Estimation of Embodied Energy Flow and Embodied Carbon Emissions in China's Steel Trade — Based on LEAP Model

Junjie Chen

School of Applied Economics, Renmin University of China, Beijing 100089, China.

Abstract: This article uses the data from 2010-2020 World Steel Association Statistical Yearbook to calculate the main indicators of China's steel trade, eliminates the invisible carbon emissions from intermediate products in China's steel production based on Low Emissions Analysis Platform. Also, from the perspectives of the producer and consumers, this article uses the "process method" to calculate the embodied energy flow and embodied carbon emissions of China's steel industry. The study found that in the past ten years, the crude steel output of China's steel industry was greater than the direct steel consumption, and the direct steel consumption was further greater than the indirect steel consumption, which shows that China provides a large amount of steel products to countries around the world. Furthermore, the data of embodied energy consumption and embodied carbon emissions of China's steel industry shows that the export flow is greater than the import flow. The rising international demand for steel makes China's steel industry bear more carbon emissions.

Keywords: International Trade; Steel Industry; Carbon Neutrality; LEAP Model

1. Introduction

Since China put forward the long-term goal of achieving carbon peak in 2035 and achieving carbon neutrality in 2060, the steel industry, as the type of industry with the largest carbon emissions, is facing tremendous pressure to reduce carbon emissions. In this context, to truly achieve the goal of carbon peaking and carbon neutrality in the steel industry, it is not only necessary to consider how to reduce production and increase efficiency, but also to study the international trade factors faced by the steel industry. In fact, steel is one of China's important export products, and international trade conditions usually have a huge impact on the steel industry because it contains the embodied energy flow and embodied carbon emissions. Therefore, it is particularly important to classify and calculate the emissions of CO2 more accurately.

2. Research methods and data sources

2.1 Research methods

2.1.1 Key concepts of steel trade

"Steel Demand" refers to the amount of steel products that users in a country/region are willing and able to buy at a certain price in a certain period of time. The World Steel Association has developed several methods for measuring steel demand. One of the most commonly used is Apparent Steel Use (ASU), which is the value of steel delivery minus net direct exports of steel products.

Although the above methods have considered the trade of steel products when estimating the demand for steel, they have not considered the trade of steel products such as automobiles, ships, machinery, and white goods, that is, indirect steel trade. Indirect steel trade covers the import and export of steel-containing products. On this basis, the World Steel Association developed the concept of True Steel Use (TSU). The True Steel Use is the Apparent Steel Use Minus Net Indirect Export

Volume.

Related concepts and formulas are as follows:

ASU = Delivered Volume of Steel Product - Net Direct Export Volume (1)

TSU = ASU - Net Indirect Exports of Steel Product (2)

2.1.2 LEAP model introduction

The LEAP platform is essentially a simulation accounting tool, which can analyze economic development, energy efficiency technologies and policies in different sectors, and the energy consumption pattern. In this article, the energy demand and environmental impact of the industry will be simulated and calculated.

The most critical part in the construction of the model in this article is the Iron and Steel Industry module. According to the characteristics of the production process and procedures of China's iron and steel industry, and the requirements of the LEAP platform for the modeling data structure, this paper constructs a hierarchical data tree structure of the Iron and Steel Industry module. The analysis process of the LEAP model can be summarized into the following 4 parts:

2.1.2.1 Departmental production

The entire production process of steel is determined by the entire production chain including coking → sintering → iron making → steel making → steel rolling.

$$P_{\mathrm{i}} = \sum P_{\mathrm{j,i}} \tag{3}$$

P_i is the output of the i-th type of process; is the output of the i-th process produced by the equipment j.

2.1.2.2 Energy demand

$$E = \sum_{\mathrm{i}} \sum_{\mathrm{j}} \sum_{\mathrm{n}} \mathrm{e}_{\mathrm{n,j,i}} \times P_{j,i} \tag{4}$$

Among them, E is the total energy demand of the iron and steel industry; is the total amount of n types of energy consumed during the production of equipment j in the i-th process.

