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Thoughts and Prospects for Promoting Energy-Saving and Carbon Footprint Reduction in the Non-Ferrous Metal Industry

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Abstract

As the upstream of high-energy consumption industries such as metallurgy and chemical enterprises, the "carbon neutrality" ability of mining and mining enterprises can have a strong influence on the progress of China's non-ferrous metal industry to achieve the "double carbon" goal. According to the Global Mining Development Report 2021, although mining occupies an important position in global economic development, it also accounts for 4% to 7% of global greenhouse gas emissions. Therefore, as an important part of promoting China's economic development and energy structure transformation, mining will also face scale adjustment. By investigating and studying the carbon emission sources of mining enterprises at the current stage at home and abroad, the carbon neutrality method that has been implemented in mines, and the future low-carbon technologies to be developed, this paper provides the thoughts and prospects for promoting the development of green mines, as well as the reference value for the transformation of China's mining industry.

Keywords

Carbon Emission, Carbon Footprint, Low-Carbon Technologies, Green Industrial Chain

1. Background

Large mining companies occupy an important position in the global mining industry, accounting for 80% of the global market value of the top 20 companies [1] [2]. They not only have global high-quality mineral resources, but also affect the transformation plan of the global mining industry to achieve net zero carbon. In the context of global climate change, many international resource industry giants, including Glencore, Rio Tinto, Vale, BHP, Barrick and other companies, have been active [3]. In response to the Paris Agreement, they put forward their own carbon reduction goals and set deadlines for enterprises to achieve "carbon peak" and "carbon neutrality". The above-mentioned enterprises have shown in their sustainable development reports or annual reports that they have formulated corresponding action plans and strategic deployments around the established carbon reduction and carbon neutrality goals in terms of changing production methods, focusing on low-carbon production concepts, and supporting scientific and technological development [4] [5]. From capital investment to technology development, cross-field cooperation, new equipment, new materials and other aspects, we will gradually promote the development of low-carbon production and a green industrial chain of mining enterprises. The target plan for large mining companies is shown in **Table 1**.

2. Introduction

1) Carbon footprint in mines

According to the mining process, the source of carbon emissions in the mine can be roughly divided into three stages: mining, transportation and beneficiation, and each stage can be further classified according to the type of process [10] [11]. Existing data shows that the annual greenhouse gas emissions of mines are about 200 - 400 kt CO_2 equivalent [12] [13]. Due to different yields and mining methods, the floating range is large. For example, the Sino iron mine in Australia, the mine is open-pit mining, and the ore mining scale is about 2 5 Mt/a, and the annual carbon emission is about 176 kt CO_2 equivalent [14]. Under normal circumstances, the carbon emissions of open-pit and underground mining in mines under the same scale are considered to be basically the same. Among them, the greenhouse gas emissions from open-pit mines due to soil removal (ecosystem and vegetation carbon storage capacity decline) are equivalent to additional exhaust gas emissions in underground mines (deeply lengthened transportation paths).

Due to the complexity of the process flow and the diversity of equipment contained in the mine, each mine is unique and requires case analysis. Therefore, the accounting of carbon emissions and the estimation of carbon footprint in the mine face great challenges [15] [16]. So far, most mines still choose the method of deduction based on historical data, and roughly estimate the carbon emissions of the mine in years [17]. In this way, it is difficult to achieve accurate, transparent, continuous and complete detection and calculation of greenhouse gas emissions, which adds a lot of difficulty to the subsequent energy conservation and emission reduction plans, as well as the strategic deployment of neutralization and net zero. Therefore, promoting the application and popularization of digital supervision of mines can provide a good dynamic carbon emission database for real-time detection, and provide more detailed emission reports for

Table 1. Carbon neutrality goals and strategic plans of large international mining companies [6] [7] [8] [9].

