

Investigating the carbon elements based on remote sensing, UAV oblique photography, and AI technologies: A case study of Nanhui New Town, Shanghai

Wei Wei¹, Junqiao Li²

¹College of Architecture and Urban Planning, Tongji University, Shanghai, Ghibli.Wei@foxmail.com

²The Bartlett School of Architecture, University College London, London

Abstract: This study investigates carbon dynamics within Shanghai's Nanhui New Town, exploring the intricate relationships among land cover, climate factors, and carbon sequestration processes. Utilizing advanced methodologies such as remote sensing, UAV, and AI technologies, we conduct a thorough assessment of carbon sinks and emissions, with particular emphasis on the contributions of vegetation and water bodies. Our analysis highlights the importance of integrated land management strategies in optimizing carbon sequestration potential and mitigating emissions. Furthermore, we discuss Shanghai's proactive initiatives towards peak carbon emissions and carbon neutrality. Overall, this research offers valuable insights into carbon management strategies for sustainable urban development, contributing to efforts aimed at building resilient and low-carbon cities in the face of climate change.

Key words: carbon assessment, carbon neutrality, sustainable development, AI

1. Introduction

The pursuit of sustainable urban development has become increasingly urgent in the face of climate change and environmental degradation. Cities, as centers of economic activity and human habitation, play a critical role in shaping a sustainable future (Wang et al., 2023). One key aspect of this endeavor is the transition towards low-carbon cities, which prioritize reducing carbon emissions and promoting environmental sustainability. This transition aligns with broader global efforts towards carbon peaking and carbon neutrality, integral components of the Paris Agreement's goals to limit global warming (Colona, 2023).

Shanghai, China's economic powerhouse and a sprawling metropolis, exemplifies the challenges and opportunities inherent in this transition. With its dense population and rapid urbanization, Shanghai faces pressing environmental issues, including air pollution and carbon emissions. However, the city has also demonstrated a strong commitment to addressing these challenges through ambitious targets for carbon peaking and carbon neutrality.

2. Sustainable development, low-carbon city and carbon neutrality

The concept of sustainable development, first defined in the Brundtland Report of 1987, emphasizes the importance of meeting current needs without compromising the ability of future generations to meet their own (Li et al., 2023). This principle was globally embraced at the 1992 Earth Summit in Rio de Janeiro, where the Agenda 21 program was launched to foster sustainable development through global cooperation, marking a significant milestone in the integration of environmental and developmental concerns (Zou et al., 2023).

Building on the foundation of sustainable development, the movement towards low-carbon cities gained momentum as an essential strategy for mitigating climate change (Andrews et al., 2023). These cities aim to reduce their carbon footprints by integrating sustainable practices such as enhancing energy efficiency, broadening renewable energy use, promoting green urban planning, and improving public transportation systems. The success stories of cities like Copenhagen and Stockholm have illustrated the potential of urban areas to lead in reducing

greenhouse gas emissions while enhancing the quality of urban life. These cities serve as living laboratories, showcasing effective strategies for sustainability that can be replicated and adapted elsewhere.

The concepts of carbon peaking and carbon neutrality further define the trajectory towards sustainable urban development. Carbon peaking occurs when a city or country's carbon dioxide emissions reach their highest point before subsequently declining (Lijun et al., 2023). This is a crucial target for countries committed to reversing the trend of rising greenhouse gas emissions, such as China, which aims to reach carbon peak by 2030. Following this, the goal of carbon neutrality involves balancing emitted carbon with the amount removed from the atmosphere, achieving a net-zero carbon footprint. This ambitious objective is central to the Paris Agreement, encouraging nations to set and pursue strategies to neutralize their carbon emissions by mid-century.

The interplay between sustainable development, low-carbon cities, carbon peak, and carbon neutrality is integral to modern environmental strategy. These interconnected concepts create a comprehensive approach to tackling climate change, promoting economic stability, and ensuring social equity (Ran et al., 2023). The transition to low-carbon cities embodies the practical application of sustainable development principles, directly contributing to the broader goals of carbon peaking and neutrality. Each city's efforts to reduce emissions and implement sustainable practices contribute cumulatively to national and global targets.

Moreover, the shift towards these sustainable models stimulates innovation in technology and infrastructure, fostering economic opportunities and job creation in new sectors such as renewable energy and energy efficiency (Shi et al., 2023). This holistic approach not only addresses the pressing issue of climate change but also promotes a sustainable economic model that integrates environmental, social, and economic goals.

Thus, the global commitment to sustainable development through the implementation of low-carbon cities and the pursuit of carbon peaking and neutrality represents a forward-thinking approach to ensuring a balanced coexistence with our planet, aiming to secure a viable and prosperous future for all generations.