2.1.2.3 CO_2 emissions

$$CE = \sum_{\mathrm{i}} \sum_{\mathrm{j}} \sum_{n} cef_{n,j,i} \times e_{n,j,i} \times p_{j,i} \tag{5}$$

CE is the total emissions of the iron and steel industry; is the emission factor, that is, the quality of emitted by the n-type energy produced and consumed by equipment j in the i-th process

2.2 Data sources

The World Iron and Steel Association publishes steel statistical yearbooks on a regular basis every year, providing a large amount of data on the steel production and trade status of all countries in the world. Its steel industry database covers the most comprehensive countries and can meet the research needs to the greatest extent. At the same time, the relevant data on energy consumption intensity and carbon emission coefficient of the steel industry mainly come from the Intergovernmental Panel on Climate Change (IPCC), which is an international organization that evaluates science related to climate change.

The energy used by the iron and steel industry mainly includes coking coal and electricity, and carbon dioxide mainly comes from the use of coking coal in the long process of iron and steel production.

3. Empirical

3.1 The status of China's steel trade from 2010 to 2020

Through calculation, the specific number of China's steel production, apparent steel use and true steel use from 2010 to

2020 can be obtained. Among them, the net direct export refers to the trade of steel products, such as steel bars, section steel, steel coils, steel pipes, etc.; the net indirect export refers to the trade of steel-containing products, such as automobiles, ships, machinery, and white goods.

Table 1. China's steel production and consumption from 2020 to 2020 (Unit: million tons)

Year	Supply Side	Consumption Side	Embodied Crabon Emissions	Percentage of embodied carbon emissions over total carbon emissions of China's steel industry
2010	1,175.6000	1,008.09	167.51	0.14
2011	1,263.1658	1,077.54	185.62	0.15
2012	1,326.3321	1,117.15	209.18	0.16
2013	1,453.2682	1,269.51	183.76	0.13
2014	1,592.4537	1,269.01	323.45	0.20
2015	1,520.7224	1,157.29	363.44	0.24
2016	1,544.0843	1,185.19	358.90	0.23
2017	1,524.9108	1,294.81	230.10	0.15
2018	1,653.3963	1,356.31	297.09	0.18
2019	1,798.5996	1,490.26	308.34	0.17
2020	1,905.9841	1,610.99	294.99	0.15

It can be seen from Table 1 that China's steel production is showing an upward trend as a whole, but there is a significantly different trend in terms of apparent steel use and true steel use. After China's apparent steel use and true steel use peaked in 2013, they showed a downward trend, and then climbed again in 2016. Since these two indicators mainly reflect the level of domestic demand for steel products and steel-containing products, it is not difficult to find that the Chinese government’s regulation of overcapacity in the steel industry in 2013 has a certain inhibitory effect on domestic steel demand, but has a negative impact on steel companies. The actual output has endured limited impact, and companies have transferred the pressure of domestic steel demand reduction through international trade.

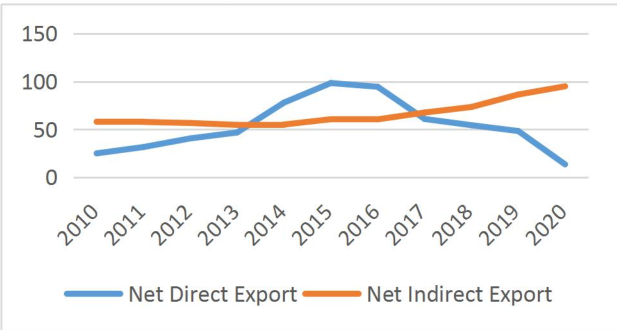

Figure 1. 2010-2020 net direct export and net indirect export of China's steel industry

The trade trend of China's steel products can be more intuitively reflected in Figure 1. The net direct export volume refers to the net export volume of steel products, which has great change amplitude. After a significant increase from 2010 to 2015, it has fallen sharply to the level before 2010; on the contrary, the net indirect export volume mainly refers to the steel-containing products. The number of net exports, as a whole, shows a steady growth trend.

