WISCO's Low-carbon Transformation Based On LEAP And Scenario Analysis

Yongping Huang [1], *Ben* Wang [1], *Wu* Yang [1], *Lushi* Sun [1,*]

[1] State Key Lab of Coal Combustion, Hua Zhong University of Science and Technology, 430074, Wuhan, China

Abstract. The paper takes Wuhan Iron and Steel Co., Ltd. (hereinafter referred to as " WISCO ") energy consumption and carbon emissions as the research object, and analyzes WISCO's carbon emissions. Through the construction of WISCO's Long range Energy Alternatives Planning system (hereinafter referred to as LEAP) prediction model for energy consumption and carbon emissions, three scenarios have been set up: a baseline scenario, an energy efficiency improvement scenario, and an energy structure change scenario to measure WISCO's carbon emissions. Based on the results of the LEAP model, this article puts forward the following recommendations for WISCO's low-carbon transformation. WISCO must strictly control steel output. WISCO should introduce electric furnaces to increase the proportion of electric furnace steel. While ensuring the supply of scrap steel resources, WISCO ought to use scrap steel efficiently. In addition, introduction of hydrogen direct reduction iron technology is also crucial to WISCO in a planned way.

1 Introduction

Statistics from the World Iron and Steel Association show that, on average, 1.8 tons of carbon dioxide are emitted per ton of steel produced in the world. The carbon dioxide emissions of the steel industry account for about 6% of the total global carbon dioxide emissions. As a major steel country, the carbon emissions of the steel industry account for about 15% of the country[1]. The study of WISCO's low-carbon transformation path is of great significance to a low-carbon pilot city like Wuhan, and at the same time provides experience for the low-carbon transformation of China's steel industry.

Many countries in the world have begun research and development of low-carbon technologies in the steel industry. Japan's most famous low-carbon metallurgical project is the COURSE50 project[2], which focuses on the research and development of blast furnace gas separation and carbon dioxide recovery technology based on hydrogen reduction. It plans to reduce carbon dioxide emissions by 30% in 2030 and to use and promote the technology in 2050. South Korea's POSCO's hydrogen-rich blast furnace ironmaking technology aims to reduce carbon dioxide emissions by 10%[3]. The low-carbon technology paths of European countries represented by Sweden and Austria are mainly green hydrogen direct reduction and electric furnaces. The Swedish HYBRIT project[4] is a breakthrough ironmaking technology that uses hydrogen to replace coking coal, coke or natural gas. If this project is put into use, Sweden's greenhouse gas emissions will be reduced by 10%[5]. The German low-carbon technology path takes into account both blast furnace hydrogen-rich smelting and direct reduction of green hydrogen[6]. In terms of long processes, the project of the German ThyssenKrupp Group converts waste gas into raw materials for chemical products, and carbon dioxide will no longer be emitted into the air. In terms of short processes, the SALCOS project in Germany aims to produce steel through the use of green hydrogen and biomethane[7].

2 Research methods

For WISCO's carbon emissions calculations, the total greenhouse gas emissions of steel production enterprises should be equal to the emissions from fossil fuel combustion, industrial production processes, and the net purchases of electricity and heat from all production systems within the boundaries of the company. The sum should also be deducted from the emissions implied by carbon sequestration products. Both the consumption of fossil fuels and the conversion coefficient required to calculate the average low calorific value of fossil fuels can be directly obtained from Wuhan Iron and Steel, while the carbon content and carbon oxidation rate per unit of calorific value are calculated using the "Guidelines for Accounting Methods and Reporting of Greenhouse Gas Emissions of Chinese Steel Production Enterprises (Trial)."

* Corresponding author: sunlushi@hust.edu.cn

This paper chooses the LEAP model as a research tool.

