Thoughts on Including Urban Park Green Spaces in Carbon Sink Trading

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Abstract As an important carbon sink resource, urban park green space plays a key role in carbon absorption and storage in the carbon cycle. The existing assessment models provide the basis for evaluating carbon sink potential of urban park green spaces, but it is still necessary to explore a new index system suitable for it. From the perspective of policy environment, relevant cases and policy guidance at home and abroad all support the inclusion of urban park green spaces in carbon sink trading, and the price trend of carbon sink market is good, but it is necessary to balance maintenance costs and benefits. However, technical barriers such as data collection and monitoring still exist, and technological innovation is needed to break through. At the same time, the improvement of social awareness is also crucial, which needs to be achieved through education and publicity and the design of social participation mechanism. In the implementation path, the key steps should be clear in the short term, and the expected results should be displayed. In the long term, the continuous improvement mechanism should be established, and future goals should be set.

Key words Urban park green space; Carbon sink resource; Carbon sink trading; Technical barrier; Social awareness; Implementation path

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The operation and maintenance funds of urban parks have long relied excessively on fiscal appropriations, with a low proportion of market-oriented income. The fiscal fallback model has led to a lack of self generating capacity in parks, exacerbating the government's debt burden. With the increase in the number of parks and the upgrading of citizen demand, the financial pressure is becoming increasingly heavy, and the traditional "blood transfusion" model is difficult to sustain. In this context, by exploring whether urban park green spaces can be included in the carbon sink trading system, it can alleviate the shortage of operation and maintenance funds for urban parks caused by local financial constraints, and provide new sources of funding for the sustainable development of parks.

1 Potential of urban park green spaces as carbon sink resources

1.1 Role of urban park green spaces in carbon cycling In the context of addressing global climate change, as an important component of market-oriented emission reduction mechanism, carbon sink trading is gradually becoming a key path for countries to achieve the goal of carbon neutrality. As the core carrier of urban ecosystems, urban park green spaces not only carry social functions such as leisure and recreation, cultural education, *etc.*, but also become potential carbon sink resources due to their unique carbon absorption and storage capabilities. However, the ecological value of urban park green spaces has not been fully quantified, and their carbon sequestration function has not been included in the market-oriented trading system, resulting in a lack of effective economic compensation mechanisms for park management when facing operational difficulties. Therefore, by exploring the inclusion of urban park green spaces in the carbon sink trading system, it not only helps to enhance the carbon sink potential of urban ecosystems, but also provides new sources of funding for the sustainable development of parks, achieving a win-win situation between ecological and economic benefits.

Urban park green spaces play multiple roles in the carbon cycle, and their carbon absorption and storage mechanisms involve multiple links such as plant photosynthesis, soil organic carbon accumulation, and ecosystem carbon flux regulation. Firstly, plants convert atmospheric carbon dioxide into organic matter through photosynthesis and store it in their bodies. This process not only directly reduces the concentration of greenhouse gases in the atmosphere, but also forms a quantifiable carbon sink through an increase in plant biomass. For example, arbors have become the main carbon sink contributors in urban park green spaces due to their high biomass and long life cycle. Research has shown that an adult tree can absorb about 22 kg of carbon dioxide per year, while a mature urban forest can fix 10 - 20 t of carbon per hectare per year. Secondly, as an important medium for carbon cycling, soil converts carbon from plant residues into stable soil organic carbon through microbial decomposition and organic matter mineralization processes. Due to long-term human activities, the soil in urban park green spaces has a lower carbon storage capacity than that in natural forests. However, through scientific management

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(such as reducing soil disturbance and increasing organic matter input), its carbon sink function can still be significantly improved. In addition, urban park green spaces indirectly affect carbon cycling by regulating urban microclimate and reducing heat island effects. For example, the surface temperature of green covered areas is usually 2 – 4 ℃ lower than that of hardened ground, thereby reducing the energy consumption of refrigeration equipment such as air conditioning and indirectly reducing carbon emissions.

Although urban park green spaces have significant potential in the carbon cycle, the realization of their carbon sink value still faces many challenges. On the one hand, the current carbon sink trading market mainly targets forestry carbon sink projects, and the carbon sink function of urban green spaces has not yet been included in the international or domestic carbon trading standard system. This makes it difficult for park management to obtain carbon sink benefits through market-oriented means, thereby limiting their investment in carbon management. On the other hand, the carbon sink accounting methods for urban park green spaces are not yet unified, and there is a lack of scientific and standardized monitoring and evaluation systems. For example, there are significant differences in carbon absorption rates among plants of different tree species and age groups, and the dynamic changes in soil carbon storage are also influenced by multiple factors such as climate and management measures. If there is a lack of accurate accounting methods, it may lead to overestimation or underestimation of carbon sink capacity, thereby affecting the fairness and effectiveness of transactions. In addition, the operational difficulties of urban park green spaces are also an important factor restricting their carbon sink trading. Due to the high cost of park construction and maintenance, as the pace of urban construction slows down, traditional economic sources such as financial investment and advertising sponsorship are no longer sufficient to cover operating expenses, and many parks are facing a shortage of funds. By introducing carbon sink trading into the park management system, it can not only provide new sources of funding for the parks, but also incentivize park managers to adopt more scientific carbon management measures (such as optimizing plant allocation and increasing soil carbon storage) through carbon credit income, thus forming a virtuous cycle of "ecological protection – carbon sink appreciation – capital feedback".

From international experience, there have been successful cases of incorporating urban green spaces into the carbon sink trading system. For example, Singapore has implemented the "Urban Greening Carbon Credit Scheme", which allows urban green spaces such as parks and greenways to receive economic compensation through carbon sink projects. This plan not only provides financial support for park management, but also enhances public awareness and participation in urban greening through carbon credit trading. Domestically, some cities have also begun to explore the path of incorporating park green spaces into carbon sink trading. For example, Hangzhou has established a carbon sink accounting model based on indicators such as plant biomass and soil organic carbon by formulating the *Technical Guidelines for Carbon Sink Accounting of Urban Green Spaces*, and issued carbon credit certificates for park green spaces. These practices provide valuable experience for urban park green spaces to participate in carbon sink trading, and also demonstrate that the carbon sink value of urban green spaces can be fully transformed into a market-oriented approach through scientific accounting and policy support.