Comparing the two indicators, it is not difficult to find that the net direct export volume of China's steel industry has a significant correlation with the international economic situation. China's "Belt and Road" strategy has increased the demand for Chinese steel and reduced the surplus faced by steel companies. After 2016, China's production control of steel companies has achieved significant results, focusing on financing overseas steel projects. China's net indirect steel exports mainly measure the exports of steel-containing products, and their exports are mainly determined by overseas consumer markets, which shows that the competitiveness of China's steel-containing products is still strong.

3.2 The embodied energy flow and embodied carbon emissions of China's steel industry from 2010 to 2020

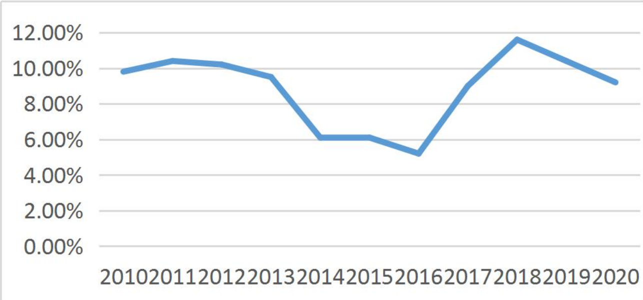

Figure 2. The proportion of short-process production in China's steel industry from 2010 to 2020

There are two main types of steel production processes, including long process and short process. Among them, the fuel for the long process is mainly coke, and steelmaking is realized through the converter, while the electric furnace is mainly used for the short process. Compared with the long process that requires iron ore as a raw material for production, the short process can also use waste steel as a raw material to achieve steelmaking. Therefore, the short process has gradually become a more preferred mode of production for iron and steel companies, which can generate less carbon emissions, and achieve the recycle of steel. Figure 2 shows the use ratio of long and short processes in China's steel industry. As long and short processes have significant differences in energy requirements and carbon dioxide emissions in the steel production process, they need to be considered separately.

Table 2. China's steel energy demand from 2010 to 2020 (Unit: thousand gigajoules)

Year	Supply Side			Consumption Side			Embodied Energy Flow
	Short-process	Long-process	Total	Short-process	Long-process	Total	
2010	0.2777	11.0979	11.3756	0.2381	9.5165	9.7547	1.62
2011	0.3502	11.9245	12.2747	0.2987	10.1722	10.4709	1.80
2012	0.3598	12.5208	12.8806	0.3031	10.5461	10.8492	2.03
2013	0.3644	13.7191	14.0835	0.3183	11.9844	12.3027	1.78
2014	0.2471	15.0330	15.2801	0.1969	11.9796	12.1765	3.10
2015	0.2357	14.3559	14.5915	0.1793	10.9250	11.1043	3.49
2016	0.2020	14.5764	14.7785	0.1551	11.1884	11.3434	3.44
2017	0.3598	14.3954	14.7552	0.3055	12.2232	12.5287	2.23
2018	0.5176	15.6083	16.1259	0.4246	12.8038	13.2283	2.90
2019	0.4980	16.9791	17.4771	0.4126	14.0683	14.4809	3.00
2020	0.4680	17.9928	18.4608	0.3955	15.2080	15.6036	2.86

Through calculation, the embodied energy consumption and embodied carbon emissions of China's steel industry from 2010 to 2020 can be obtained. It can be seen from Table 2 that the embodied energy consumption of China's steel industry exceeded 1.6 KJ for every year, with the highest reaching nearly 3.5 KJ. This shows that through the steel trade, China indirectly exports a large amount of energy consumption to other countries, which also produces a large amount of CO2 emissions.

