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Construction of Low-Carbon Land Use and Management System in Coal Mining Areas

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Abstract: In 2021, the Chinese government set the national development goal of 'carbon peak and carbon neutrality'. Defining the carbon cycle process of land use is the first step for the implementation of low-carbon land use in coal mining areas. In this study, the carbon income and expenditure of land use in coal mining areas were analyzed theoretically using normative analysis, and thus the corresponding conceptual model of the carbon budget was formed. Concretely, carbon emissions from the coal industry were mainly from two aspects, that is, soil carbon emissions caused by drastic changes in land use in the coal exploration and exploitation stage and greenhouse gas emissions in the coal collection stage. Moreover, carbon in the air is sequestered in the soil when exploration land and mining land were reclaimed into woodland and grassland. Meanwhile, to optimize the utilization of land resources and realize the land low-carbon pattern from the management perspective, the logic system of land low-carbon use management in coal mining areas was explored using normative analysis and literature review. Thus, a complete management system including the management objective, subject, object, means, and implementation guarantee mechanism was built in detail. This study provided ideas for carbon reduction in coal mining areas and laid a decision-making basis for regional low-carbon land use and sustainable development.

Keywords: coal mining areas; land use; carbon budget; low carbon; management system

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1. Introduction

The massive emission of greenhouse gases is one of the causes of global warming [1], and the low-carbon economy has become an important development strategy for various countries in the new era. In September 2020, at the 75th session of the United Nations General Assembly, China put forwards the strategies of reaching the carbon peak by 2030 and carbon neutrality by 2060 and formulated the carbon emission intensity target for 2030. That is, CO_2 emissions per unit of GDP in 2030 are reduced by at least 65% compared with those in 2005. Carbon peak and neutrality have been the most important tasks in China in recent years.

Human activities, especially fossil fuel combustion [2–5] and land cover change [6–11], deeply affect the global carbon cycle. Irrational land use has become the main cause of greenhouse gas emissions, second only to fossil fuel combustion [12,13]. From 1850 to 1990, land-use changes resulted in carbon emissions of 124 Pg into the atmosphere, and the value was equivalent to approximately half of the emissions from fossil fuel combustion over the same period [14]. Changes in land-use types, patterns, and processes can cause strong disturbances to soil and vegetation carbon pools [9,15,16], resulting in carbon escaping into the atmosphere and an increase in the global greenhouse effect [17,18]. Scientific management and optimization of policies can not only improve land use conditions [19] but also optimize soil quality for carbon sequestration [9]. Lal (2002) found that more than half of the carbon that has been lost could be sequestered through better land use and management [20].

Coal is an important energy resource in our current society. However, coal mining led to surface subsidence in mining areas [21–23] and drastic changes in land-use types [24–26], which would result in huge carbon emissions. Thus, the coal industry has become an important area of governance for carbon emission reduction. China is the world's largest producer, consumer, and trader of coal [27], and in 2021, it supplied 2.90 billion metric tons of coal, which accounted for 50.5% of global coal production and consumed 2.93 billion metric tons of coal. In 2018, there were 3986 coal mines in production in China, mainly in Shanxi province, Inner Mongolia province, Shaanxi province, and Xinjiang province, according to the latest official data from the National Energy Administration in China [28]. Along with the production of a large number of coal resources, the land use of coal mining areas underwent drastic changes. For example, the Antaibao Open-pit Coal Mine in Shanxi province is the largest world-class open-pit coal mine in China. In 1976, no large-scale exploitation of coal resources was here, and the main land types were arable land and forest land. However, when the Antaibao Coal Mine was put into production formally in 1987, cultivated land and forest land area decreased by 992.25 hm^2 and 199.71 hm^2, respectively, and their proportion decreased to 45.05% and 13.56%, respectively [29]. Especially, by 2009, the original landform farmland and forest land were all developed into mining land [30]. Another example is the Xilinhaote coal mining area in Inner Mongolia, a large coal power base in China. From 1991 to 2020, 73.48 km^2 of land area was developed for industrial and mining use, 95.59% of which was previously grassland [31]. It can be concluded that at different development stages in coal mining areas, a large number of agricultural land such as arable land, forestland, and grassland were developed and converted into industrial and mining land to meet the needs of the expanding scale of coal mining. This indicated the potential for significant carbon emissions. For example, in Pingshuo mining area in Shanxi province, one of China's largest coal production bases, carbon emissions due to land damage reached 591.2×10^4 tons from 2011 to 2015 [32]. Therefore, scientific land management and low-carbon regulation in coal mining areas are very important for effectively restricting carbon emissions caused by land use in mining areas, which would increase the overall carbon reserve of the global ecosystem to a certain extent [33].

For low-carbon land use and management, scholars have studied both macromanagement [34–38] and micromanagement [39–46]. At the macro level, some scholars proposed the development of compact cities [33] from the perspective of urban planning, hoping to reduce carbon emissions by increasing the composite performance of urban land use [35]. Others optimized the quantitative structure for the overall land use in cities or regions and put forward policy suggestions for low-carbon land optimization, such as an 'urban growth boundary' and an 'ecological red line' [33,36]. Aydin et al. (2012) proposed rationally arranging green areas according to the form and density of residential areas to achieve a carbon and oxygen balance [37]. The micro research mainly focuses on agricultural land types such as farmland [39,40], grassland [41,42], and forestland [43–46]. For farmland, measures such as the combined application of organic and inorganic fertilizers and returning straw to fields have great carbon sequestration potential [40]. For grassland, the implementation of reproductive balance and grazing bans, as well as that of grassland vegetation restoration and protection projects, can effectively improve the carbon sink function [42]. For forestland, while reducing deforestation and increasing afforestation, effective land use and management can absorb a large amount of carbon [46]. Therefore, the study on the carbon change in a single land-use type will provide a reference for low-carbon land use in coal mining areas. In particular, there is little research on the carbon cycle of land use in coal mining areas, and the carbon budget change caused by the change in land-use type needs to be further discussed. In addition, studies on how to organize and manage land use effectively to reduce carbon emissions in coal mining areas are very limited, and thus the relevant guiding theory should be sorted out. In this study, a conceptual model of the land use carbon budget in coal mining areas in China was elaborated theoretically.