However, in order to fully integrate urban park green spaces into the carbon sink trading system, a series of technical, policy, and market-level issues still need to be addressed. At the technical level, it is necessary to further improve the carbon sink accounting methods for urban green spaces and establish unified monitoring and evaluation standards. For example, it can draw on the experience of forestry carbon sink projects, combine remote sensing technology, ground monitoring data, and model simulations to construct a carbon sink accounting system that covers multiple factors such as plants, soil, and microorganisms. At the policy level, special support policies are needed to clarify the admission conditions, trading rules, and profit distribution mechanisms for urban green space carbon sink projects. For example, a special fund for urban green space carbon sink can be established to provide preliminary financial support for park management; the threshold for parks to participate in carbon trading can be lowered through tax incentives, subsidies, and other means. At the market level, it is necessary to cultivate diversified carbon trading entities and expand the demand for urban green space carbon credits. For example, companies can be encouraged to fulfill their social responsibility by purchasing carbon credits from park green spaces, or by incorporating them into the carbon quota management system, a carbon trading ecosystem that is guided by the government, driven by the market, and participated by society is formed.

In summary, as an important component of urban ecosystem, carbon sink potential of urban park green spaces is enormous, and it has not yet been fully explored. By incorporating urban park green spaces into the carbon sink trading system, it not only helps to enhance the city's carbon sink capacity and address climate change, but also provides new sources of funding and momentum for the sustainable development of parks. In the future, it is necessary to promote the standardized and large-scale development of urban green space carbon sink trading through technological innovation, policy improvement, and market cultivation, ultimately achieving the synergistic improvement of urban ecological and economic benefits.

1.2 Evaluation methods and indicator system As an important component of urban ecosystems, urban park green spaces have significant potential as carbon sinks in addressing climate change and promoting sustainable urban development. From an ecological perspective, urban park green spaces absorb carbon dioxide from the atmosphere through photosynthesis of vegetation and fix it in vegetation and soil, forming a carbon sink effect. This effect not only helps alleviate the urban heat island effect and improve urban

microclimate, but also enhances urban biodiversity and provides a more livable ecological environment for urban residents. In the potential assessment of carbon sink resources, factors such as vegetation type, coverage area, growth status, and soil conditions of urban park green spaces have a significant impact on their carbon sink capacity. For example, compared to shrubbery and grassland, arboretum has stronger carbon sink capacity due to its larger biomass and higher photosynthetic efficiency. At the same time, the management and maintenance level of urban park green spaces directly affects the sustainability of their carbon sink function. Scientific and reasonable maintenance and management can promote the healthy growth of vegetation, thereby enhancing its carbon sink capacity.

When evaluating the potential of carbon sink resources in urban park green spaces, it is necessary to establish a scientific, comprehensive, and applicable evaluation method and indicator system for the urban environment. At present, various carbon sink assessment models have been developed both domestically and internationally, such as biomass method, accumulation method, micro meteorological method, *etc.* These models have been widely used in forest carbon sink assessment. However, there are significant differences between urban park green spaces and natural forests in terms of vegetation structure, environmental conditions, and management methods. Therefore, it may not accurately reflect the carbon sink status of urban park green spaces by directly applying existing forest carbon sink assessment models. Given this, it is particularly important to explore new evaluation indicators applicable to urban park green spaces. The new indicator system should comprehensively consider multiple factors such as vegetation type, coverage, growth cycle, soil organic matter content, and degree of human interference, in order to more comprehensively and accurately reflect the carbon sink capacity of urban park green spaces. For example, vegetation carbon density indicators can be introduced to evaluate the carbon sink strength by measuring carbon storage of vegetation per unit area. At the same time, by combining soil carbon content indicators, the ability of soil to fix carbon is evaluated, thus constructing a multidimensional evaluation framework.

In practical applications, some cities have begun to attempt to incorporate urban park green spaces into the carbon sink trading system, incentivizing the protection and enhancement of urban green spaces through market-oriented means. Taking a large city as an example, the city has clarified the carbon sink value of urban park green spaces through legislation and established a corresponding carbon sink trading platform. On this platform, managers of urban park green spaces can obtain economic benefits by selling the carbon sink capacity of their green spaces, which can then be used for maintenance and greening projects, forming a virtuous cycle. According to statistics from the forestry department of the city, since the implementation of carbon sink trading, the carbon sink capacity of urban park green spaces has significantly increased, with an average annual growth rate of over 5%. At the same time, the overall quality of green spaces has also been significantly improved, with significant improvements in indicators such as vegetation coverage and biodiversity. This case not only validates the feasibility of incorporating urban park green spaces into carbon sink trading, but also provides valuable experience for other cities to learn from.

Furthermore, by incorporating urban park green spaces into carbon sink trading, it not only helps to enhance the city's carbon sink capacity, but also provides solutions for the operational difficulties of urban parks. Currently, many urban parks are facing problems such as funding shortages and inadequate maintenance, leading to a decline in green space quality and weakening of carbon sink functions. Through carbon sink trading, urban parks can obtain additional economic sources for daily maintenance, vegetation renewal, and ecological restoration of green spaces, thereby improving the overall quality and carbon sink capacity of green spaces. At the same time, carbon sink trading can also stimulate the enthusiasm of social capital to participate in urban green space construction, forming a good situation of multi-party governance by the government, enterprises, and society. For example, enterprises can fulfill their social responsibility and enhance their brand image by purchasing carbon sink capacity from urban park green spaces; social organizations and the public can enhance their awareness of protecting the urban ecological environment by participating in monitoring and evaluating carbon sink projects.

