related emissions account for the largest proportion, as illustrated in Figure 5. As global carbon neutrality goals advance, the steel industry must transition from fossil fuels to renewables. However, this shift introduces cost volatility. For example, UK-based hydrogen-based green steel production faces far higher electricity costs than conventional methods. Rising power costs not only affect steel production but also propagate downstream via supply chains. Prices of auxiliary materials like ferrosilicon and silicomanganese, heavily influenced by electricity costs, further impact final steel product prices.

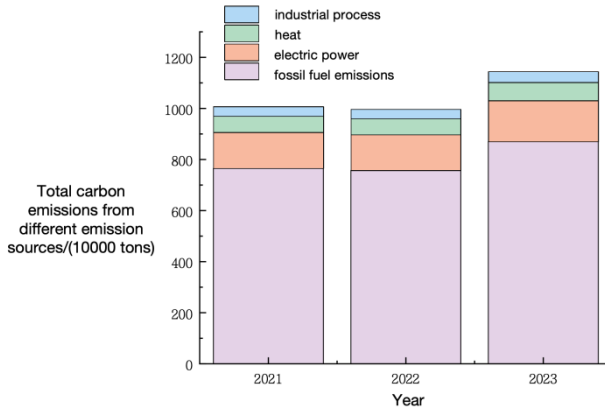


Fig. 5. The total amount and proportion of carbon emission sources in China's steel industry from 2021 to 2023 Source: Created by the author

To boost product competitiveness, steel enterprises adopt several strategies. First, product innovation: Developing high-value-added products (e.g., radiation-resistant steel for nuclear plants, high-toughness hot-stamping steel for automotive lightweight, and corrosion-resistant Al-Zn-Mg coated steel) replaces imports and extends profit margins by 30%-50%. Second, technological breakthroughs: Innovations like FINEX (using iron ore fines to cut investment by 20% and emissions by 30%) and thin-strip casting (reducing energy use by 50% via single-step forming) enhance efficiency. Third, market-driven R&D: Demand-driven customization ensures product stability and brand value. Fourth, sustainable ecosystems: Transitioning to green materials—such as hydrogen-based zero-carbon steel (e.g., HYBRIT) and recycled scrap steel—aligns with ESG trends and secures carbon tariff benefits [14].

4 Strategic Suggestions for Steel Enterprises

4.1 Enhancing energy governance to optimize energy utilization rates

As a policy instrument, electricity price adjustments can drive the steel industry to phase out obsolete production capacities and optimize its industrial structure through cost transmission mechanisms and market regulation effects.

Most Chinese steel enterprises currently grapple with contradictions between cost pressures and operational efficiency, a high-carbon energy structure, low waste heat recovery rates, and outdated management systems. Industry surveys indicate that 90% of China's steel sector relies on coal-based energy sources, with scrap-based electric arc furnace (EAF) processes accounting for merely 10% of total production, highlighting significant transition challenges. The industry's waste heat recovery rates remain below 50%, while its low-temperature waste heat utilization rate stands at merely 0.069%, reflecting substantial energy efficiency gaps compared to global benchmarks.

To strengthen energy management and enhance energy utilization efficiency, the primary step is to optimize the energy structure and reduce reliance on coal. This

involves advancing short-process steelmaking to increase the proportion of electric arc furnace (EAF) steel to 30%—the international average—while promoting scrap preheating technology and enhancing bath heat transfer efficiency through bottom-blown CO₂ injection. Deploying photovoltaic power generation on factory rooftops and integrating clean energy alternatives such as hydrogen metallurgy pilot projects can progressively reduce the share of coal and coke in energy consumption.

Furthermore, maximizing secondary energy recovery is critical. For instance, the cascade utilization of waste heat—such as high-temperature waste heat recovery via Coke Dry Quenching (CDQ) technology—can elevate annual benefits to tens of millions of yuan, while adopting Combined Cycle Power Plants (CCPP) improves power generation efficiency. However, the steel industry currently does not adequately recover and utilize waste heat and energy, as illustrated in Figure 6. This demonstrates that the Chinese government must still implement additional policies and enhance awareness among steel enterprises to improve the recovery rate of waste heat and energy.

Concurrently, an equipment-system-factory three-tier energy efficiency evaluation model should be established, leveraging digital twin technology to simulate and optimize energy recovery pathways. These integrated measures ensure systematic improvements in energy efficiency and sustainability across production processes.

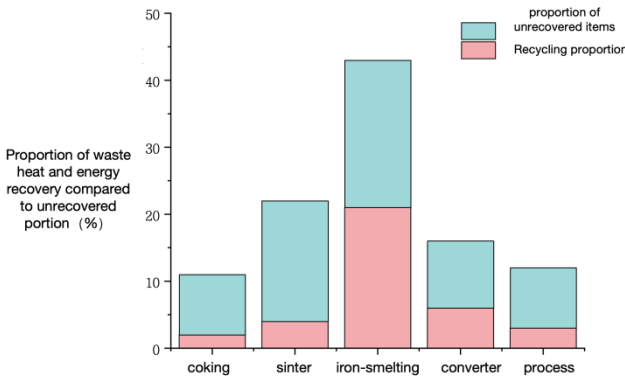


Fig. 6. Proportion of waste heat and energy recovery compared to the unrecovered portion
Source: Created by the author