Then, through the construction of a low-carbon land-use management system from the perspective of management, the low-carbon land-use management institution in coal mining areas was explained. Thus, we hope to provide a theoretical basis and decision-making reference for the control of low-carbon land in coal mining areas under the goal of "carbon peak and neutrality".

2. Land Use Conceptual Model of the Carbon Budget in Coal Mining Areas

The coal mining area refers to a micro land use area specifically for mineral resources exploration, development, and collection. Generally, the independent mining area includes the mine production area and the living area. Mine production areas are mainly used for mineral resource exploration, development, and collection. In comparison, mine living areas are mainly for the needs of the mine workers and their families.

Most of China's mines were initially located far from towns. Before mining, there were various types of land use in the region, including cultivated land, forestland, grassland, unused land, etc., and some areas may include a small amount of transportation and construction land and water land. The land use carbon cycle is a natural carbon process that connects the atmosphere, ground plants, animals, and the soil. In this process, plants capture the atmospheric CO_2 through photosynthesis, while plants and animals release CO_2 through respiration. Meanwhile, plant litter and animal waste are decomposed by microorganisms and converted into organic carbon in the soil. In comparison, In the process of mineral resource exploration, the natural state of land resources in the region is destroyed, and cultivated land, forestland, grassland, and other land types are transformed into exploration land. According to a large number of studies, cultivated land [47–50], forestland [50–52], and grassland [50,53,54] can solidify and absorb organic carbon, acting as carbon sinks. The carbon absorption coefficients of cultivated land, forestland, and grassland were 0.07~4.79 $t/hm^2 \cdot a$ [47–50], 1.03~5.9 $t/hm^2 \cdot a$ [50–52], and 0.029~0.95 $t/hm^2 \cdot a$ [50,53,54], respectively (Table 1). The exploration process may destroy the vegetation of forestland and grassland, resulting in a significant reduction in biomass and vegetation carbon storage [9]. At the same time, vegetation destruction may increase carbon emissions [13]. Exploration land is temporary land. After exploration, if mineral resources are found, they may be developed into mining land, resulting in a large amount of carbon emissions. In contrast, if there are no mineral resources, it may be returned to transportation land and construction land, with a carbon emission coefficient of 58.76~96.90 $t/hm^2 \cdot a$ for transportation land and 342.15~399.84 $t/hm^2 \cdot a$ for urban industrial and mining land [50] (Table 1). Both types of land use will lead to an increase in carbon emissions [55,56]. In the stage of mineral resource development and collection, the original natural landform in the mining areas changes dramatically. A large amount of farmland, woodland, grassland, and other agricultural land is transformed into mining land, which would serve the whole mine production cycle of the mine until the end of the mining activity. During this period, the change in land-use type would lead to a significant decrease in biomass, carbon emissions from vegetation residues, and soil carbon sequestration. Also, in the stage of mineral resource development and collection, coalbed methane emissions, fossil fuel combustion, explosive consumption, and electric energy consumption will all bring about direct or indirect carbon emissions into the atmosphere [32]. During the whole process of exploration, exploitation, and collection, the carbon-containing wastes discharged from prospecting land and mining land are decomposed into soil organic carbon and form a soil carbon pool. After the functional utilization of mining land, it should be reclaimed and transformed into cultivated land, forestland, or grassland, which can effectively promote carbon balance and carbon storage [57,58].

Table 1. The carbon absorption coefficient and carbon emission coefficient in different land-use types.

Study Period	Types of Land Use	Carbon Absorption Coefficient (t/hm^2 a)	Carbon Emission Coefficient (t/hm^2 a)	Reference
2020	Cultivated land	4.55~4.79	2.16~2.24	Zhao et al. (2013) [50]
	Garden plot	3.19~4.31	0.73~0.96	
	Forest land	3.81	0.06~0.14	
	Pasture land	0.95	-	
	Urban industrial and mining land	1.93~2.05	342.15~399.84	
	Rural settlement Land	1.93~2.15	7.22~11.27	
	Transportation land	-	58.76~96.90	
	Water area	0.80~0.84	0.46~0.95	
2001–2010	Forest land	1.03	-	Fang et al. (2018) [51]
2000	Forest land	1.7~5.9	-	Yu et al. (2013) [52]
1980–1990	Pasture land	0.029~0.050	-	Piao et al. (2009) [53]
1961–2013	Pasture land	0.045	-	Zhang et al. (2016) [54]
1980–2000	Cultivated land	0.07	-	Sun et al. (2010) [47]
1980–2010	Cultivated land	0.22~0.34	-	Xie et al. (2010) [49]

Mine living areas serve the needs of mining workers and their families, and their land-use types are similar to those in towns. In this region, plants and animals provide food for human survival, which is rapidly consumed by the human body. Some of the food is converted into CO_2 and released into the atmosphere through respiration, while the rest is left in excrement and returned to the soil. Also, microbes in the soil decompose excreta of humans and animals, as well as garbage and waste decomposition generated in human life. Some of the carbon generated in this process is released into the atmosphere as CO_2 and the rest as organic matter into the soil. Meanwhile, human beings use wood and energy provided by plants as raw materials to carry out construction activities and the production of furniture, books, and newspapers. Thus, the processing and transportation of plants would use fossil fuels, resulting in a large number of carbon emissions. Then, energy-driven transportation also consumes fossil fuels and releases CO_2, CH_4, and other greenhouse gases into the atmosphere. Although buildings, furniture, books, newspapers, and other living materials can fix some of the carbon, when they are used up and turned into rubbish, some of the fixed carbon is burned and decomposed back into the atmosphere.

In addition, there is a carbon exchange between the atmospheric carbon pool and the water carbon pool. In this process, the algae in the water ecosystem fixes the carbon in the form of organic matter in its body through photosynthesis, and then passes it along the food chain to other aquatic life. With the death and deposition of algae and other aquatic life, part of the carbon fixed by photosynthesis enters the water sediment and becomes a stable carbon pool. The release of carbon from water mainly refers to the evaporation of gaseous carbon. Accordingly, a conceptual model of the land use carbon budget in coal mining areas would be built, as shown in Figure 1. Obviously, the mine production area is the main area of low-carbon land-use management in the coal mining areas, and this management should run through the whole life cycle of the coal mine (including the exploration, development, collection, and reclamation stages).