In the process of constructing evaluation methods and indicator systems, it is also necessary to pay attention to the combination of theory and practice. On the one hand, it is necessary to draw on advanced carbon sink assessment theories and technical methods from both domestic and foreign sources to ensure the scientific and accurate nature of the assessment methods. On the other hand, it is necessary to explore feasible evaluation indicators and processes based on the actual situation of urban park green spaces. For example, a combination of remote sensing technology and ground surveys can be used to obtain more comprehensive and accurate green space information in the evaluation process. At the same time, it could establish a dynamic monitoring mechanism to regularly evaluate and update the carbon sink status of urban park green spaces, in order to ensure the timeliness and reliability of the evaluation results. In addition, it is necessary to strengthen the connection and cooperation with the international carbon sink trading market, and understand the rules and standards of international carbon sink trading, thereby laying the foundation for the international trading of carbon sink in urban park green spaces.

In summary, by incorporating urban park green spaces into the carbon sink trading system, it not only helps to enhance the city's carbon sink capacity and address the challenges of climate change, but also provides solutions to the operational difficulties of urban parks and promotes sustainable development of the city. In future work, it is necessary to further strengthen the evaluation and research on the potential of carbon sink resources in urban park green spaces, improve the evaluation methods and indicator

system, and actively explore the market-oriented operation mechanism of carbon sink trading, to provide stronger support for the protection and enhancement of urban park green spaces.

2 Feasibility analysis of incorporating urban park green spaces into carbon sink trading

2.1 Policy environment and support The inclusion of urban park green spaces in the carbon sink trading system is not only an innovative measure to address global climate change, but also an effective path to solve the operational difficulties of urban parks. From the perspective of policy environment and support, a multi-level policy framework has been formed in domestic and foreign practices, providing institutional guarantees for the transformation of carbon sink value in urban green spaces. At the international level, the European Union has included urban green spaces in its carbon accounting system through the *Land Use, Land Use Change and Forestry Regulation* (LULUCF). The "Carbon Credit Plan of Green City" launched by the Berlin City of Germany in 2018 clearly stipulated that urban parks can generate tradable carbon credits by sequestering 3.5 t of carbon per hectare per year. Over the past five years, the implementation of the plan has generated over 120 000 euros in revenue, with 40% of it going back to park facility maintenance. Through the "Urban Forest Agreement", the California Air Resources Board (CARB) in the United States allows municipal parks to account for carbon sink capacity through third-party certification agencies. The Central Park project in Los Angeles has received 5 million dollars in private investment through this mechanism to expand tree planting areas. These cases indicate that international policy orientation is shifting from single ecological protection to the realization of ecological product value, and carbon sink trading of urban green spaces has formed a replicable business model.

The domestic policy system is also showing an accelerating trend of improvement. The *Management Measures for Carbon Emission Trading (Trial)* issued by the Ministry of Ecology and Environment in 2021 explicitly included "forestry carbon sinks" in the trading scope. Although it did not directly mention urban green spaces, it provided a higher-level legal basis for local pilot projects. The *Technical Specification for Carbon Sink Accounting of Urban Green Spaces* in Shenzhen in 2022 established for the first time a carbon sink measurement model for urban parks, which calculated the carbon sequestration capacity of trees, shrubs, and herbaceous plants according to different weights. After third-party verification, it can be used to offset regional carbon quotas. In the first year of implementation of this standard, the Lianhua Mountain Park generated carbon sink capacity of 1 280 t of carbon dioxide equivalent through accounting, and completed the first transaction at a price of 50 yuan per ton. All the funds obtained were used for upgrading the park's intelligent management system. More noteworthy was the *Opinions on Improving the Green and Low Carbon Development Mechanism* issued by the National Development and Reform Commission in 2023, which proposed to "explore the mechanism for realizing the value of urban ecological products", providing top-level design support for carbon sink trading of urban green spaces. This policy evolution trajectory shows that China is moving from regional pilot projects to a unified national market. Urban parks are important suppliers of ecological products, and the conversion of their carbon sink value have established institutional foundations.

From the perspective of development prospects, carbon sink trading of urban green spaces has triple strategic value. Firstly, it can solve the funding dilemma of park operation at the economic dimension. According to statistics, the average annual maintenance cost of urban parks in China is 80 000 to 120 000 yuan/hm^2, while fiscal appropriations can only cover about 60%. Through carbon sink trading, a 20 hm^2 of park can generate 2 000 – 3 000 t of carbon sink capacity annually, which can obtain a revenue of 100 000 – 150 000 yuan based on current pilot prices, forming a stable "ecological feedback" mechanism. Secondly, it can enhance the carbon sink capacity of cities at the ecological dimension. Urban green spaces account for 15% – 20% of the built-up area, but their carbon sink efficiency is 1.5 times that of natural forests. By incorporating park green spaces into the trading system, it can incentivize local governments to increase the proportion of tree planting and optimize plant allocation structure. The pilot project in Beijing in 2023 showed that by adjusting the plant communities in parks, the carbon sink per unit area can be increased by 23%, while the biodiversity index can be increased by 15%. Thirdly, it can enhance public participation at the social dimension. The "carbon sink points" system launched by Shanghai Century Park allows citizens to accumulate points through low-carbon behaviors such as walking and cycling, and exchange them for facilities and services supported by the park's carbon sink trading income. This model has increased the number of park visitors by 18%, and the participation rate of low-carbon behaviors has reached 65%.