4.2 Accelerate technical upgrading initiatives for cost optimization in manufacturing processes

The differentiated electricity pricing policy imposes an additional charge of RMB 0.5 per kWh on elimination-category facilities and RMB 0.1 per kWh on restriction-category facilities, posing significant cost-structure shocks to steel enterprises—particularly small and medium-sized electric arc furnace (EAF) steel mills reliant on purchased electricity. Steel production involves three critical stages: blast furnace ironmaking, steel rolling process [15], and short-process EAF steelmaking. Notably, the blast furnace ironmaking stage accounts for over 50% of the total energy consumption in the entire production process, while the steel rolling process consumes

a significant proportion of electricity usage. The short-process EAF steelmaking stage alone consumes approximately 600 kWh of electricity per ton of steel produced. These three stages collectively account for a substantial portion of production costs.

Therefore, critical equipment upgrades and process innovations are imperative. Optimization of blast furnace systems and retrofitting of steel rolling processes can effectively reduce costs and enhance the competitiveness of steel products. Process restructuring and energy structure optimization also represent a vital development direction. Steel enterprises should vigorously promote short-process electric arc furnace (EAF) steelmaking while phasing out long-process methods, as the former generates 60% lower CO₂ emissions per ton of steel compared to the latter.

For instance, the German Steel Federation has proposed establishing a carbon labeling system for steel products to demonstrate their carbon neutrality levels, thereby boosting market competitiveness. Sweden's H2 Green Steel achieves carbon emissions of 0.4 tons per ton of steel through green hydrogen-based direct reduced iron (DRI). The Japan Iron and Steel Federation has advanced the COURSE50 project to reduce carbon emissions by 30%, while JFE Steel developed ultra-low CO₂ EAF technology, increasing the scrap steel utilization ratio to 95% [16].

4.3 Strategic engagement in emissions trading systems (ETS) for mitigation of environmental compliance costs

The differentiated electricity pricing policy drives the green transition of the steel industry through price leverage, primarily via dual mechanisms of cost pressure and technological forcing. By 2024, China's national carbon market has expanded to cover the steel sector, encompassing 560 enterprises with total carbon emissions reaching 1.8 billion tons, creating strategic business opportunities.

First Opportunity: Allowance Revenue and Cost Hedging

Enterprises that complete ultra-low emission retrofits receive additional free carbon allowances, with surplus allowances tradable for profit. For example, Shougang Group Co., Ltd. generated RMB 143 million by transferring 1.48 million tons of Chinese Certified Emission Reductions (CCERs).

Second Opportunity: Market-Driven Technological Upgrades

Starting in 2025, the Chinese government will further incentivize the adoption of low-carbon technologies such as hydrogen metallurgy and carbon capture, utilization, and storage (CCUS). EU experience demonstrates that hydrogen-based direct reduced iron (DRI) technology becomes cost-competitive when carbon prices exceed € 150 per ton.

Enterprises can achieve policy synergies through multiple pathways. The first involves dynamic allowance management, which entails accurately forecasting carbon emissions and optimizing the timing of allowance purchases or sales in alignment with production plans. For example, adjusting production schedules to leverage off-peak electricity pricing can reduce power costs and lower carbon allowance consumption. The second pathway focuses on fund recycling, where revenues from carbon markets—such as proceeds from allowance sales—are reinvested into energy-saving retrofits to qualify for electricity price incentives. The third pathway centers on low-carbon technology certification and premium pricing. This includes developing high-value-

added products like "zero-carbon steel," which command market premiums through carbon footprint certification. Notable examples include Germany's ThyssenKrupp, which utilizes hydrogen-powered blast furnace technology (Blast Furnace 2.0) to target a 30% reduction in carbon emissions by 2030, and Luxembourg's ArcelorMittal, which invests in hydrogen-based direct reduced iron (DRI) plants with an annual production capacity of 9 million tons, offsetting technological investments through carbon market revenues. These strategies collectively enhance operational efficiency and sustainability while aligning with regulatory and market demands.

5 Conclusion

China's differentiated electricity pricing policy is designed to guide rational resource allocation, promote energy conservation and emission reduction, optimize industrial structure, and facilitate coordinated regional development through tiered electricity pricing. For steel enterprises, this policy presents a double-edged impact. In the short term, it directly increases electricity costs and accelerates the phase-out of outdated production capacities. Over the long term, steel manufacturers can drive industry transformation toward greener and more intensive development through technological upgrades, operational layout optimization, and energy transition. Looking ahead, as green electricity costs decline and the national unified electricity market matures, steel enterprises will leverage market-oriented mechanisms to mitigate electricity price fluctuation risks and achieve sustainable development.

China's differentiated electricity pricing framework will align closely with the nation's dual carbon goals, energy structure transition, and demands for high-quality economic development. Multidimensional explorations will be conducted across policy refinement, technology empowerment, regional coordination, and international benchmarking. This policy not only provides theoretical underpinning for China's carbon neutrality pathway but also offers valuable insights for emerging economies seeking to balance development priorities with decarbonization commitments. By institutionalizing market-driven resource allocation mechanisms and fostering cross-regional energy cooperation, the policy will serve as a strategic instrument for industrial upgrading and low-carbon transformation in energy-intensive sectors.

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