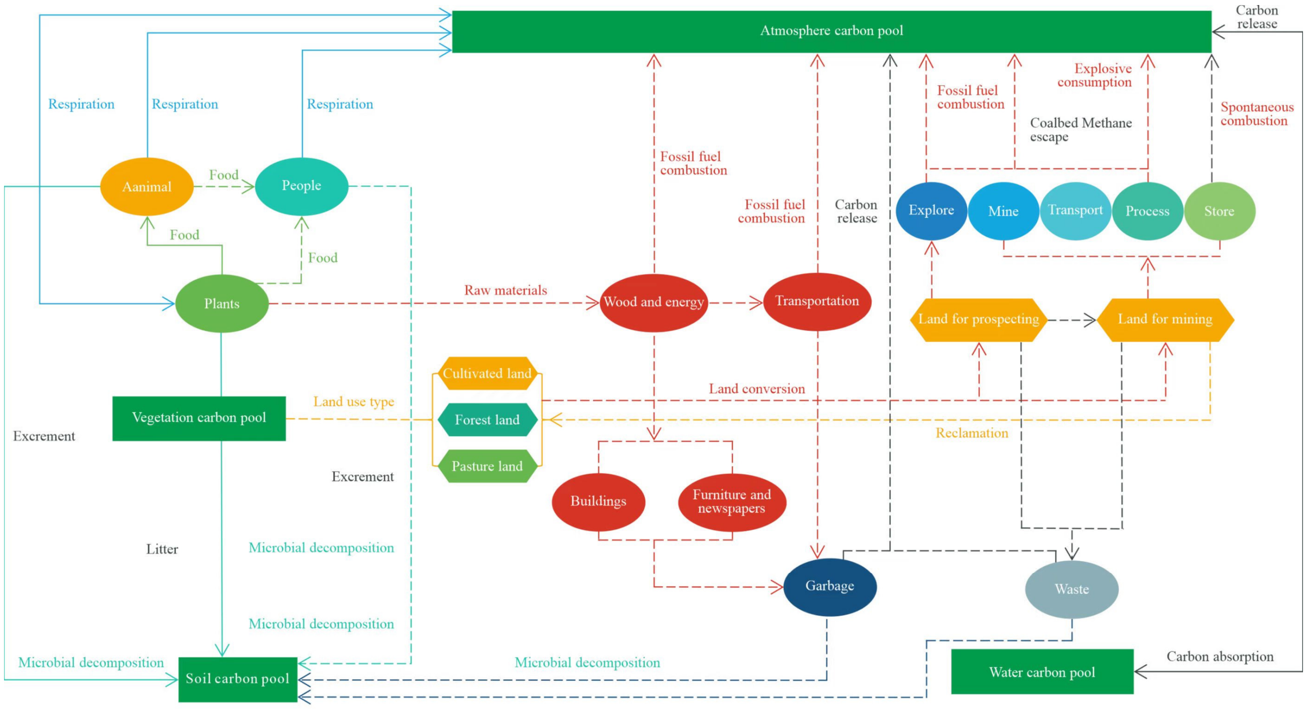

Figure 1. The conceptual model of land use carbon budget in coal mining areas.

3. Construction of a Low-Carbon Land-Use Management System in Coal Mining Areas

The low-carbon land use and management system in coal mining areas involves five aspects: Management objective, management subjects, management objects, management means, and the implementation guarantee mechanism (Figure 2).

3.1. Management Objective

The objective of coal production in coal mining areas is to obtain coal products and realize economic benefits. China has put forward a strategy of ecological civilization construction and made strategic deployments for the realization of 'carbon peak and carbon neutrality'. Energy conservation and emission reductions in coal mining areas have become important goals of mine management. Therefore, the low-carbon land use and management system in coal mining areas need to coordinate the contradiction between economic development and environmental protection. On the one hand, it is necessary to ensure the output of coal products in mining areas and promote the development of local economies. On the other hand, the adverse impact of coal mining on the ecological environment, the consumption of fossil energy in the process of coal mining, and the carbon emission intensity of coal production should be reduced to increase the carbon sink function in coal mining areas.

3.2. Management Subjects

The management subjects fall on the organization and personnel assuming management responsibility and deciding the direction and the management process, including the originators and the executors of management activities. The main body of low-carbon land use and management in coal mining areas involves administrative departments related to land resource management, as well as the subjects of mineral resource development and utilization, that is, the government and enterprises. The government is mainly the land resource management department and the local government, which, as the manager of public affairs, is closely related to the overall and long-term interests of society and the low-carbon goal of land use. The main goal of enterprises is to obtain economic benefits, but their pursuit of economic benefits must accept government management and meet government requirements. Therefore, as the management subject, the government mainly manages enterprise behavior according to national policies and regulations, and enterprises should achieve their economic goals and cater to the requirements of government policy and regulations. The low-carbon land use and management in coal mining areas should be based on scientific policy and regulations formulated by the government and the effective management of enterprises.