The LEAP model (The Long range Energy Alternatives Planning system) is a software widely used in energy policy analysis and climate change assessment jointly researched and developed by the Stockholm Environmental Research Institute and Boston University in the United States[8]. It has been used by hundreds of countries in 150 countries around the world. Used by thousands of organizations, including government agencies, non-governmental organizations, academic institutions, energy units, and consulting companies[9]. LEAP has now become an effective tool for many countries to implement energy development planning and greenhouse gas emission assessment. The model takes energy supply, energy consumption and environmental impact as the research object, according to energy demand and future social and economic development trends, according to different policies and technology choices, set up different scenarios, and use mathematical models to predict the energy of various sectors demand and environmental impact, detailed economic benefit analysis of various energy options. This model realizes the simulation of the energy consumption system and is usually referred to as the "terminal energy consumption model". This article uses the scenario analysis method, sets the scenario analysis time interval to 2019-2050, and designs different emission reduction scenarios to explore reasonable emission reduction measures.The scenarios are described as follows:

2.1 Scene settings

(1) The baseline scenario is the reference scenario. The relevant parameters of steel production in 2019 are used as the baseline parameters, and other emission reduction approaches or methods are optimized schemes relative to this scenario. Under this scenario, based on the development status of WISCO during the 13th Five-Year Plan period, combined with existing policy plans, predict WISCO's future development in accordance with current development trends. The scenario is set as the slow process of structural adjustment, green development and independent innovation; elimination of outdated production capacity; the impact of market recovery and slower implementation of policies, occasional fluctuations in crude steel production, and slower decline; promotion of energy conservation and emission reduction, but unit product energy consumption declines slowly; WISCO's electric furnace steel ratio remains zero without an increase; there is a large gap between the iron-to-steel ratio and the domestic advanced level, the penetration rate of non-blast furnace ironmaking technology has grown slowly; the utilization rate of scrap steel has increased slowly. WISCO's energy consumption structure and energy technology level remain basically unchanged in 2019.

(2) Under the energy efficiency improvement scenario, we will increase efforts to eliminate outdated production capacity and strictly prohibit new steel production capacity. WISCO's crude steel production will gradually decline after reaching its peak in 2018; deepening energy conservation and emission reduction, and the overall energy consumption per ton of steel will drop rapidly; the iron-steel ratio has begun to slowly decline, but there is still a large gap with the domestic advanced level. Non-blast furnace ironmaking technology has accelerated popularization; scrap steel utilization has been greatly improved.

(3) The energy structure change scenario is based on the energy efficiency improvement scenario. Under this scenario, the key energy saving and emission reduction technologies are fully popularized, and advanced energy saving and emission reduction technologies are gradually promoted; the overcapacity of crude steel is contained; the product structure is optimized and the output is stable decrease; long-process steelmaking is gradually replaced by short-process steelmaking; Wuhan Iron and Steel's unit product energy consumption has dropped significantly, reaching the international advanced level; it is set that the proportion of electric furnace steelmaking in Wuhan's iron and steel industry will continue to increase from 2019 to 2050, and non-blast furnace ironmaking technology popularization; the utilization rate of scrap steel has been greatly increased, and the ratio of iron to steel has been declining; the consumption of fossil energy has dropped significantly.

2.2 parameter settings

The influencing factors of this study mainly include steel product output, energy intensity, equipment structure, production structure, electric furnace ratio, blast furnace ratio, iron-steel ratio, and energy-saving low-carbon technology penetration rate. The specific settings of the parameters are based on five time nodes: 2020, 2025, 2030, 2035, and 2050.

(1) Crude steel output

This article is based on the policy opinions issued by the National Development and Reform Commission in the “Key Points for Resolving Excess Capacity in Iron and Steel in 2019” and the “Implementation Measures for Capacity Replacement in the Iron and Steel Industry” issued by the Ministry of Industry and Information Technology, combined with the actual situation of WISCO. During 2019-2050, WISCO's crude steel output showed a slow downward trend. After parameter adjustments, the crude steel output declines at different rates in the three different scenarios. Due to the decline in crude steel production, the consumption of various fossil energy sources has decreased.

(2) Energy intensity

In 2020, the comprehensive energy consumption per ton of steel of WISCO is 569 kg of standard coal. Considering that the electric furnace ratio between foreign steel and WISCO and the scrap utilization gap are too large, the comprehensive energy consumption per ton of steel of WISCO is set at 540 kg in the energy efficiency improvement scenario. Coal/ton of steel declines at different rates under different scenarios.