Table 3. China's steel carbon emissions from 2010 to 2020 (Unit: metric tons)

Year	Supply Side	Consumption Side	Embodied Crabon Emissions	Percentage of embodied carbon emissions over total carbon emissions of China's steel industry
2010	1,175.6000	1,008.09	167.51	0.14
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From the perspective of "producer responsibility", the embodied energy flow or embodied carbon emissions on the production side refers to the energy flow or embodied carbon emissions of a country's intermediate production input in order to meet the final demand of the country and foreign countries; From the perspective of "consumer responsibility", the embodied energy flow or embodied carbon emissions on the consumer side refers to the energy flow or embodied carbon emissions in the final demand generated by a country's demand, whether it occurs at home or abroad.

Table 2 and Table 3 show the import and export flows of embodied energy consumption and carbon emissions from the perspective of producers and consumers respectively, which is greater than the implied energy flow and implied carbon emissions of import and export on the consumer side.

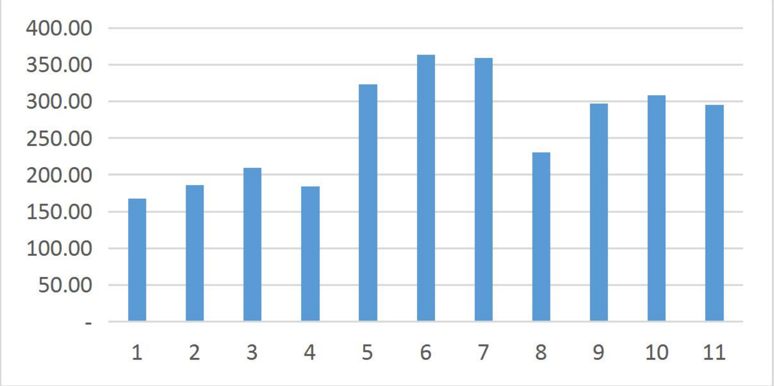

Figure 3. The embodied carbon emissions of China's steel industry from 2010 to 2020

Figure 3 shows the embodied carbon emissions borne by China's steel industry in the process of steel trade. It has shown an overall upward trend since 2010, highlighting the challenges faced by China's steel industry in reducing carbon under the goal of "carbon neutrality". Many challenges include not only the pressure from domestic economic growth, but also the impact of uncertainty in the international steel market. Since energy-intensive industries need to use a lot of energy, intermediate products usually have the characteristics of high energy consumption and large amounts of carbon dioxide. Developed countries absorb a large amount of external energy consumption from developing countries through import and export substitution. When China trades steel with other countries, it indirectly consumes a large amount of energy resources and generates a large amount of embodied carbon emissions.

4. Conclusions and recommendations

Based on the Low Emissions Analysis Platform, this study analyzed the embodied energy flow and embodied carbon emissions of China's steel trade from 2010 to 2020. The main conclusions are as follows. (1) From the perspective of international trade, both energy consumption and embodied carbon emissions are greater than direct energy consumption and direct carbon emissions in China’s steel industry, which indicates that the intermediate links and final demand of the steel industry directly or indirectly consumed a large amount of energy and generated a large amount of carbon dioxide emissions. (2) The embodied energy consumption and embodied carbon emissions from the perspective of the producer are greater than the embodied energy consumption and embodied carbon emissions from the perspective of the consumer, and they account for a large proportion of the total carbon emissions of Chinese steel companies.

From the perspective of ecological development, we provide China with the following suggestions: (1) China should pay more attention to energy use in trade transactions, and reduce the use of fossil energy, thereby reducing carbon dioxide emissions. In addition, it is necessary to actively explore green investment technologies, implement energy-saving emission reduction strategies, strengthen international ties, promote trade integration, and protect the ecological environment based on low-carbon economy, and implement a green trade model. (2) China has become a major energy consumption and carbon emission country, and certain energy consumption and carbon emissions will be generated in the manufacturing process of various commodities. Therefore, China should pay more attention to systematically measuring the indirect energy consumption and indirect carbon emissions of intermediate products, and optimize the trade structure to better establish an efficient energy-saving and emissions-reduction system and a green trade system.

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