Environment, Social and Governance; Vol.2, No.2; 2025
E-ISSN: 3006-3973 P-ISSN：3006-3965
DOI: https://doi.org/10.70267/ esg2025.v2n2.0111
Published by: Zeus Press

Research on the Optimization of Low-Carbon Spatial Layout for Construction Land in Central Urban Areas

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Abstract

With the acceleration of urbanization, the construction land in central urban areas not only promotes economic growth but also faces significant carbon emission pressure. To achieve low-carbon development goals, optimizing the spatial layout of construction land in central urban areas has become an urgent issue. Based on the needs of low-carbon development, this study proposes a low-carbon spatial layout optimization method based on algorithms and models. By constructing a spatial layout optimization model and integrating Geographic Information System (GIS) technology with optimization algorithms (such as Genetic Algorithm and Particle Swarm Optimization), this study conducts an in-depth analysis of the low-carbon layout optimization of construction land in central urban areas. Experimental results indicate that this optimization method effectively reduces carbon emissions from urban construction land, improves spatial resource utilization efficiency, and provides scientific decision-making support for urban low-carbon development.

Keywords

central urban area, construction land, low-carbon spatial layout, optimization algorithm, spatial model, sustainable development

1. Introduction

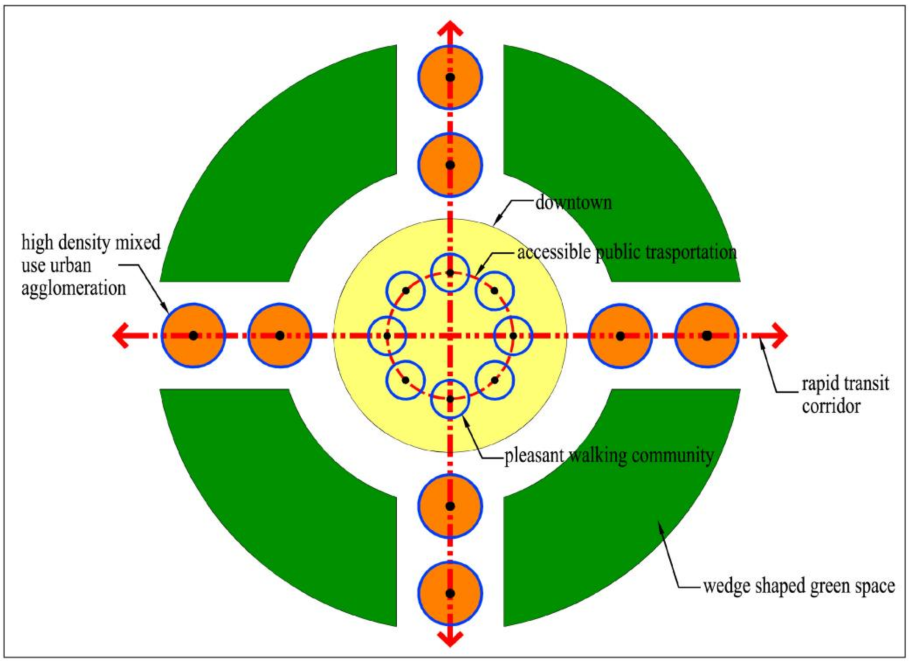
As global climate change intensifies, urban carbon emissions have become a major challenge for environmental sustainability. Central urban areas, as the most concentrated zones for economic, population, and transportation activities, have spatial layouts that directly impact energy consumption and carbon emissions. Traditional urban development models often lead to inefficient land use, worsening traffic congestion, and an unbalanced industrial structure, thereby increasing urban carbon emission pressure. Consequently, optimizing urban spatial layouts to reduce carbon emissions while ensuring urban functionality and economic growth has become a crucial issue in contemporary urban planning and management. In recent years, both domestic and international research has made progress in low-carbon urban planning, compact city design, and public transportation optimization. Internationally, many cities have adopted Mixed-Use Development (MUD) and Transit-Oriented Development (TOD) strategies to shorten commuting distances, enhance public transport utilization, and lower carbon emissions. Domestically, an increasing number of cities are implementing low-carbon policies, such as promoting green buildings, optimizing industrial structures, and expanding urban green spaces. However, challenges remain, including high carbon emissions from industrial clusters, excessive energy consumption in transportation, and insufficient optimization of spatial layouts. Moreover, optimizing low-carbon spatial layouts involves multi-objective and multi-constraint problems, which traditional planning methods struggle to solve effectively. Therefore, intelligent optimization algorithms are urgently needed to reduce carbon emissions while optimizing urban resource allocation (Wang et al., 2021).

