Predicting CO_2 Emissions from China's Full Scrap Electric Furnace Steelmaking Process Based on Different Carbon Reduction Scenarios for 2025-2030

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Abstract. To address climate change and achieve carbon neutrality goals, the electric arc furnace (EAF) short process, as one of the typical production processes in the steel industry, has the advantage of energy conservation and emission reduction. Currently, research on carbon emissions mainly focuses on the blast furnace-basic oxygen furnace (BF-BOF) long process, with less research on the EAF short process. In response, this paper takes the energy efficiency benchmark of the EAF short process steelmaking in the steel industry as the research object, adopts the carbon emission factor method, and based on three different carbon reduction scenarios, predicts the carbon dioxide emissions per ton of steel in the steelmaking process for the years 2025-2030. The results indicate that between 2025-2030, the reduction in carbon emissions from the EAF steelmaking process under different carbon reduction scenarios is roughly between 4.43% and 12.73%, indicating significant potential for carbon reduction.

Keywords: iron and steel industry; total scrap; electric furnace steelmaking process; carbon dioxide emission

1 Introduction

In response to global climate change, China has proposed to peak carbon by 2030 and become carbon neutral by 2060[1]. As a traditional resource-and energy-intensive industry, iron and steel industry emits a huge amount of carbon dioxide (CO_2), accounting for 15% of China's total CO_2 emissions. According to the International Energy Agency (IEA), to meet global energy and climate targets, CO_2 emissions from the global steel industry should fall by at least 50% by 2050, and by about 60% per tonne of steel, from 1.4 tonnes to 0.6 tonnes[2]. The plan for the adjustment and upgrading of the steel industry (2016-2020) points out that the steel industry is currently faced with major opportunities for deepening reform, structural adjustment and demand upgrading, it also faces severe challenges such as overcapacity, insufficient capacity for innovation and development, increasing environmental and energy constraints, and operating difficulties[3].

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In the aspect of steel production process, it can be divided into"From ore to steel" process and"From scrap to steel" process, one is the short process represented by the electric furnace steelmaking process. The internationally recognized short process is the electric furnace steelmaking process with scrap as the main iron-containing raw material and the non-blast furnace ironmaking + electric furnace steelmaking process, non-blast furnace ironmaking includes direct reduced iron (DRI) process and molten reduced iron process[4]. The short-flow process is characterized by low carbon dioxide emission and low energy consumption intensity, which eliminates the use of coking coal and the iron pre-process such as sintering and coking. The development of our country's iron and steel industry has basically formed a situation in which the long flow of blast furnace-converter is"Main" and the short flow of electric furnace is"Auxiliary". As for the proportion of EAF steelmaking, the paper points out that by 2025, the proportion of short-process steelmaking in our country will reach more than 15% , and by 2030, it will reach 20% .

In recent years, more and more studies have been conducted on the impact of process flow in the steel industry on greenhouse gas emissions, many scholars have studied and analyzed the different methods of calculating CO_2 emission in the process of iron and steel production, the CO_2 emission in the specific process of iron and steel industry and the scheme of reducing CO_2 emission. For example, Liu Hongqiang used three methods to compare the carbon emission of a blast furnace-converter long process[5], and analyzed the cause of the difference of CO_2 emission caused by different calculation methods Nahongming studied the carbon emission of"Chinese Type" electric arc furnace short process, and expounded the reason of the current situation of converter of electric arc furnace in China Yao studied the calculation and analysis of carbon emission in short process of continuous charging EAF for all scrap steel[7]. In the research of carbon emission, most scholars focus on the blast furnace-converter long process, the short process of EAF steelmaking carbon emission less research.

This article explores and predicts the trend of carbon dioxide emissions per ton of steel produced by electric arc furnace (EAF) steelmaking in China under the benchmark of energy efficiency for all-scrap EAF production from 2025 to 2030. Based on the simplification of a system model, the carbon emission factor method is used to calculate and analyze the carbon dioxide emissions per ton of steel for the EAF steelmaking process.

2 Research Methods

2.1 Study Boundary

Based on the determination of the carbon emission analysis boundary, the system model is simplified and the carbon emission of the whole scrap electric furnace short process is analyzed.

Based on 'the research of CO_2 emission characteristics and emission reduction path of Chinese steel industry-based on ARIMA-LEAP model'[6], the typical production flow of steel industry is shown in Figure 1. Steelmaking process is divided into two types: converter and electric furnace, electric furnace steelmaking energy input mainly for electricity, gas and other.

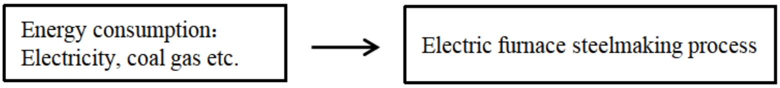

Fig. 1. energy classification of short-flow steelmaking process of all-scrap EAF in typical iron and steel industry

2.2 Carbon Emission Factor Method

The calculation of product carbon emissions often uses the substance flow-carbon flow and carbon emission factor method. This article only involves the steelmaking process, therefore, the carbon emission factor method is chosen.