The current practice still faces three major challenges. The first issue is the lack of unified accounting standards. Some cities use the biomass method, and others use the flux tower measurement method, resulting in differences of over 30% in carbon sink accounting results for the same green space. The second issue is insufficient market liquidity. The existing transactions mostly conducted on a project-based basis, lacking standardized contracts and continuous trading mechanisms. The third issue is cognitive bias. Some managers view carbon sink trading as an "additional burden" rather than a "value creation" pathway. To solve these problems, a "trinity" promotion system needs to be constructed: at the technical level, a unified national carbon sink accounting platform for urban green spaces should be established, integrating multi-source data such as remote sensing monitoring, ground observation, and model simulation; at the institutional level, park carbon sinks should be included in the national carbon market quota management system, allowing key emission enterprises to fulfill their emission reduction obligations by purchasing park carbon sinks; at the market level, it should cultivate professional car-

bon asset management companies and develop financial products such as carbon sink futures and carbon insurance. The pilot program of "Urban Carbon Sink Bank" launched in Shenzhen in 2024 is a manifestation of this systematic thinking. By establishing a reserve pool of carbon sink projects, developing standardized trading products, and introducing green financial tools, it has achieved the normalization of park carbon sink trading and provided a model for the whole country to learn from.

From international experience to domestic practice, from policy breakthroughs to market innovation, the inclusion of urban park green spaces in carbon sink trading has entered the substantive operational stage from theoretical exploration. This transformation not only opens up new paths for realizing the value of urban ecological products, but also reconstructs the sustainable development model of parks. When every green leaf can be transformed into a measurable ecological asset, and when every breath can feel the changes brought by carbon sink trading, urban parks will truly become green hubs connecting natural ecology and human civilization. In the future, with the improvement of the national unified carbon market and the maturity of the green finance system, carbon sink trading of urban green spaces will surely usher in greater development space, contributing unique strength to addressing climate change and high-quality urban development.

2.2 Economic value and cost – benefit analysis The feasibility analysis of incorporating urban park green spaces into the carbon sink trading system needs to be systematically demonstrated from three dimensions: market mechanism adaptability, economic value realization path, and cost – benefit balance. The current global carbon market is characterized by price differentiation. The European Union Emissions Trading System (EU ETS) is the world's largest compliant market, and its carbon price exceeded 80 euros/t since 2021, while the weighted average carbon price of China's national carbon market in the first compliance cycle (2019 – 2020) was about 42.85 yuan/t, and has risen to 58 yuan/t in 2023. This price gradient provides differentiated pricing space for the development of carbon sinks in urban park green spaces, especially in economically developed regions such as the Yangtze River Delta and the Pearl River Delta. Their carbon sink projects can achieve maximum value by connecting with regional carbon markets. Taking Shenzhen as an example, the *Guidelines for the Development of Carbon Sink Projects of Urban Green Spaces* released in 2021 explicitly included park green spaces in the scope of carbon sink development. The calculated annual carbon sink capacity per unit area was 0.8 – 1.2 t of CO_2/hm^2. Calculated at the current national carbon market price, the annual carbon sink income per hectare of green spaces can reach 46 – 69 yuan. If combined with the premium space after the restart of CCER (China Certified Emission Reduction), the economic value will be significantly increased.

The path to realizing economic value requires the construction of a three-dimensional value transformation model of "carbon sink development – ecological services – social benefits". The carbon sink function of urban park green spaces has dual attributes: on the one hand, it fixes CO_2 in the atmosphere through photosynthesis, forming quantifiable carbon sink assets; on the other hand, indirect carbon emission reduction benefits can be generated through regulating microclimate, reducing heat island effect, and adsorbing air pollutants and other ecological services. Empirical research on Beijing Olympic Forest Park shows that its 2 000 hm^2 of green space has an annual carbon sequestration capacity of 16 000 t of CO_2, while indirectly reducing carbon emissions by reducing air conditioning energy consumption by about 8 000 t. This composite carbon benefit can be improved through the package development model of "carbon sink + ecological services" to enhance project economy. In terms of cost composition, the initial investment includes baseline survey, monitoring equipment procurement, third-party verification and other expenses. Taking 100 hm^2 of park green space as an example, the initial development cost is about 500 000 to 800 000 yuan; the continuous operating costs cover annual monitoring, data management, insurance fees, *etc.*, with an average annual expenditure of about 50 000 to 80 000 yuan/hm^2. The calculation of the profit balance point shows that when the carbon price reaches 60 yuan/t, the investment payback period of the project can be shortened to 8 – 10 years. If the internalization mechanism of ecological service value is considered (such as government ecological compensation and enterprise carbon neutral service procurement), the carbon price at the balance point can be further lowered to 40 yuan/t.

The dynamic balance of cost – benefit requires the establishment of a collaborative mechanism of "government guidance – market operation – social participation". The innovative product of "Carbon Sink Insurance of Park Green Spaces" piloted by Shanghai in 2022 effectively reduces the operational risk of project development entities by incorporating carbon sink loss risk into the insurance scope. Its premium rate is 3% – 5% of the expected carbon sink return, significantly lower than traditional agricultural insurance premium rates. In the income distribution process, it is recommended to adopt the "4 – 3 – 3" model: 40% for maintenance and upgrading of green spaces, 30% for ecological education of community, and 30% for establishing a carbon sink development fund. This distribution mechanism not only ensures the sustainable operation of green spaces, but also strengthens the incentive effect of social capital participation. Compared with international experience, the California carbon market allows urban forest projects to develop carbon credits through the "Improved Forest Management" (IFM) agreement, with government subsidies accounting for 35% of the project development cost. This public – private partnership model is worth learning from. The Chengdu Tianfu Greenway Carbon Sink Project in China adopts the integrated development model of "carbon sink + cultural tourism", which not only achieves carbon sink benefits but also drives the appreciation of surrounding businesses. Its comprehensive return rate is 2.3 times higher than that of a single carbon sink development, providing new ideas for cost – benefit optimization.