(3) Equipment structure

In the baseline scenario and the energy efficiency improvement scenario, the energy structure is not changed, and the electric furnace ratio remains zero. In the energy structure change scenario, the electric furnace ratio parameter setting refers to the increase in the rate of change of the electric furnace ratio in developed countries. Electric furnace steel accounts for about 30% in the world, while the United States accounts for 60%[10]. From 1960 to 1985, the ratio of electric furnaces in the United States is rising, and the long-term trend is to gradually increase the proportion of electric furnace steel. With reference to the above data and the actual situation in my country, the electric furnace ratio parameters of WISCO continue to rise.

(4) Emission factors

The emission factors of fossil fuels remain basically unchanged, set to constant values, using WISCO's statistical monitoring values or the default values in the "Guidelines for Accounting Methods and Reporting of Greenhouse Gas Emissions for Chinese Steel Production Enterprises (Trial)" [11].The default value of IPCC in the LEAP model TED template and the power carbon emission factor are adopted by the central China regional power grid carbon emission factor of the State Grid.

(5) Scrap ratio

According to calculations by the Metallurgical Industry Economic Development Research Center in 2015, my country's steel reserves have reached 8 billion tons. In 2020, my country's steel reserves will reach 11.5 billion tons, and will reach 15 billion tons by 2025. By 2030, domestic steel reserves will be basically completed. After industrialization, it reached 17 billion tons. In the future, China's scrap supply will be sufficient to meet the growth of domestic scrap demand. In the medium and long term, the increase in the amount of scrap steel will cause the price of scrap steel to fall, which in turn will drive the increase in demand for scrap steel. The parameter setting refers to the forecast results of my country's total scrap steel resources from 2015 to 2030 in the "Strategic Research Report on a Powerful Country in Ferrous Metal Mineral Resources" compiled by the special group of "Strategic Research on a Powerful Country in Ferrous Metal Mineral Resources".

Table 1. Parameter settings under the baseline scenario.

Year	2020	2025	2030	2035	2050
Crude steel production (10,000 tons)	1556	1493	1440	1410	1300
Clean coal (10,000 tons)	756	704	672	639	576
Coke (10,000 tons)	56	71	79	87	97
Anthracite (10,000 tons)	220	210	204	199	190
Bituminous coal (10,000 tons)	104	94	90	85	75
Natural gas (10,000 cubic meters)	4149	4200	4250	4300	4350
Electricity (million kWh)	5000	4860	4780	4690	4620
Iron to steel ratio (%)	93.03	85	82	80	78
Electric furnace ratio (%)	0	0	0	0	0
Scrap ratio (%)	16.7	17.4	18	18.4	20

Table 2. Parameter setting under the energy efficiency improvement scenario.

Year	2020	2025	2030	2035	2050
Crude steel production (10,000 tons)	1556	1361	1259	1164	1000
Clean coal (10,000 tons)	744	679	628	588	500
Coke (10,000 tons)	47	40	38	35	30
Anthracite (10,000 tons)	216	204	485	174	150
Bituminous coal (10,000 tons)	102	85	76	67	45
Natural gas (10,000 cubic meters)	4149	4115	4089	4064	4000
Electricity (million kWh)	5000	4730	4570	4430	4220
Iron to steel ratio (%)	86	82	78	74	68
Electric furnace ratio (%)	0	0	0	0	0
Scrap ratio (%)	17	20.5	23.2	26.2	32.3

Table 3. Parameter setting under the energy structure change scenario.