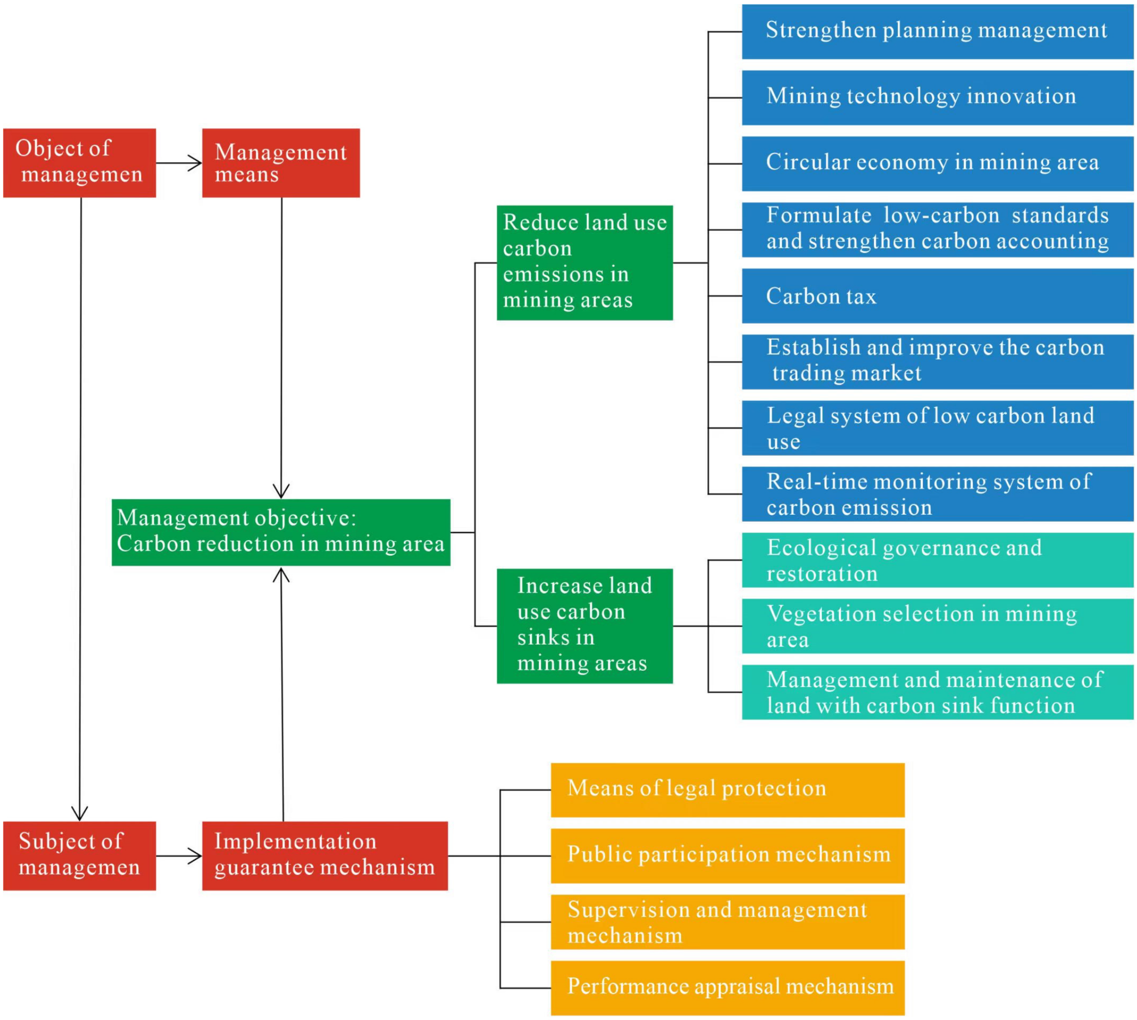

Figure 2. The management system of low-carbon land use in coal mining areas.

3.3. Managing Objects

The management target refers to the object of management activities or the recipient of management. In coal mining areas, it mainly covers land use behavior, including mineral resource exploration, development, collection, transportation, discharge, creation, and reclamation. All units and individuals involved in such behaviors should accept the management and carry out production and other activities in accordance with relevant policies and regulations.

3.4. Management Means

Management is a comprehensive activity carried out by the management subject under certain environmental conditions using certain ways or means for the management object, which aims to effectively achieve the established objective. Therefore, management is an important way to achieve the management objective and the key to the success of management systems. The low-carbon land use and management in coal mining areas should run through the whole life cycle of coal production, including exploration, development, collection, and reclamation, which is a complex process and needs to be managed by any means. There are two main management ideas. The first is to restrict the carbon emissions of the management objects through direct management in coal mining areas and the second is to guide the management object in indirect ways to actively implement the behavior of increasing the carbon sink of land use in the coal mining areas. A large number of scholars have studied the means of low-carbon land use, which provides valuable experience for the management of low-carbon land use in coal mining areas. The specific management means include administrative means, economic means, technical means, and legal means. In comparison, studies on the means of low-carbon land use in coal mining areas are limited. In this study, we will try to introduce the existing research into low-carbon land use and management in coal mining areas and provide some modifications that are suitable for the land use characteristics in coal mining areas to build a detailed system for low-carbon land management.

(1) Administrative means

The setting of carbon reduction targets, the scientific planning of land use, and the arrangement of ecological restoration projects all need to be achieved through administrative means. First, structure optimization is a common administrative approach to achieving low-carbon land use [59–61]. Generally, urban areas and construction land are the main sources of regional carbon emissions [55,56,58,62–64], while cultivated land, forestland, and grassland contribute to the carbon sink [58,65,66]. Research evidence reveals that an optimized land use structure slowed a declining rate of vegetation carbon storage and reduced energy-related carbon emissions by 12% [59]. Compared with the natural development scenario, China's optimized land use structure reduced carbon emissions by 31.66% [60]. Therefore, rational organization of land use could satisfy social and economic development and reduce carbon emissions, and thus land planning is an important way to organize land use. Wei et al. (2022) found that after the Beijing Municipal Government promulgated the 'Master Plan For Land Use' in 1999 and 2009, the growth of land use carbon emissions dropped significantly, and the carbon sink effect of the overall change in land use significantly reduced carbon emissions [61]. Thus, it could be seen that guiding and controlling the land use structure through land use planning can realize low-carbon land use. Second, intensive land use [67,68] and the implementation of ecological restoration projects [65,69] often lead to better carbon reduction effects. Wu et al. (2022) found that urban intensive land use is conducive to low-carbon development, and carbon emissions would be reduced by 3.61% when intensive land use is increased by 0.1 units [67]. The promotion effect of intensive land use on carbon emission reductions is mainly manifested in energy, capital, science, education, and other factors. Capital-intensive land use has a greater impact on carbon efficiency. It can increase the intensity of capital investment per unit of land, enhance the innovative effects of land spatial agglomeration and economies of scale, and thus promote the application of more advanced low-carbon technologies. Meanwhile, capital investment can provide solid financial support for a circular economy, which would promote the reuse and recycling of waste, and increase carbon emission efficiency more noticeably [67]. Kong et al. (2020) found that during 1993–2012, the forest biological carbon content in the Yangtze River Basin increased by 329.26 Tg C, which was mainly due to the ecological restoration project invested in after 2000 [69]. Zhou et al. (2020) studied the function of carbon storage in watershed ecosystems and found that the contribution of land use and cover change brought about by ecological restoration projects to the increase in carbon storage in ecosystems was as high as 103.71% [65]. Moreover, the setting of carbon-reduction targets often has incentive effects. To achieve the 'carbon peak and neutralization' goal, the Chinese government has set a carbon intensity target for 2030, and corresponding provinces have also set regional carbon intensity targets for the 14th Five-Year Plan. Song et al. (2022) found that during the 12th Five-Year Plan in China, the average marginal effect coefficient of the carbon emission reduction policy on carbon emissions was 2.008, indicating that every 1% increase in the carbon intensity reduction target would reduce regional carbon emissions by 200.8% [70]. Yuan et al. (2022) held that the more stringent the carbon constraint policy of enterprises, the higher the optimal emission reduction rate of enterprises [71]. The binding policy of carbon emission reduction targets causes producers to face severe pressure to reduce emissions, thus affecting their production decisions and guiding them to implement carbon emission reduction technologies. Therefore, the setting of carbon reduction targets has a significant emission reduction effect in both macro- and micromanagement.