3. Decarbonization and carbon neutrality of Shanghai

Shanghai, as China's economic hub and a densely populated metropolis, has been actively addressing the challenges of climate change and environmental protection (Terhaar et al., 2023). To combat global climate change, the Shanghai government has set a series of targets for peak carbon emissions and carbon neutrality, while also initiating the construction of a carbon financial market to promote the development of a low-carbon economy. Firstly, Shanghai's peak carbon emissions target aims to reach the peak of carbon dioxide emissions by 2030, followed by a gradual reduction. This commitment is a significant part of Shanghai's efforts to combat climate change and is aligned with China's broader efforts to reduce emissions globally. To achieve this goal, Shanghai has implemented a series of measures, including improving energy efficiency, increasing the use of clean energy, and promoting the optimization of industrial structures. Additionally, Shanghai has set an ambitious target to achieve carbon neutrality by 2060. Carbon neutrality refers to reducing carbon emissions to zero or balancing emissions with carbon absorption, thereby achieving climate neutrality. Shanghai's carbon neutrality target means that by 2060, all economic activities in the city will no longer produce carbon emissions, or emissions will be offset through carbon compensation and carbon absorption. To achieve this goal, Shanghai will continue to intensify emission reduction efforts,

promote green technological innovation, and strengthen carbon trading and carbon market construction.



Fig.1 Shanghai's carbon peak and carbon neutrality goals and plans

In addition to setting peak carbon emissions and carbon neutrality targets, Shanghai has also begun constructing a carbon financial market to promote the development of a low-carbon economy. A carbon financial market refers to a financial market centered on carbon emissions rights, promoting carbon trading, carbon quota allocation, and carbon financial products to facilitate carbon emission reduction and carbon marketization. The construction of Shanghai's carbon financial market mainly includes the following aspects: Firstly, establishing a carbon trading platform. Shanghai will establish a dedicated carbon trading market or platform to provide carbon emissions rights trading, carbon quota allocation, and carbon trading services. This will provide enterprises and institutions with a convenient channel to participate in carbon market transactions. Secondly, promoting the innovation of carbon financial products. Shanghai will encourage financial institutions to innovate carbon financial products, including carbon emissions rights futures, carbon trust funds, and carbon asset securitization, to meet the needs of different market entities. Thirdly, strengthening carbon market supervision. Shanghai will establish a sound carbon market supervision system, strengthen supervision and management of carbon trading, carbon reporting, and carbon auditing, to ensure the fairness, transparency, and effective operation of the market. Lastly, promoting international cooperation in the carbon market. Shanghai will actively participate in international cooperation in the carbon market, strengthen cooperation with international carbon trading platforms and institutions, and promote the interconnection and cooperative development of global carbon markets.

Overall, Shanghai's targets for peak carbon emissions and carbon neutrality, as well as the construction of a carbon financial market, demonstrate the city's proactive exploration and efforts in addressing climate change and promoting the development of a low-carbon economy. With the continuous improvement and implementation of relevant policies and measures, Shanghai is expected to become a leader in low-carbon transformation, making greater contributions to global sustainable development.

4. Carbon elements assessment based on big data

In the five new towns of Shanghai, we have conducted carbon assessment work, primarily focusing on evaluating carbon emissions and carbon sinks. To achieve carbon neutrality at the scale of the new towns, which entails no net carbon emissions from the new towns externally, it is essential for the quantity of carbon emissions to be equivalent to that of carbon sinks within the new towns. Carbon emissions refer to the carbon produced by various elements and human activities within the urban space. This includes carbon dioxide emissions from energy consumption, transportation, industrial production, as well as emissions of other greenhouse gases. On the other hand, carbon sinks are natural or artificial systems within the urban space capable of absorbing and storing carbon, such as forests, wetlands, vegetation, and soil. By assessing the carbon emissions and sinks of the new towns, we can gain a better understanding

of their carbon footprint, providing a scientific basis for implementing emission reduction measures and enhancing carbon sinks.

Taking Nanhui new town as an example, we conducted a series of assessment. Nanhui New Town, situated at the juncture of the Yangtze River estuary and Hangzhou Bay, exhibits diverse land cover types, with arable land comprising the majority at 54.93% of the total area. Forest land, grassland, wetland, water bodies, and built-up land are also notable components of the landscape. According to the land use data from 2020, the town features 5.11% forest land, 0.43% grassland, 0.08% wetland, and 5.53% water bodies, with built-up land accounting for 33.70% of the area. Analysis of river network density reveals a value of 1.62 km/km² for Nanhui New Town, with the southern region exhibiting a slightly lower density of 1.34 km/km². Additionally, meteorological data indicates an average annual sunshine duration of 2114.8 hours and an average solar radiation total of 4793 MJ/m², contributing to favorable conditions for carbon sequestration.