2. Theoretical Foundation of Low-Carbon Spatial Layout Optimization

2.1 Low-Carbon Cities and Spatial Planning Theory

The development of low-carbon cities is one of the key challenges in modern urban planning. The core objective is to enhance energy efficiency and effectively control carbon emissions through rational spatial layouts, optimized transportation systems, and well-planned green infrastructure. Figure 1 presents an optimized model for low-carbon spatial layout, integrating various low-carbon planning concepts, including compact urban development, high-density mixed-use land allocation, rapid public transportation systems, pedestrian-friendly communities, and well-structured green infrastructure. Together, these elements form a low-carbon, sustainable urban spatial structure (Li et al., 2022).

Figure 1: Low-carbon spatial layout model of central urban area



The compact city development model plays a crucial role in optimizing low-carbon spatial layouts. Figure 1's “High-Density Mixed-Use Urban Clusters” illustrate this concept by increasing urban density in central areas and integrating commercial, office, and residential functions within a relatively confined space. This approach reduces commuting distances and dependence on private vehicles, thereby lowering carbon emissions. In addition to improving land-use efficiency and curbing urban sprawl’s ecological impact, this model enables centralized energy management, optimizing building energy consumption and further reducing overall carbon emissions. Transit-Oriented Development (TOD) is another essential strategy for achieving low-carbon spatial layouts. Figure 1’s “Rapid Transit Corridors” and “Accessible Public Transport” embody this principle by establishing efficient public transportation networks to enhance accessibility across urban functional zones and minimize private vehicle usage. This model prioritizes transit infrastructure by placing multiple transport hubs around the urban core, ensuring residents can commute efficiently using metro systems or Bus Rapid Transit (BRT) (Zhang & Zhang, 2023). Furthermore, optimizing urban transit corridors enhances mobility, reduces congestion, and fosters economic activity along transit lines, reinforcing the low-carbon benefits of compact city development. Pedestrian and bicycle-friendly community design is another key component of low-carbon urban planning. Figure 1’s “Convenient Walkable Communities” emphasize optimizing pedestrian environments to reduce reliance on short-distance motorized transport while improving accessibility within central urban areas. Pedestrian-friendly community designs involve not only strategically placed sidewalks, bike lanes, and pedestrian-only zones but also optimized street scales, controlled building density, and functional land-use integration. This spatial configuration enables residents to meet daily needs within walking distance, significantly reducing short-distance travel emissions while fostering vibrant public spaces and improved urban livability. Moreover, pedestrian-friendly communities encourage healthy lifestyles, enhance social interaction, and contribute to the overall goal of low-carbon urban development. Green infrastructure development is equally crucial for low-carbon spatial optimization. Figure 1's "Wedge-Shaped Green Spaces" illustrate a typical green infrastructure layout strategy for low-carbon cities, where strategically placed green spaces and ecological corridors improve urban environmental quality (Liu et al., 2022). These green areas act as carbon sinks, absorbing CO_2 emissions and mitigating urban heat island effects. Additionally, they enhance resilience against extreme weather conditions and serve as natural buffers between different urban functional zones, reducing industrial pollution impacts on residential areas and improving overall urban livability. The structure in Figure 1 presents a multi-layered, multi-factor coordinated low-carbon spatial layout model. The central urban area integrates high-density mixed-use zones and walkable communities to enhance land-use efficiency, while outer urban zones feature additional mixed-use clusters to balance urban functions. A rapid transit corridor network ensures efficient connections between all functional zones, increasing overall urban mobility. Moreover, the wedge-shaped green spaces not only enhance urban ecology but also create internal ecological buffers that further contribute to reducing urban carbon emissions. Through this optimization model, the fundamental objectives of low-carbon spatial layouts are achieved: maintaining efficient urban functionality while reducing carbon emissions, improving ecological quality, and enhancing residents' convenience and well-being. This integrated model, which combines public transit, compact urban form, walkable communities, and ecological green spaces, provides a scientifically sound planning framework for the future development of low-carbon central urban areas (Huang et al., 2021).

2.2 Key Elements of Low-Carbon Spatial Layout

The core of low-carbon spatial layout optimization lies in coordinating land use, transportation systems, ecological environment, and energy consumption to maximize urban efficiency while minimizing carbon emissions. Based on the layout model in Figure 1, the optimization of low-carbon spatial layouts should focus on several key elements, including land-use functionality, public transportation systems, pedestrian and bicycle networks, green infrastructure, and energy and carbon management. The Table 1 summarizes these key elements, their main functions, and optimization strategies (R. Wu et al., 2022).