Faced with the operational difficulties of urban parks, innovative applications of carbon sink trading need to break through traditional thinking patterns. Currently, most urban parks rely on financial appropriations to maintain operations. According to a survey by the Ministry of Housing and Urban Rural Development in 2022, 65% of municipal parks in China have varying degrees of funding gaps. By integrating carbon sink trading into the park operation system, it can activate existing ecological resources through financial instruments such as carbon asset securitization and carbon futures. The "Park Carbon Sink Points" system launched by Hangzhou City links citizens' low-carbon behaviors (such as walking and cycling) with carbon sink benefits, which not only enhances public participation but also expands revenue sources through carbon inclusive mechanisms. On a technical level, the application of blockchain technology can achieve full lifecycle traceability of carbon sinks. Shenzhen has built the first carbon sink blockchain platform of urban green spaces in China, which improves data verification efficiency by 60% and reduces costs by 40% compared to traditional models. These practices have shown that through institutional innovation, technological empowerment, and financial deepening, carbon sink trading in urban park green spaces fully meets the conditions for transforming theoretical concepts into practical operations. The synergistic release of its economic and ecological value could provide a new paradigm for urban sustainable development.

3 Challenges and suggestions for countermeasures

3.1 Technical obstacles and solutions In the process of promoting the inclusion of urban park green spaces in carbon sink trading, technical barriers pose the primary challenge, with the core focus on the accuracy and comprehensiveness of data collection and monitoring. Currently, the assessment of carbon sink capacity in urban park green spaces relies heavily on traditional ecological models and field measurement methods. Although these methods can reflect the carbon sink potential of green spaces to some extent, they are limited by spatial resolution, temporal continuity, and cost – benefit ratio, making it difficult to meet the high frequency, accuracy, and low-cost needs of the carbon sink trading market for data. Specifically, traditional methods often struggle to capture the subtle impacts of different vegetation types, age structures, management measures, and other factors on carbon sink capacity in urban green spaces, resulting in biased evaluation results and ultimately affecting the credibility and market acceptance of carbon sink projects.

In response to the challenges of data collection and monitoring, technological innovation has become the key to breaking through bottlenecks. On the one hand, the deep integration of remote sensing technology and geographic information systems (GIS) provides a new approach for dynamic monitoring of carbon sinks in urban green spaces. Through high-resolution satellite imagery and drone aerial data, combined with ground sensor networks, real-time monitoring of key parameters such as vegetation coverage, biomass, and chlorophyll content in urban green spaces can be achieved, greatly improving the spatiotemporal resolution and accuracy of data acquisition. For example, using multispectral and hyperspectral remote sensing technology, it is possible to distinguish the carbon absorption characteristics of different vegetation types, laying the foundation for refined carbon sink assessment. On the other hand, the application of big data and artificial intelligence technology has further improved the efficiency of data processing and analysis. Through machine learning algorithms, feature patterns related to carbon sink capacity can be extracted from massive remote sensing data, and predictive models can be constructed to achieve rapid assessment and dynamic updates of carbon sink capacity in urban green spaces. This intelligent analysis method based on big data not only reduces the cost of manual monitoring, but also improves the objectivity and scientificity of evaluation results.

Along with technological innovation, attention should also be paid to the development of technical standards and specifications. At present, there is a lack of unified technical standards and operational norms in the field of carbon sink monitoring and evaluation of urban green spaces, which makes it difficult to directly compare and integrate data between different research institutions or projects, and restricts the large-scale development of the carbon sink trading market. Therefore, it is an important guarantee for enhancing the credibility and market competitiveness of carbon sink projects of urban green spaces by promoting the establishment of an interdisciplinary and cross disciplinary standardization system, and clarifying the technical requirements and quality control standards for data collection, processing, analysis, reporting, and other aspects. In addition, it is also an effective way to accelerate the improvement of carbon sink technology standard system of urban green spaces in China by strengthening international cooperation and exchange, and drawing on advanced international experience and technical standards.

In the face of technological barriers, it is also necessary to consider how to stimulate technological innovation vitality through policy guidance and market mechanisms. The government can encourage research institutions and enterprises to carry out the research and application of carbon sink monitoring and evaluation technology in urban green spaces by establishing special funds, tax incentives, government procurement and other policy measures, in order to reduce the cost and risk of technological innovation. At the same time, it should establish and improve incentive mechanisms for the carbon sink trading market, such as formation mechanisms of carbon sink price, certification and regulatory systems of carbon sink project, *etc.*, to ensure that the environmental and economic benefits of carbon sink projects are unified, attract more social capital to invest in the carbon sink field of urban green spaces, and form a virtuous cycle of technological innovation and market application.

In terms of specific cases, some cities in China have taken the lead in piloting carbon sink projects of urban green spaces.

For example, a dynamic monitoring platform for carbon sink of urban green spaces has been built in a city by introducing remote sensing monitoring and big data analysis technology, achieving real-time evaluation and dynamic management of the carbon sink capacity of park green spaces throughout the city. This platform not only provides scientific basis for government decision-making, but also feeds back the carbon sink benefits of some park green spaces to maintenance and management of green spaces through a carbon sink trading mechanism, effectively alleviating the operational difficulties of urban parks and achieving a win-win situation of ecological and economic benefits. This successful case provides valuable experience for other cities, indicating that the combination of technological innovation and policy guidance is an effective path to promote the inclusion of urban park green spaces in carbon sink trading.

In summary, including urban park green spaces in carbon sink trading faces technical barriers. But through comprehensive measures such as the integration of remote sensing and GIS technology, the application of big data and artificial intelligence, the formulation of technical standards and regulations, policy guidance, and market mechanism innovation, it can effectively break through bottlenecks, promote the large-scale and standardized development of carbon sink projects of urban green spaces, and contribute to addressing climate change and promoting sustainable urban development.

3.2 Strategies for enhancing social awareness By incorporating urban park green spaces into the carbon sink trading system as a dual innovation path to address climate change and urban ecological governance, it not only faces technical barriers to institutional integration, but also requires breaking through conceptual barriers at the social cognitive level. At present, urban parks generally face a dual dilemma of insufficient operating funds and insufficient manifestation of ecological value. To achieve the transformation of ecological product value through carbon sink trading as a link, it is necessary to build a multidimensional social awareness enhancement system and collaborative participation mechanism.

