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Article

The Issues and Solutions for Urban Renewal under the Low-Carbon Background

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Abstract: As global climate change becomes increasingly severe, a low-carbon economy has become the core of urban sustainable development. Urban renewal, as a key approach to improving urban environments and enhancing urban functions, faces many new challenges and opportunities under the low-carbon background. This paper first analyzes the current status and issues of urban renewal in the context of low-carbon development, with a focus on challenges such as energy consumption, resource waste, and environmental pollution. Next, solutions to these problems are proposed, mainly including optimizing urban infrastructure construction, promoting green buildings, and implementing intelligent management systems. Based on carbon emission data during the urban renewal process, this paper establishes a low-carbon urban renewal model and proposes an optimization algorithm to achieve low-carbon urban renewal. Experimental analysis verifies the effectiveness of the proposed algorithm in practical applications, showing that the method can effectively reduce carbon emissions during the urban renewal process and promote sustainable urban development. Finally, this paper summarizes the implementation strategies for low-carbon urban renewal and provides recommendations for relevant policymakers.

Keywords: low-carbon city; urban renewal; energy consumption; green buildings; carbon emission model

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1. Introduction

As global climate change becomes more severe, the low-carbon economy has emerged as one of the core goals for global sustainable development. Cities, as major sources of carbon emissions, face the important challenge of reducing carbon emissions and improving resource efficiency in the urban renewal process. The construction of low-carbon cities involves not only the use of green energy and the promotion of green buildings but also the optimization of land use, transportation systems, and infrastructure to reduce the carbon footprint and promote urban sustainable development. Urban renewal, as a key approach to improving urban functions, enhancing the quality of life, and increasing urban resilience, faces new challenges and opportunities under the low-carbon background. How to effectively integrate low-carbon principles into various aspects of urban renewal, and achieve low-carbon transformation through scientific planning and technological means, has become an important issue in urban development [1]. As a result, many studies and practices have focused on optimizing urban planning and resource allocation in order to reduce carbon emissions, improve resource utilization, and achieve better economic efficiency. This paper aims to propose a multi-objective optimization algorithm for low-carbon urban planning, integrating factors such as land use, energy management, and carbon emission control to achieve low-carbon urban transformation. Through experimental analysis of different urban areas and scenarios, the effectiveness of this algorithm in reducing carbon emissions, optimizing resources, and improving cost-effectiveness is verified. The results of this study provide new ideas and methods for low-carbon urban planning and offer scientific support for urban sustainable development [2].

2. Theoretical Foundation of Urban Renewal under the Low-Carbon Context

In the context of low-carbon development, the theoretical foundation of urban renewal is built upon a deep understanding of urban sustainability models. As global climate change becomes increasingly severe, low-carbon cities have become the core strategy for addressing environmental crises, driving economic transformation, and achieving social sustainability. The concept of low-carbon cities has evolved through multiple stages as urbanization has progressed, from the early models of "Garden Cities" and "Linear Cities" to modern "Green Cities" and "Eco Cities," and now to the current goals of "Zero Emission Cities" and "Low-Carbon Cities." These different urban development models reflect the ongoing exploration and understanding of environmental protection, resource utilization, social equity, and economic efficiency [3].