The carbon assessment employed a comprehensive methodology integrating remote sensing analysis, meteorological data evaluation, and carbon modeling techniques. Remote sensing data facilitated land cover classification and mapping, allowing for the identification of carbon-rich ecosystems such as forests and wetlands. Meteorological data, including precipitation and solar radiation, provided insights into climatic conditions conducive to carbon uptake and storage. Carbon modeling techniques were then employed to quantify carbon stocks and fluxes, including emissions from anthropogenic activities and sequestration by natural ecosystems.

Quantitative analysis revealed significant carbon stocks and fluxes within Nanhui New Town. The predominant arable land presents a substantial carbon sink potential, with estimates suggesting carbon sequestration rates of up to 62.7 metric tons of CO₂ per hectare annually through improved agricultural practices and afforestation initiatives. However, the uneven distribution of forest and grassland areas poses challenges to optimizing carbon sequestration across the landscape. The presence of water bodies contributes to carbon storage through aquatic ecosystems, with estimates indicating carbon sequestration rates of 34.2 metric tons of CO₂ per year. Furthermore, river network density influences carbon cycling dynamics, with higher densities facilitating the transport of organic carbon and promoting carbon storage in aquatic environments.

In conclusion, the carbon assessment highlights the complex interplay between land cover, climate, and carbon dynamics in Nanhui New Town. The findings underscore the importance of implementing integrated land management strategies to enhance carbon sequestration potential and mitigate carbon emissions. Targeted interventions, including reforestation, wetland restoration, and sustainable agricultural practices, are essential for maximizing carbon sinks and achieving carbon neutrality in the region. By leveraging quantitative analysis and advanced modeling techniques, this study provides valuable insights for informed decision-making and the development of effective carbon management strategies in Nanhui New Town.



Fig.2 Land Spatial Distribution of Shanghai's Nanhui New Town

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Using data from Gaode Maps Points of Interest (POI), we conducted a comprehensive analysis of carbon emissions associated with power sources in Nanhui New Town. The integration of Gaode Maps POI data allowed us to capture a detailed understanding of the spatial distribution of carbon emissions within the area. The resulting heat map provides a visual representation of the concentration of carbon emissions, particularly highlighting the significant clustering observed in the southern region of Nanhui New Town (Figure 3). Upon juxtaposing this data with land use maps, a striking correlation emerged, indicating that areas designated for construction purposes coincide closely with high levels of spatial carbon emissions. This correlation underscores the impact of human activities, particularly those related to urban development, on carbon emissions within the region. Further analysis revealed that the primary contributors to point-source carbon emissions are buildings, factories, and clusters of human production activities. The utilization of Gaode Maps POI data not only facilitated the

identification of these emission sources but also provided valuable insights into the specific industries and infrastructural elements driving carbon emissions in the area. In addition to traditional data analysis techniques, we leveraged advanced methodologies such as Geographic Information System (GIS) technology and spatial data mining algorithms. These sophisticated approaches enabled us to extract actionable insights from the vast amount of spatial data available, ultimately informing future urban planning initiatives and the development of targeted carbon reduction strategies for Nanhui New Town.

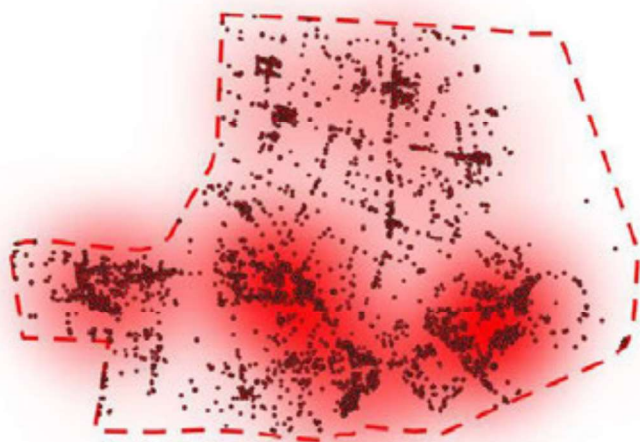


Fig.3 Point-source carbon emissions heat map of Nanhui New Town

5. Carbon sink evaluation based on Remote sensing

In order to comprehensively understand the distribution of vegetation and its role in carbon sequestration within the five new cities of Shanghai, our research utilized satellite remote sensing data and synthesized Net Primary Productivity (NPP) data for analysis and estimation. NPP, which represents the amount of energy or organic matter fixed by plants per unit area over a specific period, serves as a primary indicator of vegetation growth and is a crucial parameter in terrestrial ecosystems. Widely acknowledged in Earth sciences, NPP plays a significant role in delineating ecosystem functionality and productivity.