Insufficient social awareness is the primary bottleneck restricting carbon sink trading in urban parks. The public's understanding on the concept of carbon sink mostly stays at the level of forest carbon sink, and there is a significant deviation in their understanding of the carbon sequestration capacity of urban green spaces. According to a public carbon sink awareness survey conducted by the Environmental Development Center of the Ministry of Ecology and Environment in 2022, only 12.3% of respondents are aware that urban park green spaces have carbon sink functions, while the proportion of people who mistakenly believe that only primary forests can generate carbon sinks is as high as 67.5%. This cognitive bias directly leads to insufficient public support for the park carbon sink project. In a carbon sink pilot project in a community park in Shenzhen, the project was delayed for three months due to controversy caused by residents questioning "whether manual lawn mowing affects carbon sink capacity". The systematic lack of education and publicity system further exacerbates the cognitive gap. Currently, the proportion of content related to carbon sinks of urban green spaces in environmental education curriculum is less than 5%, and there is a lack of differentiated communication strategies for different age groups.

To solve cognitive dilemmas, it is necessary to construct a "trinity" education and publicity system. At the level of basic education, urban carbon sink knowledge should be incorporated into geography courses of primary and secondary schools, and immersive carbon footprint calculation tools should be developed, such as the "Campus Carbon Map" project introduced by some schools in Shanghai, which uses visualization technology to demonstrate the correlation between carbon sink capacity of green spaces and daily behaviors. In the field of higher education, there is a need to add a major in urban ecological carbon sink. The master's program in "Carbon Sink Management of Urban Green Spaces" newly added by the School of Environment at Tsinghua University in 2023 has trained the first batch of professional talents with carbon sink accounting and trading capabilities. In terms of social propaganda, innovative communication media should be used. The "Carbon Sink Points" mini program developed by Beijing Olympic Forest Park converts behaviors such as walking and garbage classification into carbon points, and users can exchange them for cultural and creative products of the park. The number of registered users has exceeded 500 000 in the first six months of its launch, effectively enhancing public participation.

The design of mechanisms for participation from all sectors of society needs to break through the single government led model and build a diversified governance framework. At the level of financial participation, the "carbon sink + PPP" model can be explored. The carbon sink project of Hangzhou Xixi National Wetland Park introduces social capital accounting for 40%, and risk sharing can be achieved through the establishment of a carbon sink special fund. In terms of technical participation, a collaborative platform among industry, university and research institution should be established. The "Dynamic Monitoring System for Carbon Sink of Urban Green Spaces" jointly developed by the Chinese Academy of Forestry and Vanke Group integrates remote sensing technology with ground observation data to improve the accuracy of carbon sink accounting to 92%. The innovation of community participation mechanism is particularly crucial. The "carbon sink adoption" system implemented in Chengdu Jinchenghu Park allows residents to adopt specific green areas as a family unit and obtain carbon sink right certificates through regular maintenance. This model reduces the maintenance cost of the park by 35% while increasing resident satisfaction to 89%.

The improvement of the institutional guarantee system is the foundation for the effective operation of the participation mechanism. A cross departmental collaborative management mechanism needs to be established. The *Management Measures for Carbon Sink Projects of Urban Green Spaces* (*Trial*) jointly issued by the Ministry of Natural Resources and the Ministry of Ecology and En-

vironment specifies that the urban greening department is responsible for the development of carbon sink projects, the ecological environment department is responsible for transaction supervision, and the finance department formulates tax preferential policies. At the level of standard setting, the China Quality Certification Center has released the *Technical Specification for Carbon Sink Measurement and Monitoring of Urban Park Green Spaces*, which clarifies the carbon sequestration coefficients of different vegetation types such as lawns, shrubs, and trees for the first time, providing technical basis for project development. In terms of innovative trading mechanisms, the "Carbon Sink Pre-sale" model launched by the Guangzhou Carbon Emission Trading Exchange allows park managers to lock in profits through contracts before project verification, effectively alleviating the pressure on capital turnover.

The demonstration effect of practical cases is accelerating the transformation of social cognition. The Nanjing Xuanwu Lake Park Carbon Sink Project uses blockchain technology to achieve full lifecycle traceability of carbon sinks. Each transaction can query the corresponding green space's carbon sequestration data. The 20 000 t of carbon sink of the project in the first phase was sold out immediately upon launch, with a unit price 15% higher than that of forest carbon sink. Suzhou Industrial Park combines carbon sink trading with green finance and develops a "carbon sink loan" product. The park management can use future carbon sink earnings as collateral to obtain low interest loans. This model has been replicated in 12 national level parks across the country. These innovative practices have shown that when carbon sink trading is directly linked to public interest, social awareness will increase exponentially. The survey of a community in Beijing showed that residents who have participated in carbon sink trading have a support rate for park construction 42 percentage points higher than those who have not.

In the future, it is necessary to further strengthen the synergistic effect of cognitive enhancement and participation mechanisms. It is suggested establishing a national urban carbon sink education base, setting up experiential education venues in 50 key urban parks, and using VR technology to simulate the carbon sink process of different vegetation types. At the same time, it should improve the disclosure system of carbon sink trading information, require all projects to regularly release environmental benefit reports, and accept social supervision. Through the triple drive of institutional guarantees, technological innovation, and public education, carbon sink trading in urban park green spaces is expected to break through existing bottlenecks and truly become a green link connecting ecological value and economic value, providing new solutions for urban sustainable development.

4 Implementation path planning

4.1 Short-term action plan In the process of promoting the inclusion of urban park green spaces in carbon sink trading, implementation path planning is the core link to ensure policy implementation and goal achievement. As the primary breakthrough point, short-term action plans need precise design of key steps and quantifiable expected results display, laying the foundation for the construction of long-term mechanisms in the future. The core logic of the short-term action plan is to quickly overcome existing obstacles, verify feasibility through pilot practice, and form replicable experience models. Specifically, the key steps can be divided into four levels: policy coordination, standard setting, pilot screening, and establishment of trading mechanisms.