Table 1: Key Elements and Optimization Strategies of Low-Carbon Spatial Layout

Key Element	Main Function	Optimization Strategy
High-Density Mixed-Use Development	Improves land-use efficiency, reduces commuting demand, and lowers transportation emissions.	Encourages mixed-use development (residential, commercial, office, entertainment) to reduce travel demand and enhance urban accessibility.
Rapid Public Transit Corridors	Provides efficient, low-carbon mobility options and reduces private vehicle dependency.	Develops metro, BRT, and high-frequency bus services while optimizing transfer hubs and improving regional connectivity.
Pedestrian-Friendly Communities	Encourages short-distance green mobility and reduces motorized transport emissions.	Designs walkable streets, expands sidewalks and bike lanes, and establishes car-free zones to improve pedestrian comfort and safety.
Wedge-Shaped Green Spaces & Ecological Corridors	Enhances carbon sequestration, improves microclimate, and mitigates urban heat islands.	Develops large-scale green spaces between functional areas, connects parks with ecological corridors, and promotes biodiversity.
Low-Carbon Buildings & Energy-Efficient Facilities	Reduces building energy consumption and increases energy efficiency.	Promotes green building standards, applies energy-efficient materials and smart energy management systems, and encourages rooftop gardens and solar panels.

These key elements interact to form a systematic low-carbon spatial optimization framework. For instance, mixed-use development reduces commuting demand, thereby lowering transportation emissions, while integrating rapid transit corridors ensures more efficient and accessible urban mobility. Pedestrian-friendly communities not only contribute to emission reduction by encouraging active transportation but also enhance urban quality of life. The strategic placement of wedge-shaped green spaces and ecological corridors improves environmental sustainability by increasing carbon sequestration capacity. Furthermore, low-carbon building initiatives and smart management systems enhance energy efficiency, ensuring that cities progress toward sustainable development goals. By implementing these optimization strategies, cities can maintain high development efficiency while significantly reducing carbon emissions, improving environmental quality, and fostering a livable, low-carbon, and sustainable urban model (Chen, 2023).

2.3 Evaluation System for Low-Carbon Spatial Layout Optimization

To scientifically assess the effectiveness of low-carbon spatial layout optimization, it is necessary to establish a comprehensive evaluation system that integrates economic, social, and ecological dimensions. This evaluation system should quantify the impact of land-use patterns, transportation systems, energy utilization, and environmental factors to measure the level of low-carbon urban development. Based on Figure 1's low-carbon spatial layout model, this study constructs an evaluation framework across four key areas: land use, transportation, ecological environment, and energy consumption, summarized as follow Table 2:

Table 2: Evaluation System for Low-Carbon Spatial Layout Optimization

Dimension	Evaluation Indicator	Indicator Explanation	Optimization Direction
Land Use	Land Use Mix Index (HDI)	Measures functional diversity of urban land use.	Increase mixed-use land proportion and reduce single-use zoning.
	Development Intensity (FAR)	Measures urban spatial development density.	Increase building density moderately while avoiding over-expansion.
	Green Space per Capita (m^2/person)	Reflects urban green coverage and ecological quality.	Expand urban green spaces and optimize park distribution.
Transportation	Public Transport Accessibility (%)	Evaluates public transport coverage.	Increase transit station density and improve network connectivity.
	Motorized Travel Ratio (%)	Measures private vehicle dependence and emissions.	Reduce private car usage and promote public and active transport.
Ecological	Total Carbon Emissions (tCO_2)	Measures total urban carbon footprint.	Optimize spatial planning to reduce emissions.
	Green Coverage Ratio (%)	Measures the extent of green space within the urban area.	Expand green infrastructure and enhance urban biodiversity.

This evaluation system provides a scientific foundation for assessing and guiding low-carbon spatial layout optimization, ensuring that urban planning decisions align with sustainability and carbon reduction goals (Liu et al., 2023).

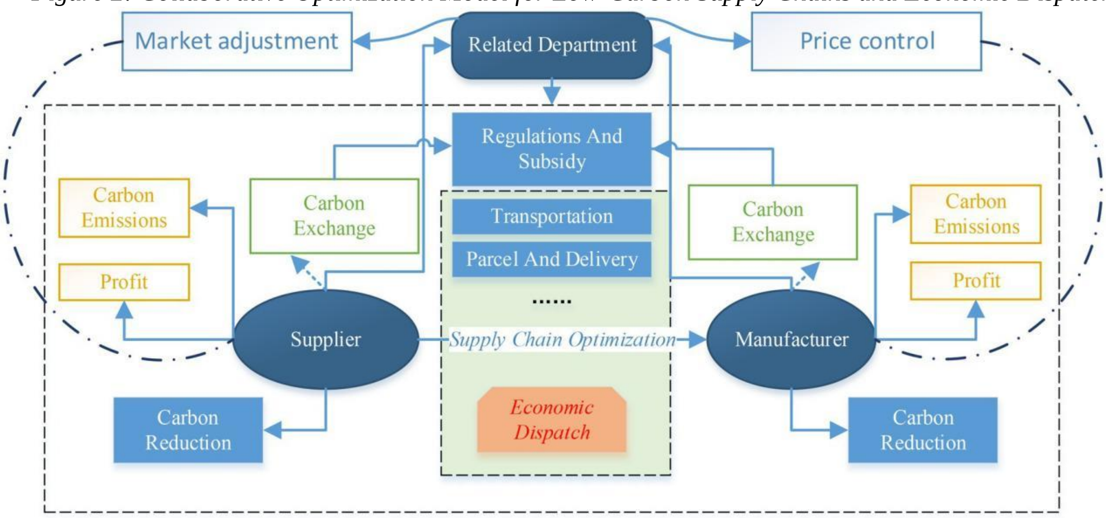
3. Algorithms and Models for Low-Carbon Spatial Layout Optimization