The carbon emission factor F is a coefficient that is derived from the statistical average of CO_2 emissions per unit of product produced or per unit of energy consumed, which is more in line with the actual situation.

Based on this, the CO_2 emission of a substance or energy is: $G = X \cdot F$

G is CO_2 emission, t; F is carbon emission factor, t/t; X is consumption of different substances or energy, t.

Based on the conclusion drawn from 'Calculation and analysis of carbon emission from short process of full scrap continuous feeding electric arc furnace' [8], in conjunction with the law of conservation of mass and the established system research boundaries, the carbon emission per ton of steel for each process is determined as follow:

$$G = \sum_{i=1}^{d} X_i \bullet F_i + \sum_{j=d+1}^{m} X_j \bullet F_j$$

G is the actual CO_2 emissions from each process, t; the first item on the right of the equation is the direct emissions from carbon-containing raw materials i, the second item is the indirect emissions from energy consumption j; F is the direct carbon emission factor, f is the indirect carbon emission factor.

Based on the actual production conditions and the need for model simplification, the following assumptions are made for the scrap steel-electric arc furnace (EAF) steelmaking process:

(1) Electricity used in all processes is purchased externally, and the CO_2 emission factor for purchased electricity is calculated based on the carbon emission factors and projections published by the National Development and Reform Commission and the Ministry of Ecology and Environment of China.

(2) The impact of CO_2 capture technologies within the process is not considered, and the output of the entire EAF short process is primarily emitted directly in the form of CO_2.

(3) Industrial dust, fresh water, oxygen, and other factors generated in various processes have minimal impact on carbon emissions and are therefore not considered.

3 Scenario Setting

Based on the above models, we need to predict the future carbon emission factors of the national power grid from 2025 to 2030. At present, the National Development and Reform Commission and the Ministry of Ecology and environment have only published carbon emission factors for 2015,2021 and 2022, which are 0.5% respectively. 6101,0. 5810,0. 5703 kg/(kW·h).

According to the scenario set out in the calculation and prediction of carbon emission factors for the national power grid from 2005 to 2035, the 2025-2030 carbon emission factors for the national power grid are divided into baseline scenario, carbon reduction scenario and enhancement scenario:

Under the baseline scenario, power generation will maintain the growth trend from 2005 to 2025. Suppose that the growth rate of thermal power generation and hydropower generation is 2.4% and 1.2% respectively from 2026 to 2035, while the growth rate of renewable energy generation and wind power generation is 8.0% , solar power will grow by 10.0% and nuclear by 2.0% .

In a low-carbon scenario, coal-fired power will grow more slowly, and renewable power will grow faster, taking into account policy guidance, development potential, power substitution, construction cycles, and energy prices. The growth rate of thermal power generation and hydropower generation is expected to be 2.0% from 2026 to 2035. The average growth rate of renewable energy generation is about 6% , of which the growth rate of wind and solar power generation is 10.0% , nuclear generation is expected to grow by 5.0% .

In the enhanced scenario, renewable energy generation technology and construction capacity has been greatly enhanced, wind and solar power generation has been maximized, and the proportion of green power has increased rapidly. Assuming a growth rate of 2.0% for thermal and 2.5% for hydropower, and an average growth rate of about 7.0% for renewable energy, of which 12.5% for wind and solar, nuclear power will grow by 5.0% .

Based on 'the calculation and prediction model of the carbon emission factors of the national power grid from 2005 to 2035'[10], the carbon emission factors of the national power grid from 2025 to 2030 are predicted as shown in Table 1, with units of $kgCO_2/kWh$:

Table 1. 2025-2030 China power grid carbon emission factors forecast table

Year	Baseline scenario	Low-carbon scenario	Enhance the situation
2025	0.5647	0.562	0.558
2026	0.5624	0.5581	0.543
2027	0.559	0.5477	0.526
2028	0.552	0.541	0.517
2029	0.547	0.535	0.502
2030	0.539	0.526	0.485

4 CO_2 Emission Forecast for Electric Furnace Steelmaking per Tonne, 2025-2030

In order to predict the carbon dioxide emission level of the whole EAF steelmaking process from 2025 to 2030, it is necessary to estimate the energy consumption level of the whole EAF steelmaking process.

In 2023, the Ministry of Industry and Information Technology published data on the energy efficiency benchmarking index for major products (processes) in the steel industry, in order to benchmark the advanced energy efficiency levels of domestic and foreign producers and determine the energy efficiency benchmarking level for high energy-consuming industries, Table 2 shows that the total energy consumption per ton of steel (water) is 65 kgce/t, of which the consumption of electricity is 320 kwh/t, and the consumption of fuel (mainly gas) is 0.04 GJ/t, the rest is negligible.