Company Name	Carbon Neutrality	Strategical Goal		
	Yr	Targets/Plans	1st Step Measure	2nd Step Measure
Glencore		Reduce absolute carbon emissions by 20%	1) Use 13% renewable energy	1) Reduce energy carbon emissions by 20%
			2) Reduce indirect carbon emissions by 20%	2) Establish a carbon transportation and storage (CCUS) research company to carry out technical research and infrastructure construction
Rio Tinto		Reduce absolute carbon emissions by 39%,improve the metallurgical grade	1) Use renewable energy and battery systems	1) Cooperate with BaoSteel and Tsinghua University to realize the low-carbon steel industry chain
			2) Use rails and trams instead of fuel	2) Cooperate with ELYSIS to establish low-cost water conservancy power generation projects
			3) Exit the coal industry and explore the lithium market and related industries	3) Research on low-carbon aluminum processing and investment in research and development of new technologies for carbon recovery
Vale	Up to 2030	Reduce absolute carbon emissions by 33%, Restore more than 100,000 hectares of vegetation	Achieve 100% independent production of clean energy in Brazil	1) Establish a low-carbon summit to link upstream and downstream industrial chain enterprises
				2) Analyze the risks caused by the fluctuation of carbon prices to production
BHP		Reduce absolute carbon emissions by 30%	1) Research on the application of electric truck fleets and renewable energy	1) Provide technical support for steel enterprises to help reduce emission intensity by 30%
			2) Purchase the renewable based PPA materials	2) Cooperate with the university to invest US$20 m in research for CCUS
				3) Establish the green alliance with large companies such as Hatch and FMG
Barrick		Reduce absolute carbon emissions by 10%	1) Reduce energy-related carbon emissions by 20%	1) Start the basic research of step 2 and set goals
			2) Research and development of battery power grid stability technology	2) Invest in carbon reduction-related technologies and set up relevant organizations of the group
			3) Start using solar energy to build natural gas power stations	3) Carry out exchanges and cooperation on low-carbon production with the upstream supply chain

mining enterprises, so as to assist in the formulation of more accurate emission reduction targets and more applicable emission reduction plans, and further accelerate the realization of the "double carbon" goal of mines.

2) Thoughts on the mine construction and development model under the goal of "double carbon"

By comparing the "double carbon" strategic planning of large international mining enterprises, it can be seen that although each enterprise is affected by the country, the location of assets and the company structure, the emission reduction plans presented by each enterprise are different, but comprehensive consideration can roughly divide the action path of "double carbon" mine construction and development into four directions.

2.1. Improve Transportation Efficiency and Reduce Direct Carbon Emissions from Production Activities

Research shows that during the whole life cycle of the mine, the proportion of direct carbon emissions from production and transportation activities in the mining stage is as high as 45% to 60%, and the proportion of energy consumption brought by transportation activities is as high as 35% [18]. Therefore, reducing the exhaust emissions of mobile devices has become one of the top priorities to achieve carbon neutrality in mines. On average, only about 0.5% of the equipment in the mine is all-electric, so there is still a lot of room for development [18]. If all transportation equipment is replaced with battery-driven, it will reduce the carbon emissions of the mine by nearly 25% [19]. Therefore, mining enterprises also need to actively assist in the research and development and promotion of new energy battery technology. By optimizing the energy storage efficiency, charging time and working time of the battery, the operational benefits of electric equipment have been significantly improved, so as to make up for the investment pressure caused by the total cost of ownership is nearly 20% higher than that of traditional diesel mobile devices [18].

In addition to directly selecting battery or oil-electric hybrid transportation equipment, some mines have also begun to use digital modeling and simulation calculations to carry out mine transportation calculations, and use information platforms for resource allocation, fleet scheduling and equipment control. The combination of intelligent platforms and networked transportation equipment can greatly shorten the transportation path and reduce the occurrence of queuing and air transportation. Some studies have also pointed out that when the transportation path is optimized, with the shortening of the path and the efficient use of trucks, the use of tire rubber can be greatly reduced, and it is also conducive to reducing the greenhouse gas emissions of the project. Such a construction concept can solve the problem from the perspective of energy consumption, and greatly improve production efficiency under the premise of ensuring the stable realization of energy conservation and emission reduction in the mine.

2.2. Optimize Process Design to Maximize Resource Utilization

Reducing the loss and dilution rate and improving the recovery rate of raw ore metal has always been the core goals of mine production. Therefore, the large-scale grinding equipment used in the beneficiation stage is the second largest source of carbon emissions for mobile vehicles in the mine. With the introduction of new equipment, the resource recovery rate will gradually increase, the processing efficiency of ore dressing equipment will also be improved, and the mining process design needs to be improved accordingly. The Global Mining Development Report 2021 also pointed out that by 2050, in order to meet the growing demand for clean energy technology, the production of minerals such as graphite, lithium and cobalt will increase by nearly 500%, and the deployment of wind energy, solar energy, geothermal energy and energy storage will require more than 3 billion tons of mineral and metal resources [1]. Therefore, the change in demand from non-ferrous metals to renewable and electrified raw materials such as nickel, lithium and rare earth will also lead to changes in mine process design.