Year	2020	2025	2030	2035	2050
Crude steel production (10,000 tons)	1500	1200	1055	950	700
Clean coal (10,000 tons)	720	594	500	450	20
Coke (10,000 tons)	46	38	34	30	19
Anthracite (10,000 tons)	210	136	113	83	20
Bituminous coal (10,000 tons)	61	20	7	0	0
Natural gas (10,000 cubic meters)	4149	3851	3206	1422	300
Electricity (million kWh)	5000	4530	4060	3500	1020
Iron to steel ratio (%)	80	75	72	69	64
Electric furnace ratio (%)	0	10	20	30	50
Scrap ratio (%)	19	23.5	26.5	30.2	36.5

3 Results and Discussion

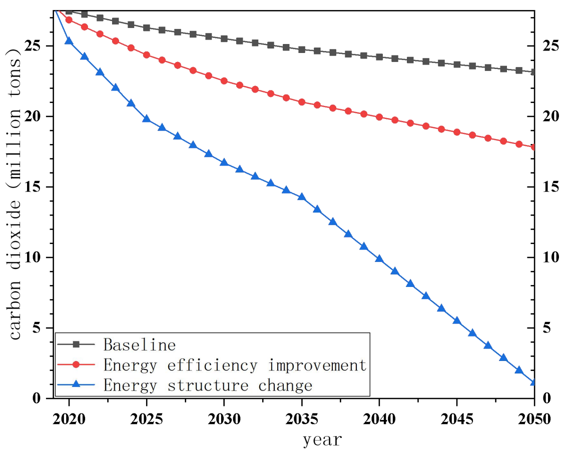

Fig. 1. Comparison of carbon emission forecast changes in three scenarios.

The above figure is a comparison chart of carbon emission forecast changes in the three scenarios. According to the baseline scenario, WISCO completed the "carbon peak" target in 2018, and the subsequent carbon emissions have been slowly decreasing year by year. By 2035, it will not be able to achieve the 35% carbon reduction target, and by 2050, it will be far from achieving the "carbon neutral" target.

According to the energy efficiency improvement scenario, WISCO completed the "carbon peak" in 2018. Carbon emissions are declining year by year. By 2035, carbon emissions will drop by about 5 million tons, which is about 20% carbon reduction. However, the target of 35% carbon reduction in 2035 and the target of "carbon neutrality" in 2050 cannot be achieved.

According to the energy structure change scenario, WISCO completed the "carbon peak" in 2018. Carbon emissions are declining rapidly year by year. By 2035, about 15 million tons of carbon will be reduced, which will reduce carbon by more than 50%, exceeding the target of 35% carbon reduction by 2035, and basically completing the "carbon neutral" target by 2050. The following focuses on the analysis of energy structure change scenarios.

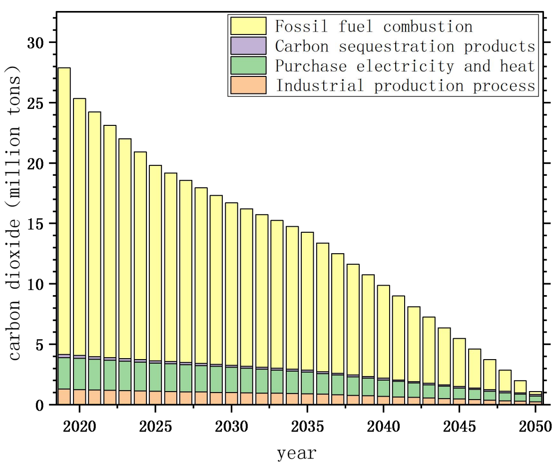

Fig.2. Carbon Emission Prediction for Energy Structure Change Scenarios

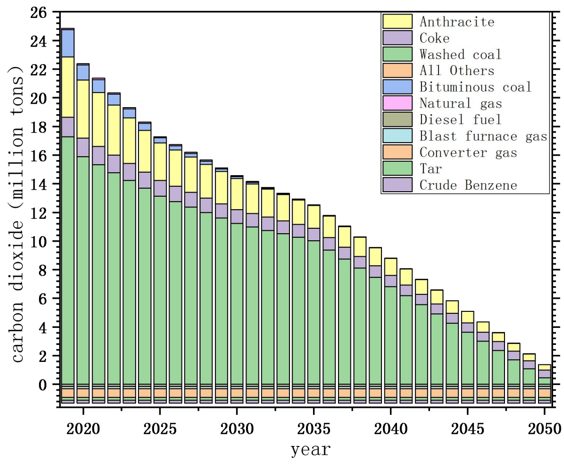

Fig. 3. Fossil fuel combustion carbon emission prediction in the energy structure change scenario