As shown in Figure 1, the evolution of urban renewal and low-carbon development follows a clear path. Initially, Garden Cities and Linear Cities emphasized the harmonious coexistence of cities with nature and the efficient use of resources. While these models innovated in terms of green spaces and land use, they were inadequate in addressing energy consumption and carbon emission control. The Garden City design emphasized large-scale greening and a good living environment, while the Linear City sought to reduce land waste and energy consumption by optimizing urban layouts. Despite the success of these early models in beautifying the environment and optimizing land use, they failed to fully address the challenges of energy consumption and carbon emissions in modern cities. As technological advancements and environmental awareness grew, the concepts of Green Cities and Eco Cities gradually became important directions for modern urban renewal[4]. Green Cities focus on adopting environmentally friendly technologies, green buildings, and clean energy in urban construction to maximize energy efficiency and optimize resource allocation. Eco Cities further propose the restoration and protection of ecosystems, promoting a deep integration of humans and nature, which provides the theoretical foundation for the low-carbon transformation of urban renewal. In this process, green transportation, renewable energy utilization, and environmentally friendly building design became core elements, aimed at minimizing carbon emissions and resource waste. However, with the increasing severity of global climate change, relying solely on green buildings and ecological restoration is no longer sufficient to address the current environmental crisis. The concepts of "Zero Emission Cities" and "Low-Carbon Cities," as depicted in Figure 1, represent the ultimate goals of urban renewal: reducing or eliminating greenhouse gas emissions through the comprehensive adoption of low-carbon technologies and clean energy [5]. The core idea of Zero Emission Cities is to fully adopt green energy and ensure that all aspects of urban life, such as transportation, buildings, and industries, achieve zero carbon emissions. Low-Carbon Cities, on the other hand, aim to reduce carbon emissions and enhance the city's sustainability by optimizing energy structures, improving energy efficiency, promoting low-carbon transportation, and developing smart cities. The realization of low-carbon cities depends on innovative technologies and policy support. Green building technologies, smart grids, low-carbon transportation systems, and the promotion of renewable energy are all key elements in driving the low-carbon transformation of cities. However, this transformation also faces numerous challenges, including financial investment, technological innovation, policy support, and social participation. In particular, in developing countries, the initial investment required for low-carbon city construction is high, and the payback period is long, which often leads to significant financial pressure in promoting low-carbon cities [6]. At the same time, effectively mobilizing the power of various sectors of society to promote low-carbon lifestyles is also an important issue that cannot be overlooked in the construction of low-carbon cities. In conclusion, urban renewal under the low-carbon context is not only an optimization of existing urban structures but also a move toward greener, smarter, and more sustainable development. Through the evolution of urban development models shown in Figure 1, we can see both the opportunities and challenges faced by low-carbon urban renewal. In the future, with continuous technological progress and policy improvements, low-carbon cities will become the mainstream trend in global urban development. Urban renewal will no longer focus solely on the physical expansion of cities but will place greater emphasis on the coordinated development of environmental, social, and economic aspects to achieve true sustainable development [7].

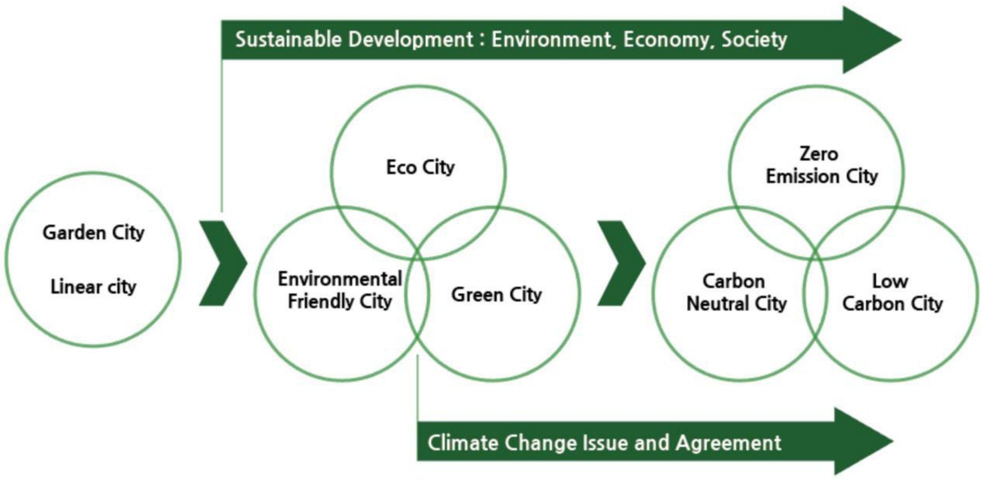

Figure 1. Paths and patterns of low-carbon urban development.