Table 2. Energy Efficiency Benchmark Index of EAF steelmaking process in China

The name of the pointer	Unit	Energy Efficiency Benchmarking Index	Notes
Energy consumption in electric furnace operation	kgce/t molten steel	65	Total scrap
Power consumption per ton of steel (water)	kWh/t	320	Total scrap
Tons of steel (water) consumed as fuel	GJ/T	0.04	

The index and the predicted grid carbon dioxide emission factors are incorporated into the calculation model of the carbon emission factors, which are obtained under the assumption that emissions factors such as coal combustion will remain unchanged in the future and only the grid carbon emission factors will change, the change trend of carbon dioxide emission in China's EAF steelmaking process from 2025 to 2030 is estimated under three scenarios: baseline scenario, carbon reduction scenario and strengthening scenario.

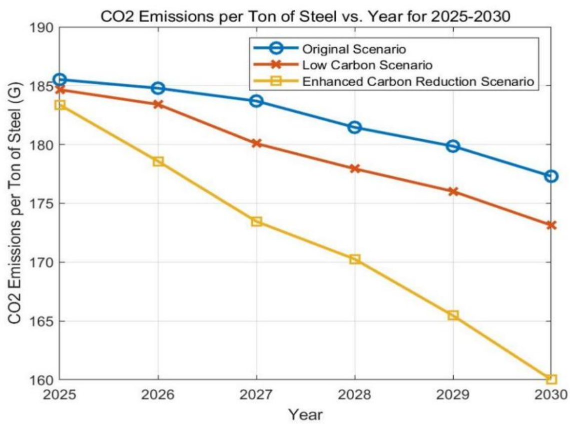

Fig. 2. Forecast of tCO_2 Emissions per Tonne of Steel from Full Scrap Electric Furnace Steelmaking Process in China, 2025-2030

The Figure 2 indicates that from 2025 to 2030, the CO_2 emissions per ton of steel in China's fully scrap-based electric arc furnace (EAF) steelmaking process will decrease from 0.1855 tCO_2 to 0.1773 tCO_2 under the baseline scenario; from 0.1846 tCO_2 to 0.1731 tCO_2 under the decarbonization scenario; and from 0.1834 tCO_2 to 0.1602 tCO_2 under the enhanced scenario.

Currently, the tCO_2 emissions per ton of steel in China's EAF steelmaking process are approximately 0.4 to 0.8 tCO_2, highlighting that there is still significant room for reduction and a huge potential for emission mitigation in China's fully scrap-based EAF steelmaking. Further analysis based on the model and assumptions reveals:

Under all three scenarios, it is projected that the CO_2 emissions per ton of steel in China's fully scrap-based EAF steelmaking process will decline overall from 2025 to 2030. Taking 2025 as the base year, the emissions are expected to decrease by 4.43% under the baseline scenario, 6.23% under the decarbonization scenario, and 12.73% under the enhanced scenario by 2030. Notably, the reduction rates in carbon emissions under these scenarios are generally in line with the decreasing rates of the grid's emission factors. Due to factors such as national policies and energy structure adjustments, the percentage of carbon reduction is the highest under the enhanced scenario, resulting in the most effective carbon mitigation.

In the decarbonization scenario, according to the "Implementation Plan for Achieving Carbon Peaks in the Industrial Sector," China aims to have a short-process steelmaking ratio of over 15% by 2025 and 20% by 2030. Combining this with national crude steel production forecasts, the total carbon emissions from the short-process steelmaking sector in China are projected to be approximately 31.15 tCO_2 in 2025 and 45.42 tCO_2 in 2030.

5 Summary

5.1 According to Figure 2, over the next 2025-2030 period, China's CO_2 emissions per ton of steel from the fully scrap-based electric arc furnace (EAF) steelmaking process are projected to decrease annually, with a notable reduction of 12.73% under the enhanced scenario. Given that electricity consumption accounts for approximately 60-80% of the total energy consumption in the fully scrap-based EAF process[9], the trend in the grid's carbon emission factor plays a decisive role in the carbon emissions of EAF steelmaking. Consequently, the trend in CO_2 emissions per ton of steel from the fully scrap-based EAF process closely aligns with that of the grid's carbon emission factor.

5.2 The data used in this paper for energy efficiency in the EAF process represents a benchmark scenario, which is relatively idealistic. However, China's current EAF operations predominantly use around 30% hot metal, with a relatively low scrap utilization rate. This results in CO_2 emissions per ton of steel ranging from 0.4 to 0.8 tons, which deviates significantly from the model's conclusions. This discrepancy underscores the vast potential for carbon reduction within China's steel industry.

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