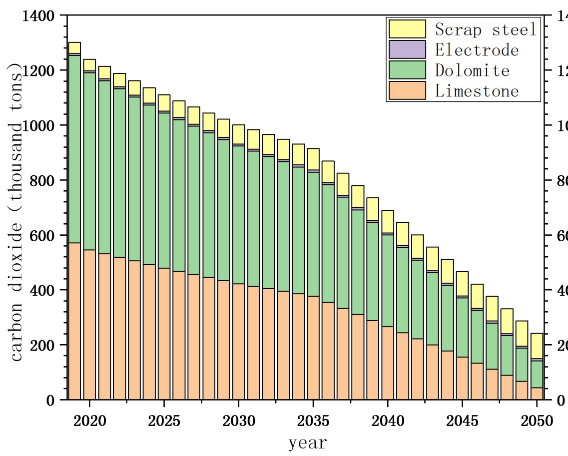

Fig. 4. Carbon Emission Prediction of Industrial Production Process in the energy structure change scenario

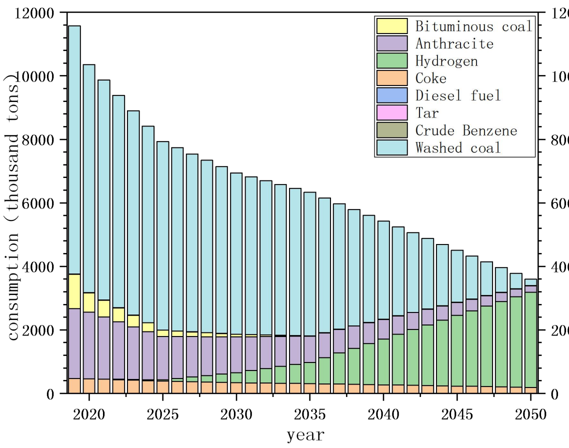

Fig. 5. Prediction of fossil fuel consumption in the energy structure change scenario

WISCO continued to develop in accordance with the energy structure change scenario. While further implementing the promotion of energy saving and emission reduction technologies, WISCO introduced new iron-making and steel-making technologies. Short-process steel-making gradually replaced traditional long-process steel-making, and the burning of fossil fuels produced a large amount of carbon emissions. After 2035, bituminous coal will be completely abandoned by Wuhan Iron and Steel, and the consumption of clean coal, coke and anthracite is also declining year by year.

It can be seen from **Fig.5** that hydrogen has begun to be used as an energy source in 2025. 2035 is an important time node. The hydrogen smelting technology is mature and the amount of hydrogen used has begun to increase significantly. Under the structural change scenario, it is assumed that the experiment of hydrogen metallurgy technology will start in 2025, and the technology will mature and be put into use in large quantities by 2035. Therefore, after 2035, fossil energy such as clean coal and anthracite will withdraw from the stage of steel smelting at a faster rate. From 2020 to 2050, the net consumption of carbon dioxide emissions from fossil fuel combustion activities continues to drop significantly. By 2050, the carbon dioxide emissions from fossil fuel combustion activities have been controlled below 500,000 tons.

The carbon dioxide emissions produced in the industrial production process are mainly due to the amount of carbon dioxide produced by the consumption of dolomite and limestone as solvents in the ironmaking process. Under the scenario of changes in the energy structure, energy-saving and emission-reduction technologies are added. Under the change of ironmaking and steelmaking technologies, Before 2035, the consumption of dolomite and limestone will decrease with the output of steel; after 2035, the consumption of dolomite and limestone will drop significantly. Due to the new steelmaking technology, hydrogen energy steelmaking will replace the traditional long-process steelmaking process, dolomite and limestone no longer act as solvents in the sintering and ironmaking processes, so the carbon dioxide emissions generated by the industrial production process will also approach zero in 2050.