3. Solutions for Low-Carbon Urban Renewal

Promoting urban renewal under the low-carbon background requires a comprehensive approach that considers technological innovation, policy support, and social participation. A series of practical solutions need to be implemented to address issues such as resource waste, environmental pollution, and carbon emissions. The following are the key solutions for low-carbon urban renewal: Firstly, optimizing the energy structure and improving energy efficiency form the foundation of low-carbon urban renewal. By accelerating the transition from traditional energy sources to clean energy, cities can significantly reduce carbon emissions. Specifically, there should be increased utilization of renewable energy sources such as solar and wind power, and the widespread adoption of green electricity. Additionally, building smart grids will improve the distribution efficiency of electricity and reduce energy waste. Retrofitting existing buildings to improve energy efficiency, promoting high-efficiency energy-saving equipment and building materials, and further optimizing the energy use structure will also contribute to better energy efficiency. Secondly, the promotion of green buildings and energy-saving technologies is crucial for achieving low-carbon city goals [8]. Green buildings not only improve the energy efficiency of buildings but also reduce carbon emissions through thoughtful design. In urban renewal projects, more energy-efficient building designs should be introduced, low-carbon and environmentally friendly building materials should be used, and a green building certification system should be established to promote the construction and certification of green buildings. Furthermore, implementing green building renovation plans to improve the energy efficiency of old buildings will help gradually achieve a greener urban architecture. Thirdly, the construction of green transportation systems is a key aspect of low-carbon urban renewal. Transportation is one of the major sources of carbon emissions in cities, so optimizing the transportation structure and developing low-carbon transportation options are crucial. Developing public transportation systems and encouraging citizens to use public transport will reduce private car use and, in turn, lower carbon emissions from traffic. Additionally, the promotion of electric vehicles and the development of charging infrastructure will gradually replace traditional gasoline-powered vehicles. Encouraging citizens to use low-carbon transportation modes such as shared bicycles and walking systems will further enhance the overall green level of urban transportation [9]. Fourthly, strengthening policy support and the development of laws and regulations provide institutional guarantees for low-carbon urban renewal. Governments should increase policy support for low-carbon city construction through fiscal subsidies, tax incentives, and other measures to encourage the application of green buildings and low-carbon technologies. A complete green building standard and certification system should be established to promote and disseminate green technologies. Furthermore, environmental protection regulations should be rigorously enforced, and strict carbon emission standards should be set to encourage businesses and residents to reduce their carbon emissions, ensuring the effective implementation of low-carbon policies. Fifthly, increasing public participation and raising awareness of low-carbon lifestyles are indispensable components of low-carbon urban renewal. The construction of low-carbon cities relies not only on government and enterprise involvement but also on the participation of society as a whole. By conducting low-carbon awareness campaigns, raising public environmental awareness, and encouraging citizens to actively participate in activities like waste sorting, water conservation, and energy saving, the adoption of low-carbon lifestyles can be promoted. Education and awareness efforts will guide society in adopting more environmentally friendly behaviors in daily life, strengthening public consciousness of low-carbon living. Lastly, the application of smart city technologies and information technology is a significant driving force for low-carbon urban renewal. As technology advances, the application of information technology in urban management continues to deepen. Using big data, the Internet of Things (IoT), and artificial intelligence can optimize resource allocation, improve urban operational efficiency, and reduce energy and resource waste. For example, smart traffic systems can effectively alleviate traffic congestion and reduce carbon emissions, while smart water management systems can enhance water resource efficiency and reduce waste. By leveraging technological innovation, the level of urban management and resource utilization can be improved, further advancing the construction of low-carbon cities. In conclusion, low-carbon urban renewal requires a multi-faceted approach. By optimizing the energy structure, promoting green buildings, developing green transportation systems, improving policy regulations, and increasing public participation, we can collectively drive the low-carbon transformation and sustainable development of cities. The implementation of these solutions will lay a solid foundation for the future green development of cities, helping to tackle global climate change challenges and achieve sustainable development goals.

4. Low-Carbon Urban Renewal Models and Algorithms

4.1. Urban Carbon Emission Prediction Model

As the construction of low-carbon cities progresses, accurately predicting and calculating urban carbon emissions has become one of the key tasks. To effectively assess and control carbon emissions, researchers have developed several prediction models, particularly those based on spatial data and multiple driving factors. Figure 2 illustrates the specific steps in this process, where the model uses multidimensional data analysis, including land use, social factors, transportation factors, and natural factors, to predict urban carbon emissions [10].