For low-carbon land use and management in coal mining areas, the main administrative means are scientific and reasonable planning and supervision and implementation. In this regard, before and during the production of the coal mining area, the planning and management of coal mining areas should be strengthened, the boundary and bottom line of land use in mining areas should be controlled, and the transformation of land use in mining areas into a high-carbon emission mode should be strictly managed to avoid an increase in carbon emissions. On the other hand, during and after production in the coal mine area, it is necessary to strictly supervise the implementation of ecological management and restoration projects in mining areas and constantly increase carbon sinks. Moreover, amid the juncture of scheme planning, evaluation, and implementation in coal mining areas, the carbon effect should be taken into account. With low-carbon emissions as one of the important planning objectives, a reasonable carbon reduction target for coal mining areas should be formulated, and the assessment, prediction, and supervision of carbon emission intensity should be conducted to ensure the realization of the carbon reduction target.

Specifically, first, in order to optimize the land use structure of coal mining areas, scientific methods such as fuzzy linear programming should be used to optimize the land use structure of coal mining areas, so as to formulate scientific and reasonable land use planning through implementation and management. In particular, a land-use control system for coal mining areas should be established in which the land use of each plot is determined, and land-use control rules are formulated to restrict the development of construction and prevent the excessive expansion of construction land strictly. For those that truly need to be developed, scientific demonstration and reasonable planning should be carried out. Second, in order to ensure the economical and intensive use of land in coal mining areas and reduce emissions, indicators such as the investment intensity and the proportion of administrative office land should be strictly controlled. In the planning and selection of road routes in mining areas, land occupation should be reduced as much as possible. Then the transportation cost of materials should be considered, and the related transportation distance should be shortened to reduce carbon emissions. Third, planning concerning land reclamation and ecological restoration projects in coal mining areas can be prepared, ecological management and restoration in mining areas can be carried out according to steps, and mining land can be gradually reclaimed. Among them, the land suitable for cultivation can be transformed into cultivated land, the land not suitable for farming can be transformed into forestland and grassland, and land without planting conditions can be transformed into reservoirs. In addition, carbon sink land, such as cultivated land, forestland, and grassland, can be increased. The reasonable land use structure in the mining area can be maintained, a complete mining area ecosystem can be established, and a life community of 'mountains, rivers, forests, fields, lakes and grasses' can be built to enhance the self-recovery ability of the mining area ecosystem. Beyond that, the subtarget of "low carbon emission" should be added to the planning goal of coal production enterprises, and the short-term and long-term goals of carbon emission intensity reduction should be determined. The assessment, prediction, and management of carbon emission intensity should be carried out in the corresponding phases of land improvement projects to guide the development of a low-carbon economy in coal mining areas.

(2) Economic means

Economic means play a role by influencing the 'cost–benefit' of economic parties' optional actions, which is indirect and instructive, and increasingly emerges as an important means to solve environmental problems. The academic community has conducted many studies on the economic means of carbon emission reduction, including carbon accounting [57], carbon taxes [72–76], and carbon emission trading markets [77–87]. Carbon accounting is the basic premise of finding energy savings and emission reduction potential and formulating emission reduction means [88]. Based on the experience of developed countries, the carbon accounting system has played a great role in promoting the development of a low-carbon society. Similarly, carbon accounting is also crucial in microenterprise management and is a prerequisite for industrial enterprises to implement lean carbon management and make decisions [57].

Carbon taxes and carbon emission trading markets are environmentally economic means used in the field of carbon emission reduction. In theory, there are two categories of principle, namely, Pigou's theory and Coase's theorem. The former puts forward the idea of the 'internalization of externalities', which induces the parties who produce externalities to bear the external costs by levying Pigou taxes. The Coase theorem proposes to 'establish market' and allocate resources through the market mechanism. Many scholars have studied the effectiveness of carbon taxes and held that imposing carbon taxes may be an effective way to reduce CO_2 emissions and protect the economy [72–75]. Lin et al. (2018) further found that when the tax rate is 10 yuan/ton, the emission reduction capacity is 0; when the tax rate is raised to 50 yuan/ton, the emission reduction capacity is 5 billion tons; and when the tax rate is up to 100 yuan/ton, the emission reduction capacity grows to 300% of the initial capacity. The higher the carbon tax rate is, the higher the emission reduction capacity and marginal emission reduction capacity, and a high carbon tax can significantly reduce the carbon emission coefficient. Moreover, under a high carbon tax scenario, the energy industry reduces energy consumption the most, which has little impact on the economy, so the focus of taxation should be on energy enterprises [76].

Regarding carbon trading, a large number of studies reveal that carbon trading systems can promote carbon emission reductions [77–82]. Wu (2022) [83] and Cao et al. (2017) [84] further found that the carbon emission reduction level increases when increasing carbon trading prices, but there is disagreement about whether carbon emission trading affects economic growth. Zhang et al. (2019) studied a carbon trading pilot in China and found that the carbon trading pilot areas in China can reduce carbon emissions by reducing the output of the industrial sector [85]. According to the research of Zhou et al. (2019), from 2013 to 2016, the carbon intensity of pilot carbon trading provinces in China decreased by approximately 0.026 tons/10,000 yuan on average every year [86]. According to Pang et al. (2021), compared with the baseline level in 2030, China's carbon emission trading system reduced CO_2 emissions by 4–22% in each province, resulting in the provincial GDP changing from -4.6% to 1.8%. China's carbon trading pilot not only reduced the carbon intensity but also promoted economic growth [87]. It can be seen that the key to carbon trading is to determine a reasonable carbon trading price and consider its impact on economic growth. The entry into force of the Kyoto Protocol makes the carbon emission trading system widely used in the world. For example, the European Union, the United States, New Zealand, South Korea, and other countries have established emission trading systems for CO_2, N^2O, PFC_S, and other gases, covering energy and other areas. In October 2011, China approved seven cities, including Beijing, Shanghai, and Tianjin, to implement carbon trading pilot projects. On 16 July 2021, national carbon emission trading was launched, covering six major industries: Steel, electric power, chemical industry, building materials, paper making, and nonferrous metals. Research on the power industry in China's carbon trading pilot areas from Liu et al. (2023) showed that the implementation of a carbon trading policy can effectively reduce the carbon emissions of the power industry. The larger the scale of carbon market trading is, the more significant the carbon emission reduction effect of the power industry in the pilot areas is [89].