Since the carbon dioxide emissions implied by WISCO's carbon fixation products account for a small proportion of WISCO's carbon dioxide emissions, the amount of change is also very small under the scenario of changes in the energy structure, which is not the focus of WISCO's carbon emission reduction work.

4 Conclusions

4.1 Control steel production

Controlling steel production is the main means to reduce carbon emissions in the steel industry. According to the crude steel output under the energy structure change scenario in the model calculation results, the specific crude steel output is shown in **Table 4**. The crude steel output in the simulation forecast does not include the scrap-electric arc furnace steelmaking process, and the crude steel of the non-scrap-electric furnace steel route. The output is strictly controlled and continues to decline.

According to the forecast result, the crude steel output of WISCO will fall to 9.5 million tons by 2035, an average annual decrease of about 3.0%. It will be reduced to 7 million tons by 2050, an average annual decrease of 2.0%. At the same time, the proportion of WISCO's scrap steel needs to be continuously increased. In 2035, the proportion of scrap-electric furnace steel will reach 30%, and the proportion of scrap-electric furnace steel will reach 50% in 2050.Crude steel production continues to decline, and the amount of scrap steel continues to increase. Finally, the growth rate of total steel production generally shows a downward trend, before 2035 The average decrease was 0.67%, and then the decrease increased to 1.43%.

Table 4. Steel production control plan.

Year	2020	2025	2030	2035	2050
Crude steel production (ten thousand tons)	1500	1200	1055	950	700
Percentage of scrap steel (%)	/	23.5	26	30	36
Total output (ten thousand tons)	/	1568	1425	1357	1093

4.2 Change the energy structure

The change of energy structure is the most important emission reduction measure. According to the forecast results, three suggestions for green transformation are given. (1) WISCO should introduce electric furnaces to increase the proportion of electric furnace steel. (2) While ensuring the supply of scrap steel resources, WISCO should use scrap steel efficiently. (3) WISCO should introduce hydrogen direct reduction iron technology in a planned way.

The above suggestions are given from the three perspectives of electric arc furnace, scrap steel, and direct reduced iron. The three suggestions are integrated in terms of energy structure changes. Use hydrogen to smelt direct reduced iron to make steel in an electric arc furnace and use scrap steel to make steel in an electric arc furnace. The basis of the two approaches is the introduction of electric arc furnaces by Wuhan Iron and Steel.

Combining the results of simulation prediction and the status quo of my country’s scrap steel industry, the specific supporting implementation plan is as follows: WISCO will begin to introduce electric arc furnaces in 2022 and gradually increase the proportion of electric arc furnaces. According to the results of the forecast model, the proportion of electric arc furnaces will reach 10% in 2025, the proportion of electric arc furnaces will reach 30% in 2035, and the proportion of electric arc furnaces will reach 50% in 2050. With the growth of my country's steel reserves and the decline in domestic scrap prices, the cost of using scrap for electric arc furnace steelmaking will gradually decrease. Before 2025, due to the cost of electric arc furnace steelmaking, the main method of putting scrap steel into the converter is still used to reduce carbon emissions. In 2025, scrap steel will be used to make steel in the electric arc furnace, and the amount of scrap steel will be increased year by year. By 2035, the use amount of scrap steel should reach 30%, and by 2050, the use amount will reach 36.5%. WISCO will start the direct hydrogen smelting direct reduced iron technology in 2025, and it will be put into use on a large scale in 2035. In 2035, the proportion of electric arc furnaces will reach 30%. WISCO can use direct reduction iron electric arc furnaces to make steel, and at the same time use scrap electric arc furnaces to make steel. It can be seen from **Fig.5** , after 2035, the use of hydrogen will increase significantly, and the output of direct reduced iron will continue to rise. Direct reduced iron will be put into electric arc furnace steelmaking. The time nodes are shown in the following table.

Table 5. Energy structure change time.

Item	2025	2035	2050
Proportion of electric arc furnaces	10%	30%	50%
Scrap steel	start	30%	36.5%
Hydrogen direct reduction of iron technology	Carry out technical research	Industrial application	

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