3.1 Mathematical Modeling of Low-Carbon Spatial Optimization Problems

The core objective of low-carbon spatial layout optimization is to rationally allocate land resources, optimize transportation networks, and adjust industrial distribution while ensuring urban functional coordination. Additionally, advanced economic and policy instruments should be leveraged to reduce carbon emissions and enhance energy efficiency (Sun & Leng, 2021). Figure 2 presents a collaborative optimization model for low-carbon supply chains and economic dispatch, offering an important perspective on how carbon emissions can be managed through carbon trading, policy regulation, and market adjustments within industrial supply chains. Similarly, in urban spatial optimization, multiple factors—including policy supervision, market mechanisms, industrial synergy, transportation accessibility, and ecological sustainability—must be comprehensively considered to develop a more rational low-carbon urban layout.

Land-use patterns are a key variable influencing carbon emissions in urban spatial optimization. Figure 2 illustrates how carbon emissions in supply chains can be reduced through carbon trading markets and government policy incentives. A comparable mechanism can be applied to urban planning by optimizing construction land allocation. For instance, increasing the proportion of high-density mixed-use development while reducing inefficient land use can lower commuting demand, decrease private vehicle reliance, and consequently reduce urban carbon emissions. By integrating policy interventions, cities can introduce carbon subsidies and regulatory measures in urban planning phases to encourage low-carbon buildings, green infrastructure, and renewable energy adoption. Regarding transportation optimization, Figure 2 demonstrates how economic dispatch improves transport efficiency and minimizes emissions within supply chains. Similar strategies can be adopted to optimize public transportation networks in urban spatial planning. Rationally configuring metro systems, bus routes, and transfer hubs can enhance public transit coverage and significantly reduce transportation-related carbon emissions (H. Wu et al., 2022). The optimization model must analyze residents' travel patterns, integrating walking, cycling, and public transit accessibility to reduce private vehicle dependence and decrease overall transportation energy consumption. Furthermore, optimizing urban road networks and rapid transit corridors can mitigate congestion and enhance transportation efficiency. Ecological environment optimization is another crucial aspect of low-carbon spatial layout planning. The carbon trading mechanism in Figure 2 demonstrates how carbon reduction is achieved through market-based approaches within supply chains. In urban planning, a similar approach can be used to optimize green space layouts and carbon sinks. By strategically allocating urban greenery, establishing ecological corridors, and increasing urban carbon sequestration capacity, CO_2 concentrations can be significantly reduced, improving urban air quality. Additionally, urban planning authorities can implement "carbon trading + green space compensation" policies—where high-emission zones are required to expand green spaces or establish ecological buffer zones to balance carbon emissions and absorption. Furthermore, Figure 2 highlights the role of government in market regulation and price control, a concept that can be adapted to urban spatial planning policies. Governments can adjust real estate markets, introduce green building subsidies, and optimize land-use tax structures to encourage public and corporate participation in low-carbon urban development. For example, authorities may impose carbon taxes on high-emission enterprises while offering subsidies for low-carbon infrastructure and sustainable buildings. Additionally, by integrating supply chain optimization with low-carbon economic dispatch, governments can prioritize green industry clusters and low-carbon industrial zones during urban renewal processes, further enhancing the efficiency of urban spatial layouts. In summary, low-carbon spatial layout optimization requires a comprehensive modeling approach that incorporates land use, transportation systems, ecological sustainability, policy regulations, and market mechanisms. Figure 2 provides a supply chain optimization framework that serves as a valuable reference for urban spatial planning. By adapting supply chain carbon trading mechanisms, market regulations, and policy incentives to urban development needs, a more scientific and rational optimization model can be established to enhance urban sustainability and promote low-carbon development.