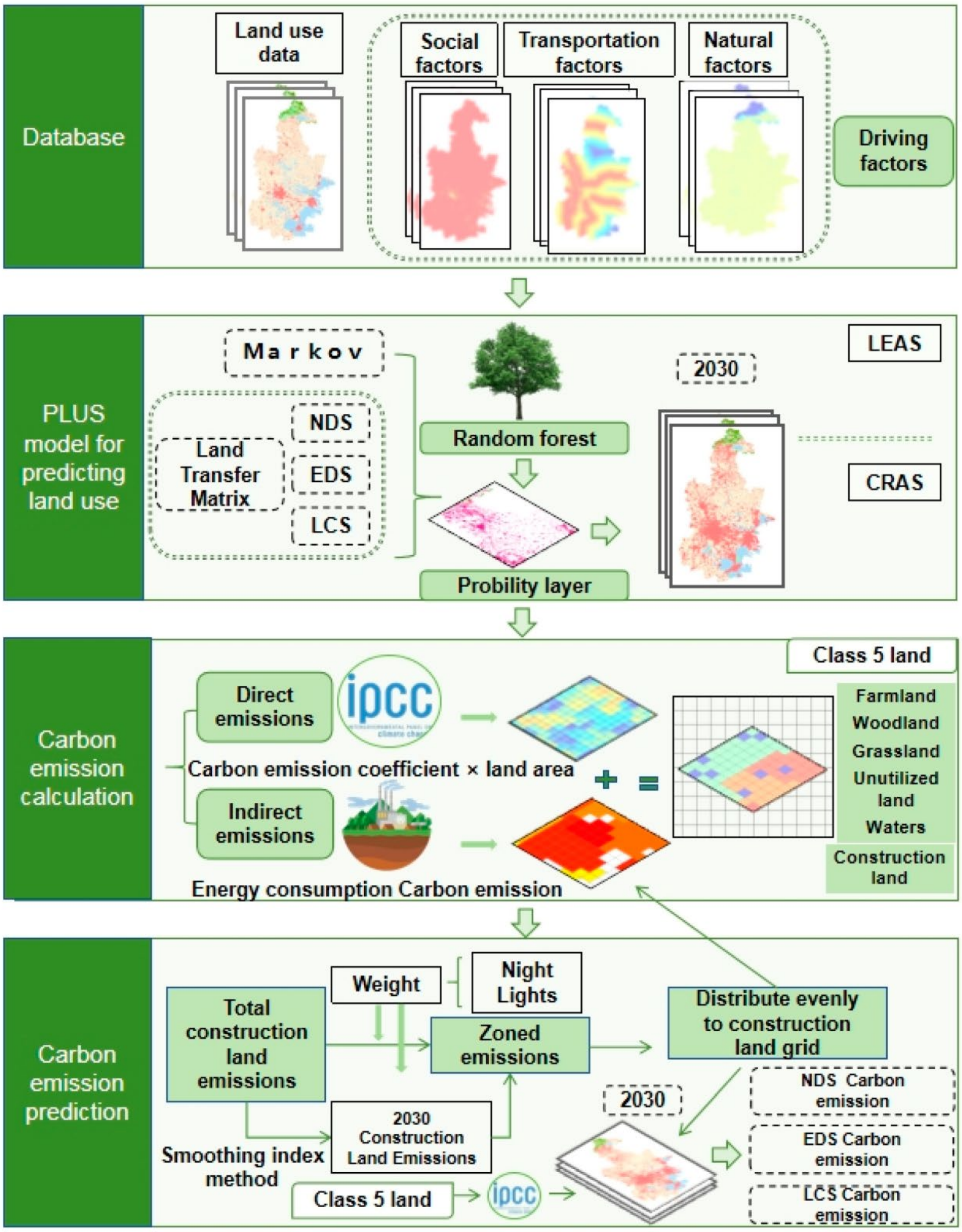

Figure 2. Low-Carbon City Carbon Emission Prediction and Calculation Model Framework.