In summary, economic means reduce carbon emissions. In the low-carbon land management of coal mining areas, carbon taxes, carbon emission trading, and other means can be used to optimize the allocation of land-use carbon emission rights through the competition mechanism and the price mechanism, guide producers to make reasonable use of carbon emission rights, constantly improve the social efficiency of carbon emissions per unit, and promote energy conservation and emission reductions in the whole mining area.

Specifically, first, it is necessary to strengthen carbon accounting and develop low-carbon standards. For this, the investigation and evaluation of carbon emissions, emission reduction potential, and emission reduction benefits in coal mining areas should be systematically carried out, and the development standard of a low-carbon economy in coal mining areas, including the indicator system, monitoring system, and evaluation system, should be established and improved to facilitate the gradual transformation of coal mining areas to low-carbon industries. Second, it is possible to introduce a carbon tax, which is a tax levied on carbon emission enterprises to make up for the external costs caused by their carbon emission behavior and belongs to the 'internalization of externalities'. Imposing a carbon tax on carbon emission enterprises can promote carbon emission reductions and has little impact on economic growth, so it is an ideal means of low-carbon land management in coal mining areas. Third, a carbon trading market could be attempted in the coal sector. At present, China's carbon emission trading market is being improved and is bound to cover the coal industry. In essence, carbon trading is the trading of carbon emission rights; that is, the buyer pays the price of carbon emission rights to obtain the amount of greenhouse gas emission reductions to achieve its emission reduction goal. Carbon trading closely combines the scientific problem of climate change, the technical problem of reducing carbon emissions, and the economic problem of sustainable development and uses the market mechanism to solve the complex problem. The key to the construction of a carbon trading market is to determine a reasonable price of carbon emission rights, which should at least make up for the marginal cost of carbon emission reduction per unit quantity. To build a reasonable carbon trading system, it is also necessary to address each relative quantity index and establish a national unified standard. Only in this way can we ensure the healthy and sustainable operation of the carbon trading market and effectively curb carbon emissions through the role of the market.

(3) Technical means

Technological progress plays an important role in reducing carbon emissions [90], and technological innovation is a vital variable conducive to carbon emission reduction [91]. Many scholars are studying technical means to reduce carbon emissions, such as the reduction in energy use, the use of clean energy [92], and the resulting circular economy [93]. At the same time, selecting energy-saving equipment and implementing the CBM mining strategy of 'pumping first and then mining' can reduce coal mine carbon emissions [94]. In addition, shortening the transportation distance and improving mechanical efficiency can also bring good carbon reduction effects [32].

For coal mining areas, the technical means of low-carbon land use and management aim to reduce the carbon emission coefficient per unit area and increase the carbon storage coefficient through innovation. The carbon source in coal mining areas mainly comes from construction land, and it is indispensable to reduce the carbon emission coefficient per unit area. The technical means include innovating mining technology and developing a circular economy. Second, low-carbon land use in coal mining areas should improve the level of carbon sinks through the transformation of land-use types.

First and foremost, it is necessary to carry out technological innovation in the mine, reduce the input of fossil energy and power per unit of land area, and achieve more coal resource production with less energy consumption. Production in coal mining areas should use clean energy, choose energy-saving equipment, and adopt advanced technology as much as possible for green construction. Moreover, we should conduct prejob training and regular assessment for mechanical drivers in mining areas, standardize their operation, and urge them to form good driving habits of energy savings and high efficiency. It is also necessary to make full use of mining machinery and improve mechanical efficiency. In the process of coal mining, it is best to perform mining while reclaiming to reduce the carbon emissions in the mining process and decrease the carbon emission coefficient of the unit area. Second, amid mining, the fine exploitation of mining resources, development of a circular economy, and recycling of mining wastes can improve the efficiency of energy use, achieve green mining, and reduce the carbon emissions per unit output of mineral resource products in mining areas.

To increase the carbon storage coefficient per unit area of coal mining areas, suitability evaluations should be carried out on industrial sites, damaged land, surrounding polluted land, and degraded land in a timely manner. Pursuant to the results, land reclamation should be conducted according to local conditions, where as far as possible, it should be reclaimed as forestland, grassland, and other high-carbon-sink land types. Meanwhile, we should choose plants with strong carbon sequestration capacity, pay attention to protecting the soil cultivation layer, and ensure the growth of vegetation to realize carbon sequestration as soon as possible. For cultivated land, forestland, grassland, and other carbon sink land types in the mining area, it is feasible to strengthen management and maintenance in the later stage, prevent soil erosion, enhance the carbon sink capacity, and finally form structurally intact, functional, and sustainable ecosystems, which provide space support for clean and efficient production in coal mining areas.

(4) Legal means

Legal means can provide legal support for the realization of the ‘carbon peak and neutrality’ and are the highest mandatory management means. For the sake of fulfilling international treaty obligations, China has set the ‘carbon peak and neutrality’ target. In 2018, ‘ecological civilization’ was included in the Constitution, which provides an ideological foundation and constitutional basis for the realization of the dual carbon goal. In 2020, the Ministry of Ecology and Environment promulgated the Measures for the Administration of Carbon Emission Trading (Trial). In September 2021, the Central Committee of the Communist Party of China and The State Council issued Opinions on Fully and Accurately Implementing the New Development Concept to Achieve the Goal of Carbon Peak and Neutrality. In October 2021, The State Council issued the 2030 Carbon Peak Action Plan, which forms a unified legal system with the Environmental Protection Law, the Air Pollution Prevention and Control Law, the Law on Promoting Cleaner Production, the Law on Promoting Circular Economy, the Law on Environmental Impact Assessment, and other relevant laws and regulations and serves as an important legal guarantee for the realization of the environmental goal.