At the level of policy coordination, priority should be given to resolving institutional conflicts between carbon sink trading and urban green space management. Currently, urban park green spaces are mostly maintained by local governments through financial appropriations or franchising models, and there is a vague boundary at their property rights and carbon sink ownership. In the short term, it is necessary to promote the joint efforts of the Ministry of Natural Resources and the Ministry of Ecology and Environment to establish the *Management Measures for the Registration of Carbon Sink Ownership of Urban Green Spaces*, clarify the priority rights of green space operators in carbon sink development, and establish a dual track ownership confirmation process of "government supervision + third-party verification". For example, Shenzhen has taken the lead in linking the ownership of carbon sinks in urban green spaces with land use rights. By revising the *Shenzhen Urban Greening Regulations*, business entities are allowed to convert excess carbon sequestration capacity into tradable carbon sinks on the premise of completing green space conservation indicators. This model provides a system reference for the whole country.

Standard setting is the technical cornerstone of short-term action. The carbon sink accounting of urban park green spaces needs to break through the traditional forestry carbon sink methodology and build an exclusive accounting system suitable for urban ecosystems. The key parameters include green vegetation type, soil organic carbon content, microclimate regulation effect, *etc.*, which need to be combined with remote sensing monitoring and ground sampling data to establish a dynamic model. The Chinese Academy of Forestry team has developed the "Technical Specification for Carbon Sink Accounting of Urban Wetlands" in the pilot project of Xixi National Wetland Park in Hangzhou. By introducing LiDAR remote sensing technology to quantify vegetation biomass and combining soil carbon flux monitoring equipment to track carbon release processes, a multidimensional carbon sink accounting method covering "carbon sequestration and oxygen release – pollutant absorption – temperature and humidity regulation" has been developed. This standard has been certified by the Ministry of Ecology and Environment of China, providing technical support for short-term promotion.

The pilot screening should follow the principle of "representativeness + operability", and prioritize the selection of urban parks with high carbon sink potential and good management foundation. The screening indicators should include green space coverage, annual average tourist volume, maintenance cost proportion, *etc.*,

while considering the activity of the regional carbon market. For example, Beijing has chosen the Olympic Forest Park as the first pilot project. The park covers an area of 680 hm^2, with an annual carbon sequestration capacity of 12 000 t. Moreover, it has established a comprehensive tourist flow monitoring system and vegetation maintenance records, which has the conditions to directly connect with the Beijing Environmental Exchange. During the pilot process, it is necessary to establish a closed-loop management system for the entire process of "monitoring, accounting, and trading", and use blockchain technology to achieve carbon sink data on the chain, ensuring transaction transparency. Data shows that the Olympic Forest Park achieved a carbon sink trading revenue of 2.4 million yuan in its first year, covering 30% of its maintenance costs and verifying the feasibility of the business model.

The establishment of trading mechanisms needs to break through the limitations of existing carbon market trading varieties. In the short term, the transaction risk can be reduced through the "carbon sink pre-sale + forward contract" model, allowing the operating entity to sign carbon sink purchase agreements with emission control enterprises during the green space construction stage, and locking in future profits. Shanghai introduced this model in the green space reconstruction project of Yan'an Middle Road. By signing a five-year carbon sink pre-sale contract with Baosteel Group, it obtained 15 million yuan of reconstruction funds in advance, which not only improved the carbon sink capacity of green space, but also eased the financial pressure. In addition, it is necessary to establish a dynamic adjustment mechanism for carbon sink prices. Taking into account the average regional carbon market price and changes in green space maintenance costs, carbon sink benchmark prices should be released quarterly to avoid price fluctuations affecting trading enthusiasm.

The expected results display should focus on the triple benefits of policy, economy, and ecology. At the policy level, the short-term goal is to complete the pilot system of 3 – 5 provincial-level administrative regions within one year, and establish scalable standards for ownership registration and accounting. At the economic level, carbon sink trading covers over 20% of the maintenance costs of urban parks, reducing fiscal dependence. At the ecological level, it promotes the transformation of green space maintenance from "extensive management" to "precise carbon sequestration", and it is expected that the average annual carbon sequestration capacity of green spaces in pilot areas will increase by 15% – 20%. Taking Guangzhou as an example, its plan is to include 50% of urban parks in the carbon sink trading system by 2025. Based on current carbon prices, the annual carbon sink revenue can reach 120 million yuan, which is equivalent to reducing financial subsidies by 40%. At the same time, it will drive technological upgrades in the greening and maintenance industry, forming a virtuous cycle of "ecology – economy".

The successful implementation of short-term action plans can not only provide practical examples for urban park green spaces to be included in carbon sink trading, but also force the transformation of urban green space management towards refinement and marketization. Through policy breakthroughs, standard guidance, pilot verification, and mechanism innovation, short-term actions will establish a diversified governance pattern of "government guidance – market drive – society participation", providing sustainable solutions to the operational difficulties of urban parks and contributing Chinese wisdom to global urban ecological carbon sink trading.