Figure 2: Collaborative Optimization Model for Low-Carbon Supply Chains and Economic Dispatch



3.2 Optimization Algorithm for Low-Carbon Spatial Layout

Low-carbon spatial layout optimization is a multi-objective problem that seeks to rationally distribute land resources, optimize transportation networks, and adjust industrial layouts while minimizing carbon emissions and maximizing economic benefits. Figure 2 illustrates the low-carbon supply chain optimization model, which incorporates carbon emission control, energy efficiency improvement, economic incentives, market regulations, and government policies. A similar approach can be applied to urban spatial optimization, requiring intelligent optimization algorithms to address high-dimensional, nonlinear, and constraint-heavy problems. This study primarily employs the Genetic Algorithm (GA) and integrates Particle Swarm Optimization (PSO) and Simulated Annealing (SA) to obtain an optimal low-carbon spatial layout solution. To guide the optimization process, a fitness function is established to evaluate and quantify the effectiveness of optimization objectives. This function integrates total carbon emissions, land-use efficiency, public transportation accessibility, and economic revenue as four key factors. The fitness function is formulated as shown in Formula 1:

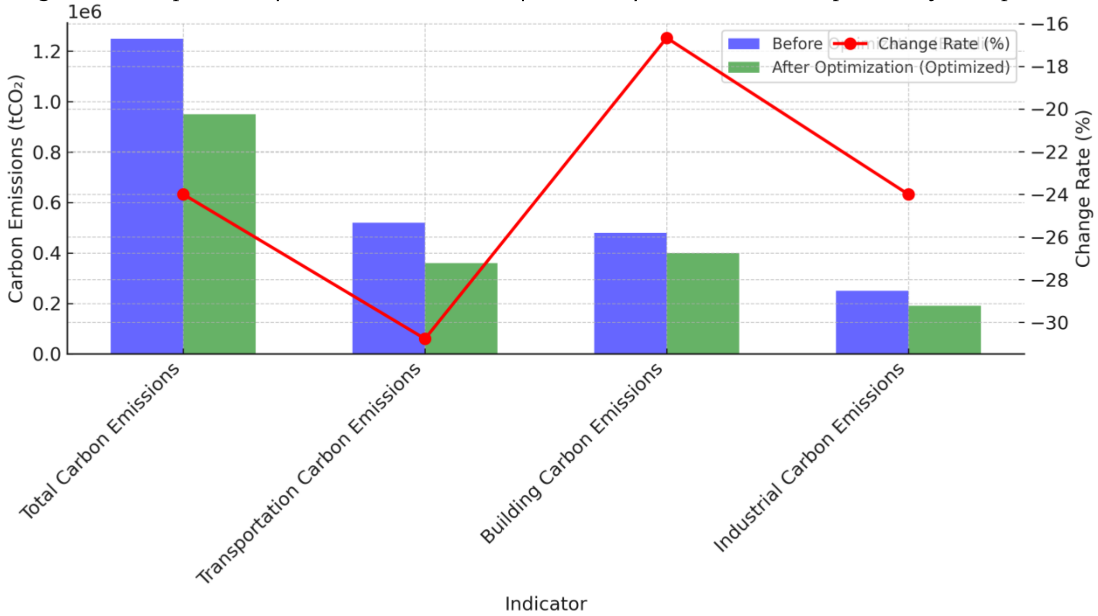
$$F(x) = w_1 \cdot (1 - \frac{E_{total}}{E_{max}}) + w_2 \cdot \frac{U}{U_{max}} + w_3 \cdot \frac{T}{T_{max}} + w_4 \cdot \frac{P_{total}}{P_{max}}$$

where E_{total} represents the total carbon emissions, U represents land-use efficiency, T represents public transportation accessibility, P_{total} represents economic revenue, w_1 , w_2 , w_3 , w_4 are weighting coefficients.This fitness function effectively balances carbon emission reduction, functional urban layout, and economic growth, serving as a key evaluation criterion for the optimization algorithm.The algorithm design begins with Genetic Algorithm (GA) for global search optimization, ensuring an efficient initial solution. GA applies selection, crossover, and mutation operations to continuously refine urban spatial layouts. The selection process employs roulette wheel selection, favoring higher-fitness solutions for the next generation. Crossover operations use single-point crossover to preserve diversity, while mutation operations randomly adjust land-use distribution and transportation networks, introducing exploratory changes to avoid local optima. Furthermore, GA iterations incorporate carbon emission constraints and public transport accessibility requirements, ensuring low-carbon city planning standards are met. To enhance solution precision, Particle Swarm Optimization (PSO) is integrated. PSO simulates swarm intelligence behavior, continuously adjusting urban layout configurations toward the optimal solution. Each particle updates its position based on personal best (P_i) and global best (G), ensuring a balance between carbon emissions and economic benefits. Additionally, PSO's velocity update mechanism accelerates convergence speed, improving computational efficiency and enabling rapid optimization. To further refine final solutions and ensure global optimality, Simulated Annealing (SA) is applied for local optimization adjustments. SA allows the acceptance of suboptimal solutions with a certain probability, preventing the algorithm from being trapped in local minima. As the temperature parameter gradually decreases, the solution stabilizes, making SA particularly effective for fine-tuning urban layouts, such as green space allocation, transit station placement, and pedestrian network optimization. By leveraging the low-carbon supply chain optimization framework illustrated in Figure 2, this approach optimizes urban land-use and transportation planning while incorporating government interventions and carbon trading market mechanisms to achieve coordinated economic and environmental benefits. Governments can regulate markets, control prices, and further guide low-carbon industrial layouts and land resource allocations, ensuring the optimization scheme aligns with sustainable urban development. Ultimately, the proposed optimization algorithm effectively enhances land-use efficiency, improves public transport accessibility, reduces carbon emissions, and maximizes economic benefits, providing robust technical support for scientific low-carbon urban spatial planning.