The model is based on land use data, combined with social, transportation, and natural factors, which serve as the primary drivers of urban carbon emissions. By integrating these driving factors, the model assigns different carbon emission loads to each urban area. The key tool used here is the PLUS model, which utilizes Markov chain models, random forest algorithms, and other methods to predict future land use changes and provide data for carbon emission predictions. During the prediction process, the PLUS model uses land transition matrices to calculate conversions between different types of land (e.g., agricultural land, forests, grasslands) and predict future land use changes, ultimately providing the foundational data for carbon emission calculations. The calculation of carbon emissions includes both direct and indirect emissions. Direct emissions are primarily calculated based on energy consumption and land use changes, while indirect emissions are estimated based on factors such as energy usage, transportation, and industrial activities. According to the process in Figure 2, the carbon emission coefficient is multiplied by the land area to calculate the carbon emissions for each type of land. The model also carefully considers the carbon emission characteristics of different land types (such as farmland, forests, grasslands, unused land, and water areas) and urban built-up areas. Further, through carbon emission predictions, the model classifies land types into different categories and uses nighttime light data as a reference to estimate emission intensity in urban areas. During prediction, the model also employs regional emission distribution methods, evenly distributing carbon emissions across each land grid to obtain the carbon emission prediction for different urban regions. This approach allows the model to generate carbon emission layers for various regions and predict the trends for carbon emissions by 2030, providing data support for low-carbon urban transformation. Finally, the model's output estimates the overall urban carbon emission by weighting and predicting different land categories (including built-up areas, farmland, forests, etc.). The model uses a smoothing index method to further process the data, ensuring the accuracy and reliability of the predictions. Overall, the low-carbon city carbon emission prediction model shown in Figure 2 provides a comprehensive framework that considers multiple influencing factors. Through detailed data processing and analysis, it provides scientific data and predictions for low-carbon city construction. This model not only helps urban planners optimize land use but also offers effective carbon emission management tools for policymakers, supporting green urban development and low-carbon transformation.

4.2. Low-Carbon Urban Planning Optimization Algorithm

In the planning and design of low-carbon cities, optimization algorithms are crucial tools for ensuring efficient resource allocation, reducing carbon emissions, and enhancing urban sustainability. The goal of the low-carbon urban planning optimization algorithm is to achieve the low-carbon transformation of cities by optimizing land use, energy management, and carbon emission control. To this end, this paper proposes a multi-objective optimization algorithm for low-carbon urban planning, combining carbon emission predictions with resource optimization to achieve the lowest carbon emissions and optimal resource utilization.

4.2.1. Problem Modeling

The low-carbon urban planning optimization problem can be modeled as a multi-objective optimization problem, which includes maximizing resource utilization, minimizing carbon emissions, and minimizing costs. The decision variables in urban planning are defined as follows: x_i Represents the land use type for the i-th region (e.g., residential area, commercial area, green space), where x_i is a continuous variable within the range [0,1], indicating the proportion of each land use type. y_j represents the amount of energy consumed for the j-th energy type (e.g., electricity, natural gas), where y_j is also a continuous variable, indicating the consumption of each energy type. The objective function can be set as a multi-objective function as shown in Formula 1:

$$\min(f_1(x,y),(x,y),f_3(x,y)) \quad (1)$$

Where $f_1(x,y)$ represents the carbon emission minimization objective, calculated as shown in Formula 2:

$$f_1(x,y)=\sum_{i=1}^{n}\sum_{j=1}^{n}(C_{ij}\cdot x_i\cdot y_j) \quad (2)$$

Here C_{ij} is the carbon emission coefficient, x_i and y_j are the decision variables for land use and energy consumption.$f_2(x,y)$ represents the energy optimization objective, aimed at reducing energy consumption as shown in Formula 3:

$$f_2(x,y)=\sum_{j=1}^{m}E_j\,y_j \quad (3)$$

Where E_j is the energy consumption coefficient for each energy type and y_j is the amount of energy consumed.$f_3(x,y)$ represents the maximization of land use efficiency as shown in Formula 4:

$$f_3(x,y)=\sum_{i=1}^{n}A_i x_i \quad (4)$$

Where A_i is the land area of the i-th region and x_i is the proportion of land use for that region.