In addition, China implemented the Environmental Protection Tax Law on 1 January 2018, with CO_2 not listed in the tax scope. Du et al. analyzed and evaluated the carbon emission reduction effect of the Environmental Protection Tax Law on 107 Chinese cities from 2015 to 2019 and revealed that the act significantly reduced industrial sulfur dioxide emissions, particulate matter emissions, and CO_2 emissions by 14%, 14%, and 13%, respectively [95].

On the one hand, the legal means of low-carbon land management in coal mining areas lies in the introduction of legal systems; on the other hand, it lies in its strict supervision and implementation. First, it is necessary to establish and improve the legal system of low-carbon land use, take the carbon emission standard of land use as an important action criterion, determine a reasonable carbon emission standard as the boundary and bottom line on the basis of scientific carbon emission accounting, formulate a strict reward and punishment system, and institutionalize and legalize it. Second, a complete real-time monitoring system for carbon emissions should be established, and enterprises that produce CO_2 exceeding carbon emission standards should be punished to truly realize low-carbon land use and management. Low-carbon land use is one of the important components of a low-carbon economy, and there is still a long way to go to realize low-carbon land use. Government departments should give full play to government functions, advocate low-carbon economic land use, and use administrative means to control low-carbon land use. At the same time, they should use economic means to guide land-use behavior towards low-carbon use, make low-carbon use one of the important goals of land use, make the economy a powerful lever of land use, determine strict behavioral boundaries and bottom lines, and constantly regulate low-carbon land use. At the micro level, the technological innovation of low-carbon land use should be strengthened to continuously support the realization of low-carbon land use.

3.5. Implementation Guarantee Mechanism

Determining how to ensure the effective implementation of low-carbon land use is the key to achieving low-carbon land use, and only the effective implementation of low-carbon land use can ensure the realization of low-carbon land use. Considering this, it is necessary to build a low-carbon land use guarantee mechanism in coal mining areas, which mainly includes four aspects.

(1) Legal protection mechanism

Improving the relevant laws of low-carbon land use is the prerequisite and fundamental guarantee for the implementation of low-carbon land use and management. At present, China has not issued relevant laws and regulations on low-carbon land use. Thus, it is urgent to carry out relevant system research and formulate a scientific and reasonable system as soon as possible, including the standards and methods, economic compensation, tax standards, and reclamation standards of administrative rules related to low-carbon land use.

(2) Public participation mechanism

The improvement in public awareness of energy conservation and emission reduction is of great significance to the reduction in carbon emissions, and the realization of low-carbon goals cannot be achieved without public participation. Liu et al. found that public education expenditure plays an important role in limiting the growth of CO_2 emissions. Increasing public education expenditure is more conducive to improving people's awareness of energy conservation and emission reduction and is more likely to promote low-carbon products and reduce CO_2 emissions [89]. Du et al. found that consumers' low-carbon preferences not only increase channel profits but also facilitate emission reduction [96].

The public participation mechanism of low-carbon land use in coal mining areas involves two aspects, where one is the public participation of workers in coal mining areas. For instance, we can provide technical training for workers in coal mining areas so that they can master the technology of improving production efficiency and reducing energy consumption and carbon emissions through the reasonable manipulation of machinery and equipment in the production process and guide workers to widely participate in energy conservation and emission reduction to constantly promote the implementation of low-carbon land use.

The second relies on the extensive participation of the public, especially the public in the coal mine living area. Through publicity and education, people can be guided to establish the values of energy conservation, emission reductions, and environmental protection and form consumption habits and living habits that are energy-saving, emission-reducing, and environmentally friendly. At the same time, the public can be encouraged to supervise the production process in coal mining areas and urge the application of energy-saving emission reduction technology and low-carbon production behavior. In addition, they can also be motivated to supervise land reclamation and late management and protection work in coal mining areas, urge ecological restoration of damaged land in a timely manner, and ensure the effective implementation of land reclamation in coal mining areas. The extensive participation of the public is an important driving force for low-carbon land use and ecological environmental protection in coal mining areas, which can enhance the understanding and cognition of stakeholders on the ecological environment in coal mining areas and promote the implementation of low-carbon land use in coal mining areas.

(3) Supervision and management mechanism

Supervision and management mechanisms are among the necessary prerequisites for establishing and improving the low-carbon land use and management system in coal mining areas, which runs through every link of work in coal mining areas and includes the supervision of carbon emissions at different stages, such as exploration, development, and collection, supervision of the green mining level in coal mining areas, supervision of reclamation plans, supervision of post reclamation management and maintenance level, supervision of the management subject, and evaluation and review of each link. It requires the participation of more public and even special supervision departments.

(4) Performance evaluation mechanism

The performance evaluation mechanism evaluates the performance of the implemented low-carbon land use and management to provide a scientific basis for promoting subsequent management work. The standard of performance evaluation can be carried out from two dimensions: Whether the low-carbon land use and management in coal mining areas achieve the expected goal, that is, the management effect, and what the ratio between the amount of input and the effect of low-carbon land use and management in coal mining areas is, that is, the management efficiency.

4. Discussion

The change in land use and the carbon cycle process in coal mining areas was analyzed at different stages including exploration, exploitation, and collection, and thus a conceptual model of carbon income and expenditure of land use in coal mining areas was constructed in this study. The model established a clear cognitive framework for the carbon cycle of land use in coal mining areas. Also, it provided a theoretical basis for the study of land low-carbon utilization in coal mining areas. Furthermore, a relatively complete management system of land low-carbon utilization in coal mining areas was constructed from the perspective of management science. This system answered the questions of "Who should manage", "What to manage", and "How to manage" in the management of low-carbon land use in coal mining areas and put forward the management means and methods of low-carbon land use in the whole life cycle of coal mining areas. Meanwhile, the implementation of the security mechanism was discussed. Surely, the management system of low-carbon land use in coal mines is a theoretical framework based on the application effect of low-carbon land-use management. This conceptualization study will provide a clear idea for land low-carbon management in coal mining areas and provide a reference for land low-carbon management both in coal and non-coal mining areas. Note that once the land in the coal mining areas has been developed, the land use will change dramatically, and carbon emissions will accompany the entire life cycle of the mine. Therefore, the management of low-carbon land use in this region should pay special attention to the systematization of the whole management system, and apply the specific management means in different production stages to achieve the management goal. Thus, future research should focus on the matching of different management methods and their 'coordination effect', thus forming a 'resultant force' to provide security for low-carbon land use in coal mining areas and being helpful to achieve peak carbon and achieving carbon neutrality.