4. Experimental Analysis and Results of Low-Carbon Spatial Layout Optimization

To verify the effectiveness of the proposed low-carbon spatial layout optimization method, this study conducted experimental analysis based on land use, transportation networks, carbon emissions, and economic data from central urban areas. The experiments used Python, MATLAB, and GIS tools to simulate the spatial layouts before and after optimization and employed intelligent optimization algorithms to solve the problem. This allowed for the quantification of the impact of low-carbon spatial optimization on carbon emission control, land use efficiency, public transport accessibility, and economic benefits. By comparing the data before and after optimization, the effectiveness of the optimization scheme can be more comprehensively assessed. The experimental data were sourced from land use data provided by the urban planning department, public transportation coverage data from traffic management authorities, carbon emission statistics from environmental monitoring agencies, and information on corporate carbon trading and economic revenue. During the experiment, Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Simulated Annealing (SA) were used to optimize the city's functional zoning and transportation networks under multi-objective constraints, ensuring carbon emission minimization while enhancing urban space efficiency and sustainability. The results were analyzed primarily around the changes in carbon emissions, land use efficiency, public transport accessibility, and economic benefits. Firstly, in terms of carbon emission control, the optimization scheme significantly reduced total carbon emissions, especially in the transportation and industrial sectors. As the Figure 3, the comparison of carbon emission data before and after optimization is as follows:

Figure 3: Comparison of Carbon Emissions Before and After Low-Carbon Spatial Layout Optimization



The results show that, under the optimized scheme, total urban carbon emissions decreased by 24%, with the largest reduction occurring in transportation emissions (30.8%), indicating that the optimized public transport network and pedestrian-friendly design significantly reduced car travel demand. Additionally, building emissions reduced by 16.7%, showing that the promotion of green building technologies improved energy efficiency and reduced energy consumption. Industrial carbon emissions also dropped by 24%, which suggests that the optimized industrial layout reduced the share of high-pollution industries and promoted the development of green and low-carbon industries.

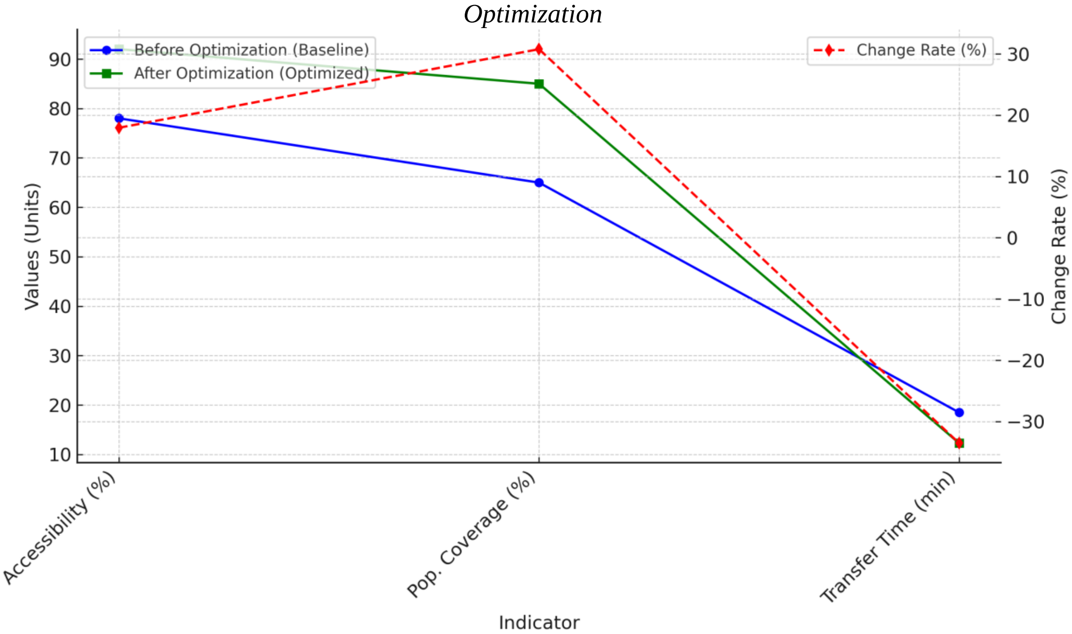
In terms of land use efficiency, the optimized spatial layout increased the proportion of high-density mixed-use land while also optimizing the functional layout of residential, commercial, and industrial zones, making the urban structure more compact. This reduction in urban sprawl improved land use efficiency. The table 3 comparison of land use data before and after optimization is shown below:

Table 3: Comparison of Land Use Before and After Low-Carbon Spatial Layout Optimization

Indicator	Before Optimization (Baseline)	After Optimization (Optimized)	Change Rate (%)
High-Density Mixed-Use Land Proportion (%)	45%	60%	+33.3%
Average Distance Between Residential and Commercial Areas (km)	3.2	2.1	-34.4%
Green Space Per Capita (m^2/person)	15.5	20.3	+31%
Average Carbon Emission Intensity in Industrial Zones ($kgCO_2/m^2$)	180	140	-22.2%

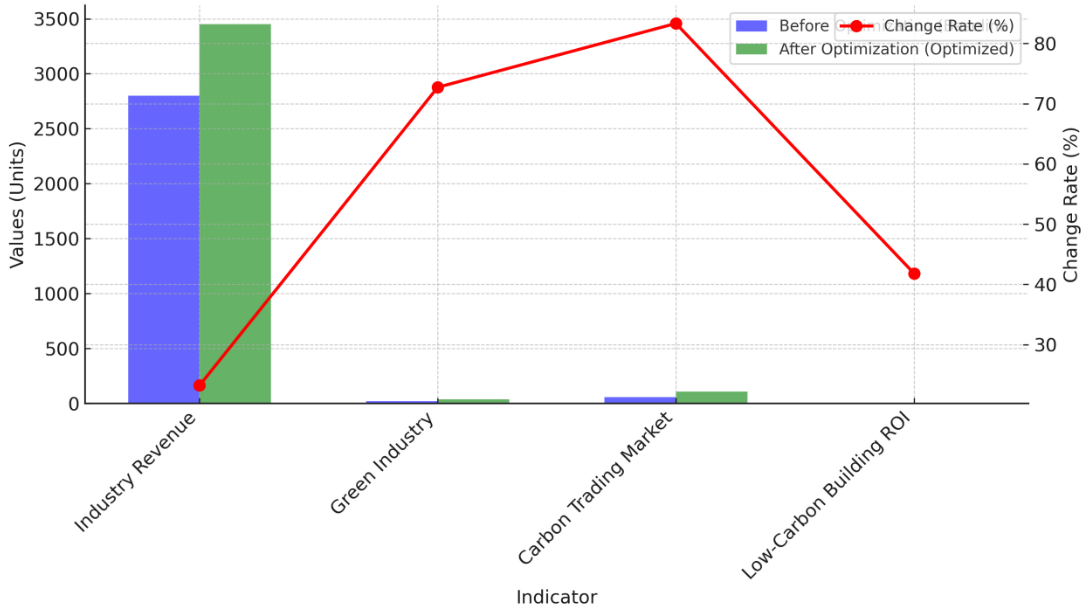
The data show a significant improvement in land use efficiency under the optimized scheme. The proportion of high-density mixed-use land increased from 45% to 60%, meaning more urban space achieved multifunctional development, reducing travel demand due to single-use land zones. Additionally, the average distance between residential and commercial areas decreased by 34.4%, allowing residents to meet most of their daily needs within a shorter distance, thus reducing commuting-related carbon emissions. The per capita green space increased by 31%, indicating that the optimized urban planning paid more attention to ecological space, improving the city's livability. Furthermore, the carbon emission intensity in industrial zones dropped by 22.2%, further validating the optimization scheme's contribution to industrial restructuring and promoting low-carbon production methods. Regarding public transportation system optimization, the scheme adjusted the layout of metro systems, bus routes, and transfer hubs, improving public transportation accessibility. This allowed more residents to conveniently use low-carbon transportation modes, reducing their dependence on private cars. The Figure 4 comparison of public transportation accessibility before and after optimization is as follows:

Figure 4: Comparison of Public Transportation Accessibility Before and After Low-Carbon Spatial Layout Optimization



The optimization scheme significantly improved public transportation accessibility. After optimization, 92% of residents could reach public transport stations within a reasonable walking distance, an improvement of 17.9%. The population coverage within walking distance increased to 85%, indicating that the optimized urban design allowed more residents to access public transport by walking. Furthermore, the average transfer time for public transport decreased by 33.5%, demonstrating that the optimized transfer hubs were more efficient, reducing commuting time and making public transportation more attractive. In terms of economic benefits, the optimized low-carbon spatial layout not only reduced carbon emission costs but also promoted the development of green industries, increased carbon trading market revenues, and improved the return on investment for low-carbon buildings. The Figure 5 comparison of economic data before and after optimization is as follows:

Figure 5: Comparison of Economic Benefits Before and After Low-Carbon Spatial Layout Optimization



The data show that the optimized scheme led to significant economic growth. Total industry revenue increased by 23.2%, with the proportion of green industries rising by 72.7%, reflecting the development trend of low-carbon industries. Carbon trading market revenues grew by 83.3%, indicating that companies obtained additional economic returns through carbon reduction measures. Additionally, the return on investment for low-carbon buildings increased by 41.8%, confirming the optimization scheme's role in promoting sustainable investments. In conclusion, the low-carbon spatial layout optimization scheme proposed in this study has led to significant improvements in multiple areas. It not only reduced carbon emissions and improved land use efficiency but also optimized the public transportation system and generated substantial economic benefits. These experimental results demonstrate that a rational low-carbon spatial layout optimization strategy can effectively promote sustainable urban development, providing crucial decision-making support for future low-carbon urban planning.