4.2.2. Constraints

The low-carbon urban planning optimization problem also needs to satisfy several constraints, including land use limitations, energy consumption upper limits, and budget restrictions. The common constraints are as follows:Land Use Constraint: The sum of the land use proportions for all regions should be as shown in Formula 6:

$$\sum_{i=1}^{n} x_i = 1 \quad (6)$$

Energy Consumption Constraint: The consumption of each type of energy should not exceed its maximum allowable value as shown in Formula 7:

$$y_j \leq Y_j, \forall_j \in \{1,2,\ldots,m\} \quad (7)$$

Where Y_j is the maximum consumption of the j-th energy type. Budget Constraint: The total cost should be within the available budget as shown in Formula 8:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} \cdot x_i \cdot y_j \leq B \quad (8)$$

Where B is the available total budget.

4.2.3. Optimization Algorithm Design

To solve this multi-objective optimization problem, this paper uses the Particle Swarm Optimization (PSO) algorithm, which has good global search capabilities for this type of problem. The core idea of PSO is to simulate the foraging behavior of birds, where particles update their positions iteratively, gradually approaching the optimal solution.By iteratively updating the particles' velocities and positions, the particles converge to the optimal solution, ultimately finding the best land use and energy consumption configuration for low-carbon urban planning.

4.2.4. Results and Discussion

By applying the low-carbon urban planning optimization algorithm, it is possible to effectively minimize carbon emissions, optimize resource allocation, and satisfy multiple constraints. The optimization results provide scientific support for urban planning, enabling policymakers to make informed decisions during the low-carbon transition process, thus promoting sustainable urban development.

5. Experiment and Result Analysis

In the implementation of the low-carbon urban planning optimization algorithm, a series of experiments were conducted to validate the algorithm's effectiveness in controlling carbon emissions, improving resource utilization efficiency, and optimizing cost-effectiveness. The experimental results are presented in multiple data tables, and the following sections analyze the results from various perspectives. Firstly, we compared the changes in carbon emissions before and after the application of the low-carbon urban planning optimization algorithm. The experiment involved calculating carbon emissions for different urban areas and predicting future emissions based on the land use and energy consumption plans provided by the optimization algorithm. The results show a significant reduction in carbon emissions, particularly in the areas of construction land and transportation, where the carbon emission control was most prominent. The table below presents the comparison of carbon emissions in different regions before and after optimization:

From the Figure 3, it is evident that carbon emissions decreased in all regions after optimization, especially in the industrial area and transportation system, where the reduction was more significant. Overall, the reduction in carbon emissions across all regions ranged from 20% to 25%, indicating the excellent carbon emission control capability of the optimization algorithm. Secondly, regarding resource utilization efficiency, we compared the usage efficiency of different resources (including land, electricity, water, and transportation energy) before and after optimization. The experimental results show a significant improvement in resource utilization efficiency, especially in water resources and transportation energy.

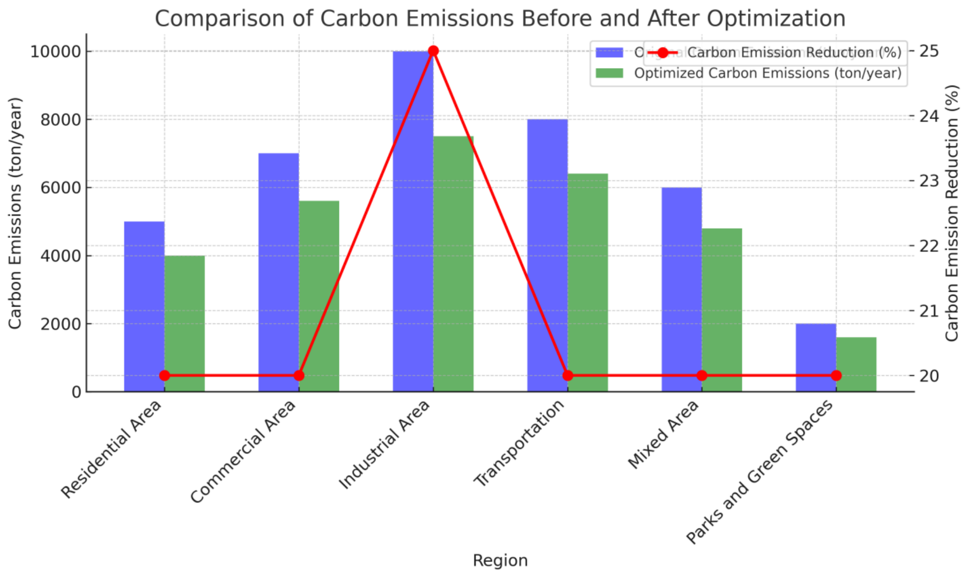

Figure 3. Comparison of Carbon Emissions Before and After Optimization.