An integrated management system is an important guarantee for low-carbon land use in coal mining areas. Though the management system was constructed after being fully and seriously considered, which contained many contents such as the management objective, subject, object, means, and implementation guarantee mechanism, the complete management system also needed to explain the management mechanism. The management mechanism is composed of the related management elements, which is a system running to achieve the predetermined goal. The management of land low-carbon use belongs to the management of public affairs, so here the management mechanism mainly refers to the administrative management mechanism, and it includes the establishment of state administrative organs, the division of administrative powers, and the rules and regulations established to ensure the smooth operation of administration. It is the main way for a country to carry out political and public affairs management that could organize a reasonable administration and manage public affairs in accordance with legal norms. The administrative management mechanism is an important part of the management system, and its organization, posts and personnel, and its administrative efficiency are related to the realization of the important implementation of the management goals. However, the administration management mechanism is the superstructure of society, and it is an integral part of the political system of the state. Thus, the establishment of a new administration management mechanism would be a complex process and may need to consider many complex factors including the basic political system, the economic base, and the national cultural traditions of the country. The key point of this study is the micro-management of low-carbon land utilization in coal mining areas, so the establishment of the administration management mechanism in a micro-region should comply with the national administrative system and model within the boundaries allowed by national legal norms. In fact, a government restructuring was carried out in 2018 in China, with the creation of the Ministry of Ecology and Environment. A climate change department attached to the Ministry of Ecology and Environment was established for tackling climate change and reducing greenhouse gas emissions. The same institutions were set up to take charge of the regional climate change and greenhouse gas emissions affairs attached to the departments of ecology and environment of provinces, autonomous regions, and municipalities. However, the grass-roots ecological and environmental departments lack specialized agencies and personnel for greenhouse gas emission reduction, as well as relevant consulting, monitoring, and other service-oriented institutions. It is clear that the Chinese government has started to pay attention to the establishment of regulatory bodies to deal with climate change and carbon emission reduction at the macro level, but there is still room for improvement in the regulatory mechanism. Obviously, the management system of low-carbon land use in coal mining areas needs further study on the premise of the improvement of the relevant national management system.

The management system of low-carbon land use in coal mining areas is a complex comprehensive system. After the management system is completed, the detailed management method and policy means also need to be deeply studied. First of all, for each management means, the scientific and reasonably defined management boundary needs to be further studied, such as setting reasonable carbon emission standards, scientific levels of taxes and fees, and reasonable carbon prices, all of which require a large amount of cost–benefit analysis. Secondly, the application of specific management methods and policy instruments in the management system also needs further study. For example, in economic means, both the tax policy and the carbon emission trading market can achieve carbon emission control. However, whether to choose tax or carbon emission trading markets or to use them together and the difference in policy efficiency remain unknown and need to be considered after further study. Thirdly, in the low-carbon land use management system, each management means has different management methods. It is necessary not only to realize the scientific rationality and efficiency effect of a single management method but also to avoid mutual interference among management means, which requires in-depth analysis of the links and on the choice of management means.

The management system of low carbon land use in coal mining areas was constructed theoretically in this study, but its management and practical effect also need more research to verify, such as the actual reduction in carbon emission in coal mines after the implementation of the management system, the actual carbon reduction efficiency, the temporal scales to achieve low-carbon use, and so on. In particular, more research should also focus on the ecological effects of the application of a low-carbon management system in coal mining areas. For example, the scientific optimization of the land-use structure in coal mining areas can control the disorderly expansion of mining land and maintain a reasonable share of farmland, woodland, grassland, and other agricultural land in mining areas, so as to achieve the balance of the whole region's land ecosystem. Moreover, reclamation and ecological restoration projects in coal mining areas can also increase the area of forests and grasslands with significant ecological effects, such as promoting carbon sequestration, purifying the air, and maintaining soil and water conservation. Thus, it will provide a material foundation for the healthy operation of the coal mining area ecosystem.

Surely, although there are many deficiencies and room for improvement in the management system of low-carbon land use in coal mining areas in the study, the carbon budget model provides ideas for the management of low-carbon land use in coal mining areas. Moreover, the management system of low-carbon land use will be helpful for carbon emission reduction management in coal mining areas, and even other types of mining areas.

5. Conclusions

Scientific organization and optimization of land resources and their utilization can not only improve land use conditions but also improve soil quality and promote soil carbon sequestration to form carbon sinks. To realize low-carbon land use in coal mining areas, we constructed a conceptual model of the carbon budget in coal mining areas and built a low-carbon land use management system from the perspective of management science as follows:

(1) The carbon budget conceptual model in coal mining areas analyzes the carbon budget amid the whole production from the perspective of land use. The production process of coal mining areas includes three stages: Exploration, development, and collection. In this process, land-use type changes seriously affect the regional carbon budget. Specifically, land-use types that have strong carbon sink functions, such as cultivated land, forestland, and grassland, have been transformed into exploration land, mining land, transportation land, and construction land, severely disturbing the soil carbon pool and vegetation carbon pool, reducing the carbon sequestration capacity, and increasing carbon emissions. Through this analysis, the reasons for the changes in carbon revenue and carbon expenditure can be clarified, and the basis for the proposed carbon emission reduction measures can be provided.

(2) The low-carbon land use and management system in coal mining areas includes management objectives, management subjects, management objects, management means, and implementation guarantee mechanisms. Building a low-carbon land-use management system to regulate and manage all land-use behaviors in mining areas is among the important ways to promote the economic benefits and the 'win–win situation' of low-carbon emission reductions in coal mining areas.

This study can theoretically seek land-use regulation measures conducive to carbon emission reductions in coal mining areas, hoping to provide a decision-making basis for regional low-carbon land-use management and lay a theoretical basis for future low-carbon sustainable development in coal mining areas.

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