On the one hand, the mine can make trade-offs and adjustments in process design according to the ore output, energy consumption, working time and other parameters of the new equipment, so as to greatly reduce the electricity consumption of fixed equipment and the use of fossil fuels in the factory, thus reducing the carbon emissions caused by energy consumption. On the other hand, digital production and intelligent management can greatly improve resource utilization and reduce unnecessary energy losses. In the process design process, numerical models, collaborative platforms, information collection and other technologies can be used to assist in the construction of digital twin mines, maximize the utilization of raw materials, working devices, production equipment, labor and other resources, and accelerate the realization of mines in production under the premise of ensuring production progress and production safety. Energy conservation and emission reduction targets in the stage.

2.3. Realize the Transformation of the Energy Structure of the Mining Area and Fully Cover Renewable Energy

Although China's GDP coal consumption decreased from 0.85t to 0.45 t between 2010 and 2019, the intelligence of developed countries has gradually led the country's GDP coal consumption of 10,000 yuan towards 0.1 t [20]. This means that China still needs to drive the revolution of energy consumption through the "double carbon" plan, greatly improve the coverage of clean energy and renewable energy, and reduce the proportion of coal use. At present, globally, China is gradually becoming a major producer of renewable energy and the country with the highest investment at this stage. China's wind power generation has an average annual growth rate of 30 million kilowatts, and photovoltaic power generation has an average annual growth rate of nearly 50 million kilowatts [14]. It is estimated that it will achieve a large area of wind and solar energy coverage by

2030 [12]. Such a development trend can quickly reduce the cost and use price of renewable energy, thus improving its competitiveness compared with traditional fossil energy. Due to the high cost of clean energy power transportation, the construction of independent power stations in remote areas can make clean electricity more economical and widely cover the entire mining area and drive the power supply range in remote areas.

2.4. Improve the Design Greening Rate, Reduce the Amount of Waste Objects, and Improve the Carbon Sequestration Level of the Ecosystem

Vegetation loss, soil stripping and biodiversity destruction have always been important issues affecting the ecosystem balance in the mining area [14]. Mining in mining areas has seriously affected the carbon cycle in the ecological environment and its own carbon sequestration capacity, and is usually regarded as one of the fundamental problems of carbon growth. In addition, with the lower grade of ore, it directly leads to the increase of tailings and waste stone production, thus increasing the floor area of solid waste materials. Therefore, the soil protection of mining areas and the stability of biological species are a long-term and arduous problem.

For mines in production and historical legacy mining areas, successful ecological restoration can improve the carbon sequestration capacity of nearly 20% of the mining area [12], which is one of the good solutions to help achieve carbon neutrality in the mine. The source of carbon sinks in mining areas also depends on vegetation and soil. By improving the soil, repairing vegetation and other land reclamation methods to improve the ecological environment and soil function of the mining area, we can strengthen the repair ability of the damaged environment in the mining area, and at the same time improve the carbon sequestration capacity of its ecosystem, so as to achieve a balanced state of carbon reservoir. The mining area needs to adopt a method adapted to local conditions, according to the climatic and environmental conditions, species distribution, the structural scale of the mining area, etc., to make a comprehensive evaluation and customize the exclusive reclamation plan, so as to improve the carbon sequestration and circulation ability of the mining area as soon as possible [21].

3. Challenges and Opportunities

Under the background of "double carbon", for the non-ferrous metal industry, it is difficult to solve the production inertia in a short time, and ordinary emission reduction means can no longer bring more significant results. Therefore, the domestic mining industry urgently needs systematic structural adjustment. For a long time, the protection and construction of the ecological environment has played a significant strategic position in China's long-term development plan [14]. Therefore, the mining industry needs to accelerate low-carbon technology innovation in the field, promote the transformation of green and intelligent mines, improve the quality of mine production and strengthen ecological and environmental protection, so as to provide strong support for China's metal mines to achieve the goal of "double carbon".

For example, the short-term plan to build a low-carbon mine is to use electric mobile devices to reduce direct emissions from carbon emissions in transportation. Long-term development can form alliances with smelting enterprises, raw material suppliers, equipment manufacturers, etc. in the upstream and downstream industrial chain to jointly build a green and low-carbon industrial value chain, and continue to expand the influence of "double carbon" in the mining field. Mining enterprises also need to make timely decision-making adjustments, consider the environmental impact and low-carbon cost of the project in the investment stage, consider the application of new processes, energy and raw materials in the process design stage, and consider the construction of digital production and information platform in the construction stage, so as to realize the top-down top-level "double carbon" strategy draw. Under this goal, mining enterprises should also accelerate the investment and assistance in pollution reduction and carbon reduction technology, achieve major breakthroughs in green and low-carbon technology, and promote the transformation of society to green and low carbon. In order to obtain long-term social reputation, market competitiveness and business ability, they should formulate more applicable operation plans.