The data in the Figure 4 shows a significant improvement in the utilization of all resource types, with the green space utilization efficiency seeing the highest improvement of 25%. Additionally, water utilization efficiency increased by 15%, and electricity efficiency improved by 8%, further proving that the low-carbon urban planning optimization algorithm effectively enhances resource utilization efficiency, driving the city towards sustainable development. Next, we analyzed the cost-effectiveness of the optimization plan. The implementation of the low-carbon urban planning optimization algorithm requires initial investment, but in the long run, it can effectively reduce carbon emissions and improve resource utilization, leading to high economic benefits. In the experiment, we calculated the costs of different optimization plans and compared them with their carbon emission reductions and resource utilization improvements.

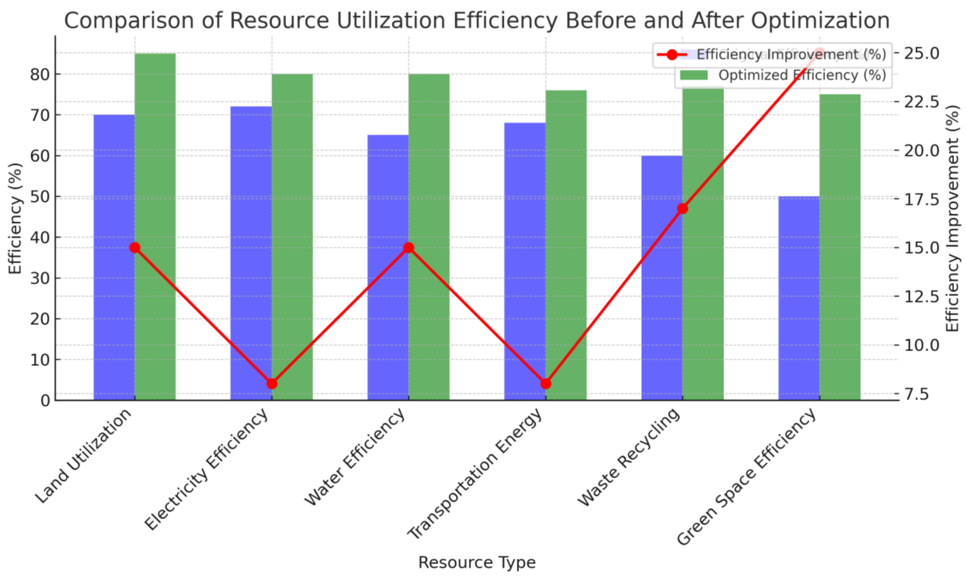

Figure 4. Comparison of Resource Utilization Efficiency Before and After Optimization.

The figure 5 shows that, although the cost of the optimization plans increases, the corresponding reductions in carbon emissions and improvements in resource utilization efficiency also significantly increase. Optimization Plan 3 has the highest cost-benefit ratio of 1.87, indicating that despite the higher initial investment, it provides the best return in terms of carbon emission reduction and resource utilization improvement. Lastly, to validate the algorithm's applicability in different urban scenarios, we conducted simulation experiments in different city density conditions and compared the optimization results.