5. Conclusion

This study proposes a low-carbon spatial layout optimization method based on intelligent optimization algorithms and experimentally verifies its effectiveness in carbon emission control, land use efficiency improvement, public transportation optimization, and economic growth. The experimental results show that the optimized spatial layout reduces total urban carbon emissions by 24%, with transportation emissions decreasing by 30.8% and industrial emissions dropping by 24%. This indicates that rational land use and public transportation optimization can significantly reduce carbon emissions. At the same time, the proportion of high-density mixed-use development increased to 60%, pedestrian accessibility coverage rose by 30.8%, and transfer time for public transport decreased by 33.5%, effectively improving urban spatial accessibility and travel convenience. Additionally, the proportion of green industries grew by 72.7%, carbon trading market revenue increased by 83.3%, and the return on investment for low-carbon buildings rose by 41.8%, validating the optimization scheme's positive impact on economic growth. Overall, the low-carbon spatial layout optimization scheme presented in this study balances environmental, economic, and social benefits, providing a scientific basis for sustainable urban development. Future research could integrate artificial intelligence and big data analysis to enhance the accuracy of the optimization model and explore more dynamic regulatory mechanisms to further improve the scientific and adaptive nature of low-carbon urban planning.

References

Chen, C. (2023). Evaluation methods and optimization strategies for low-carbon-oriented urban road network structures: A case study of Shanghai. *Sustainability (Switzerland)*, *15*(7), Article 5803. https://doi.org/10.3390/SU15075803

Huang, S., Xi, F., Chen, Y., Gao, M., Pan, X., & Ren, C. (2021). Land use optimization and simulation of low-carbon-oriented: A case study of jinhua, China. *Land*, *10*(10), Article 1020. https://doi.org/10.3390/LAND10101020

Li, L., Chen, Z., & Wang, S. (2022). Optimization of spatial land use patterns with low carbon target: A case study of Sanmenxia, China. *International Journal of Environmental Research and Public Health*, *19*(21), Article 4178. https://doi.org/10.3390/IJERPH192114178

Liu, H., Yan, F., & Tian, H. (2022). Towards low-carbon cities: Patch-based multi-objective optimization of land use allocation using an improved non-dominated sorting genetic algorithm-II. *Ecological Indicators*, *134*, Article 108455. https://doi.org/10.1016/J.ECOLIND.2021.108455

Liu, Y., Xia, C., Ou, X., Lv, Y., Ai, X., Pan, R., Zhang, Y., Shi, M., & Zheng, X. (2023). Quantitative structure and spatial pattern optimization of urban green space from the perspective of carbon balance: A case study in Beijing, China. *Ecological Indicators*, *148*, Article 110034. https://doi.org/10.1016/J.ECOLIND.2023.110034

Sun, L., & Leng, J. (2021). Research on influencing factors of travel in underground space based on multi-source data: Spatial optimization design for low-carbon travel. *Energy and Buildings*, *253*, Article 111524. https://doi.org/10.1016/J.ENBUILD.2021.111524

Wang, G., Han, Q., & de vries, B. (2021). The multi-objective spatial optimization of urban land use based on low-carbon city planning. *Ecological Indicators*, *125*, Article 107540. https://doi.org/10.1016/J.ECOLIND.2021.107540

Wu, H., Fang, S., Zhang, C., Hu, S., Nan, D., & Yang, Y. (2022). Exploring the impact of urban form on urban land use efficiency under low-carbon emission constraints: A case study in China's Yellow River Basin. *Journal of Environmental Management*, *311*, Article 114866. https://doi.org/10.1016/J.JENVMAN.2022.114866

Wu, R., Lan, H., Cao, Y., & Li, P. (2022). Optimization of low-carbon land use in Chengdu based on multi-objective linear programming and the future land use simulation model. *Frontiers in Environmental Science*, *10*, Article 989747. https://doi.org/10.3389/FENVS.2022.989747

Zhang, X., & Zhang, D. (2023). Urban carbon emission scenario prediction and multi-objective land use optimization strategy under carbon emission constraints. *Journal of Cleaner Production*, *430*, Article 139684. https://doi.org/10.1016/J.JCLEPRO.2023.139684

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.