4. Implications

In accordance with the relevant work requirements of the 20th National Congress of the Communist Party of China, Aluminum Corporation of China, or Chinalco, is accelerating its emission reduction actions and making corresponding strategic arrangements to achieve the "double carbon" goals of carbon peaking in 2030 and carbon neutrality in 2060 on time. The carbon neutrality measures that have been implemented in industrial applications and the future low-carbon technologies to be developed will provide key assistance for the development of the green non-ferrous industry.

For instance, In terms of deep-well mining, Chinalco has developed the "non-explosive short-process mechanized mining technology for deep-well hard rock deposits" technique. Using cantilever tunneling machines as the core and continuous transportation with conveyor belts, it has achieved the integrated process of mining-loading-transportation-supporting. The traditional blasting mining technology has been successfully replaced by this new mining method. In terms of energy-saving and carbon reduction, Chinalco has developed the technology of utilizing surplus energy for long-distance slurry pipeline transportation with high drop distance and successfully converted the natural drop of raw ore pipeline in high-altitude mines into transmission potential energy for power generation. In terms of clean energy utilization, Chinalco has carried out technological integration of the copper smelting process and innovatively developed the copper smelting technology consisting of side-blown furnace melting, top-blown furnace blowing, and anode furnace refining. Chinalco has also converted the heat sources from coal and natural gas to hydrogen to promote the goal of zero carbon emission in copper smelting. In the field of electrolytic aluminum smelting, Chinalco has independently developed a new energy-saving aluminum electrolytic cell with stable current insulation technology. This new technology is based on cathode stable-current optimization technology, voltage balance optimization technology, and energy balance optimization technology. This technology significantly reduces the average voltage of the electrolytic cell and dc power consumption of primary aluminum and effectively improves current efficiency.

As a large comprehensive non-ferrous metal enterprise in the world, Chinalco is committed to the construction of ecological civilization and promotes the accelerated transformation of the non-ferrous metal field to green and low-carbon in a safer, efficient, green and sustainable way by accelerating transformative technological innovation. With the goal of rational utilization of resources, energy conservation and emission reduction, protection of the ecological environment, and promotion of the harmonious development of mines, the Group has consciously assumed the social responsibility of saving and intensive use of resources, energy conservation and emission reduction, ecological environmental protection, and driving local economic and social development. At the same time, we will accelerate the construction of green mines, strictly implement environmental protection standards, promote advanced technologies of energy conservation and environmental protection, reduce solid waste emissions, strengthen the comprehensive utilization of resources, develop a circular economy, earnestly fulfill social responsibilities, and promote the economic and social development of resource areas.

Chinalco will continue to take low-carbon technology as a breakthrough, always adheres to innovation-driven, benchmark the industry first-class and improves core competitiveness. Moreover, speeding up the development in the direction of green, safe, intelligent and efficient, striving to deeply integrate big data, artificial intelligence, cloud computing, mobile Internet and other modern information technologies with the development of non-ferrous metals. Meanwhile, quickly introducing new technology means such as intelligent exploration, intelligent mining, and mining the Internet of Things. We will accelerate the development of ecological restoration technology, form a breakthrough in the new technology of smelting, greatly improve the efficiency of resource utilization, accelerate the “double carbon” process of the non-ferrous metal industry, achieve better development of enterprises, and make greater contributions to the world.

5. Conclusion

With the signing of the Paris Agreement, China has been accelerating its emission reduction campaign and has made a corresponding strategic deployment to achieve the "dual carbon" goal of a carbon emission peak in 2030 and carbon neutrality in 2060 on schedule. The investigation and research on the current carbon emission source of mining enterprises at home and broad, carbon neutrality method already implemented in mines and the future low-carbon technologies to be developed will provide a significant scientific basis for the development of green mines and referential value for the transformation of mining industry in China. Through the overview of the composition and accounting method for greenhouse gas emissions in the mining industry; the implementation path and scheme of carbon neutrality action in mining enterprises and the development direction of new technologies on energy conservation and emission reduction and auxiliary carbon sink projects, it is concluded the mining industry in China will usher in a large-scale transformation in the mix of energy consumption and industrial structure.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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