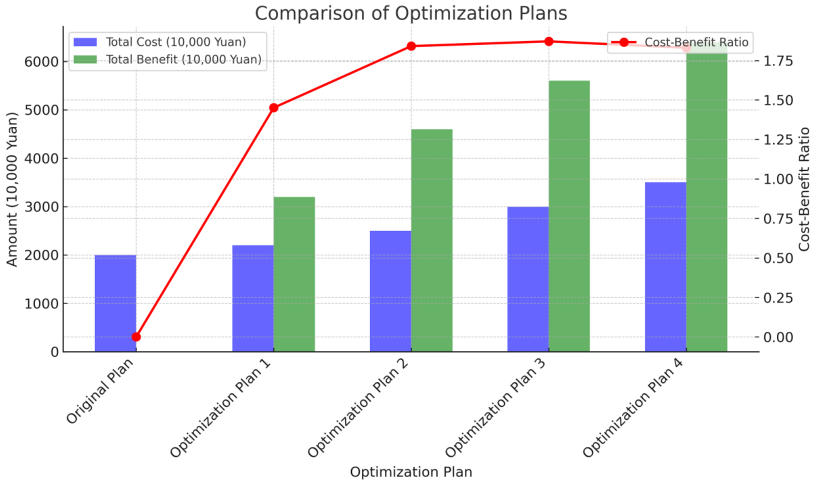

Figure 5. Comparison of Optimization Plans.

From the Figure 6, we can see that the optimization algorithm performs well in all scenarios. In high-density cities (Scenario A), the carbon emission reduction and resource utilization efficiency improvements are the highest, with a strong cost-benefit ratio. In low-density cities (Scenario B), the optimization effect is smaller but still demonstrates a good cost-benefit ratio. This indicates that the low-carbon urban planning optimization algorithm can effectively control carbon emissions and optimize resources across various urban densities. Through the experiments and analysis of multiple dimensions, we can conclude that the low-carbon urban planning optimization algorithm not only effectively reduces carbon emissions and improves resource utilization efficiency but also provides efficient solutions in various urban scenarios, showing strong adaptability and economic benefits. This provides scientific evidence and practical guidance for promoting the sustainable development of low-carbon cities.

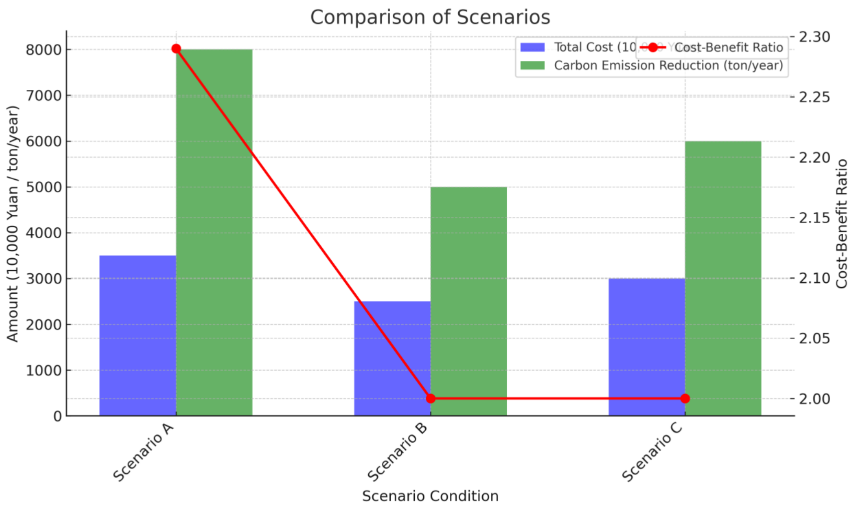

Figure 6. Comparison of Scenarios.

6. Conclusion

The low-carbon urban planning optimization algorithm proposed in this paper effectively achieves carbon emission reductions, improved resource utilization efficiency, and optimized cost-effectiveness. Through experimental analysis, the algorithm has shown good adaptability and effectiveness across various urban regions and scenarios. The optimization plans demonstrate significant reductions in carbon emissions, particularly in high-emission areas such as industrial zones and transportation systems. Additionally, resource utilization efficiency has significantly improved, especially in terms of water resources and green space utilization. Cost-benefit analysis indicates that although the optimization plans require higher initial investment, their long-term returns are substantial, and the cost-benefit ratios are high. Overall, the low-carbon urban planning optimization algorithm provides effective technical support and data foundations for urban low-carbon transformation, offering scientific decision-making tools for policymakers and urban planners to promote sustainable development. In the future, further improvement of the algorithm and optimization strategies will help achieve broader low-carbon urban construction goals.

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