4.2 Long-term development strategy When exploring the implementation path planning of incorporating urban park green spaces into carbon sink trading, it is necessary to systematically construct from two dimensions: short-term action framework and long-term development strategy, especially focusing on the design of continuous improvement mechanisms and the scientificity and foresight of future prospects and goal setting. From the short-term planning of the implementation path, the core lies in building an operational carbon sink measurement and certification system. The carbon sink function of urban park green spaces has spatial heterogeneity and temporal dynamics. The measurement of its carbon sink capacity needs to break through the single indicator limitation of traditional forest carbon sink and establish a multi-level measurement model covering trees, shrubs, herbaceous plants, and soil organic carbon. For example, the Beijing Olympic Forest Park has achieved accurate assessment of carbon storage in different vegetation types by combining LiDAR remote sensing technology with ground sample surveys. Its research results provide data support for the development of subsequent carbon sink projects. At the same time, it is necessary to establish a third-party certification mechanism to ensure the environmental integrity of carbon sink projects. This can be done by drawing on the audit process of the International Verified Carbon Standard (VCS) or China Certified Emission Reduction (CCER), and developing special certification rules for urban green spaces, and focusing on key aspects such as project boundary delineation, baseline determination, and leakage risk assessment. In terms of trading mechanism design, it is necessary to explore diversified forms of carbon sink products. In addition to traditional carbon credit trading, carbon sink derivatives based on park green spaces can be developed, such as carbon sink futures, carbon sink insurance, *etc.*, to enhance market liquidity. The "Green Carbon Ticket" system piloted by the Shanghai Municipal Bureau of Greening and Urban Appearance in 2022 allows enterprises to offset some carbon emission quotas by subscribing to carbon sink capacity of park green spaces. This model achieved a transaction volume of over 5 million yuan in the first year, verifying the feasibility of market-oriented operation.

The construction of long-term development strategy needs to be driven by institutional innovation, forming a coordinated development pattern of policy guidance, market drive, and technological support. At the policy level, it is necessary to promote special regulations at the national level, clarify the legal status and trading rules of carbon sinks in urban park green spaces, and solve the problem of insufficient legal authorization in current local pilot

projects. The *Management Measures for Carbon Sink of Urban Green Spaces* issued by Shenzhen in 2023 included park green spaces in the local carbon trading system for the first time. Its experience shows that local legislation can provide practical samples for the construction of national systems. In terms of market cultivation, it is necessary to establish a cross regional carbon sink trading platform, break down administrative barriers, and achieve optimized allocation of carbon sink resources. The "Tianfu Carbon Sink Market" jointly established by the Chengdu Plain Economic Zone has achieved unified registration and trading of carbon sink projects in 8 municipal park green spaces. The trading volume in the first half of 2024 increased by 120% year-on-year, demonstrating the scale effect of regional synergy. The improvement of the technical support system is the key to long-term development, and it is necessary to increase research and development investment in areas such as carbon sink monitoring, remote sensing inversion, and big data analysis. The "Intelligent Monitoring System for Carbon Sink of Urban Green Spaces" developed by Nanjing Agricultural University collects vegetation growth data in real time through an Internet of Things sensor network, and combines machine learning algorithms to predict carbon sink potential. Its prediction accuracy is 35% higher than traditional methods, providing technical support for dynamically adjusting carbon sink projects.

The construction of a continuous improvement mechanism requires the establishment of a closed-loop management system of "monitoring – evaluation – feedback – optimization". In the monitoring process, the "air-space-ground" integrated technology should be adopted, and satellite remote sensing, drone aerial photography, and ground sensor data should be integrated, to achieve high-precision dynamic monitoring of carbon sink capacity. The "Urban Carbon Sink Digital Twin Platform" planned to be deployed by Hangzhou in 2025 will construct a three-dimensional carbon sink model covering park green spaces throughout the city, providing a data foundation for refined management. The evaluation system needs to balance scientificity and practicality, and the life cycle assessment (LCA) method can be introduced to quantify the carbon benefits of park green spaces throughout the entire process from planning, construction to operation. The "Green Infrastructure Carbon Footprint Assessment" project carried out by the Beijing Municipal Administrative Center provides a basis for the development of low-carbon design standards by comparing the carbon emissions differences between traditional parks and sponge parks. The design of feedback mechanisms should focus on stakeholder participation, establish a multi-party negotiation platform composed of government, enterprises, communities, and research institutions, regularly release performance reports on carbon sink projects, and accept social supervision. The "Public Supervisor of Carbon Sink" system implemented by Yuexiu Park in Guangzhou has recruited volunteers to participate in carbon data verification, effectively enhancing project transparency. The optimization process requires the establishment of a dynamic adjustment mechanism, and timely correcting measurement methods, trading rules, or management strategies of carbon sink based on monitoring and evaluation results. Based on the annual carbon sink audit results, the Suzhou Industrial Park has implemented an exit mechanism for some inefficient projects and redistributed the released carbon sink indicators to high potential areas, achieving efficient resource allocation.

The future outlook and goal setting should be based on the overall situation of global climate change governance, and the market-oriented and international process of carbon sink trading in urban park green spaces should be promoted in stages. The short-term goal (2025 – 2030) should focus on institutional improvement and market expansion, striving to achieve the inclusion of parks and green spaces in the carbon trading system in more than 50% of prefecture level cities nationwide, with an annual trading scale exceeding 1 billion yuan. The mid-term goal (2031 – 2040) is to promote the alignment of technical standards with international standards, cultivate carbon sink service institutions with international competitiveness, and ensure that carbon sequestration products of urban green spaces in China have a global market share of over 15%. The long-term goal (2041 – 2060) should be to strive for the construction of exemplary model of a "community of shared life between humans and nature", and to achieve the organic unity of ecological value, economic value, and social value of urban green spaces through innovative carbon sink trading mechanisms. The concept of "Green Infrastructure Bank" is proposed in the 2050 carbon neutrality plan of the City of London, which attracts private capital to participate in the construction of park green spaces through innovative financial instruments, and it is worth learning from. During this process, it is necessary to be vigilant about the risk of "carbon lock-in" and avoid excessive commercialization leading to weakened ecological service functions. In the Berlin Tiergarten Park, 20% of core protected area has been designated for prohibiting any development activities in carbon sink project development. This approach provides an example for balancing ecological protection and market development. Through institutional innovation, technological breakthroughs, and model exploration, carbon sink trading in urban park green spaces is expected to become a Chinese solution for global climate governance, contributing wisdom to the construction of a fair, reasonable, and cooperative international carbon market system.

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