By examining satellite remote sensing NPP data covering the primary urban areas of Shanghai, our objective is to delve deeper into the dynamics of vegetation growth and the spatial distribution of carbon sinks. The acquisition of NPP data relies on the utilization of light energy and its conversion efficiency by vegetation through photosynthesis. This process is integral to the global carbon cycle, wherein plants assimilate carbon dioxide (CO₂) from the atmosphere during photosynthesis, convert it into organic matter, and store it within plant biomass or soil organic matter.

The relationship between NPP and carbon sequestration is inherently linked to vegetation's ability to absorb atmospheric CO₂ through photosynthesis and retain carbon within biomass and soils. As NPP reflects the net carbon uptake by plants, it serves as a key determinant of ecosystem carbon storage capacity. High NPP values indicate robust vegetation growth and

increased carbon fixation, thereby enhancing the carbon sequestration potential of ecosystems. Conversely, regions with low NPP may indicate limited vegetation productivity and reduced carbon uptake, potentially leading to decreased carbon storage capacity and elevated atmospheric CO₂ concentrations.

Furthermore, understanding the spatial distribution of NPP offers valuable insights into regional carbon dynamics and ecosystem services. Areas with dense vegetation cover and high NPP values often exhibit greater carbon sequestration potential, contributing to climate change mitigation efforts as carbon sinks. Conversely, regions characterized by sparse vegetation and low NPP may act as carbon sources, releasing stored carbon back into the atmosphere through processes such as deforestation or land degradation.

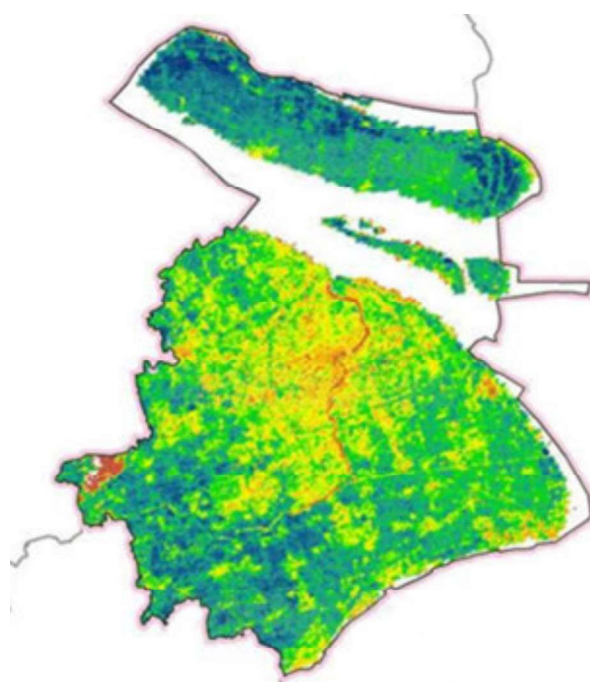


Fig.4 NPP map of Shanghai

In summary, the analysis of NPP data provides a comprehensive perspective on vegetation dynamics, carbon sequestration potential, and ecosystem health. By elucidating the intricate relationship between NPP and carbon sequestration, our research aims to contribute to the sustainable management of ecosystems and the mitigation of climate change impacts at a regional scale. Expanding upon this, our study delves into the nuances of NPP dynamics across different vegetation types and land-use patterns within the urban context of Shanghai's five new cities, offering insights into the efficacy of carbon sequestration strategies and informing decision-making processes for sustainable urban development.

6. Carbon sink evaluation based on UAV and AI

At the microscale, we have developed a method for calculating urban carbon sinks based on UAVs and AI. To investigate vegetation carbon sinks at the microscale, we have advanced a workflow primarily comprising "UAV scanning and model cleaning - extraction of vegetation

physical characteristics - deduction of carbon sink logic". We employ quadcopter UAVs equipped with image sensors to scan on-site scenes and utilize the structure from motion (SfM) algorithm to construct three-dimensional scene scan models. Following manual and intelligent algorithmic repairs to these models, we utilize artificial intelligence image recognition algorithms to extract urban green vegetation from the models and identify vegetation types. Based on the physical characteristics of various types of vegetation, such as vegetation height and crown diameter, and biological properties such as chlorophyll content per unit volume, we compute the carbon sink value of urban green vegetation. Through this methodology, we achieve a detailed understanding of carbon sequestration dynamics at the microscale, providing valuable insights for urban planning and environmental management strategies.



Fig.5 UAV 3D modelling and carbon sink assessment

As shown in the figure, we have established a 3D model of a park area in the new city through UAV scanning and modeling. Using AI, we automatically extract vegetation and calculate the vegetation carbon sink. The calculated carbon sink generated by this park is 30,041 tons per year. Our approach is highly suitable for precise carbon sink measurement at the microscale, complementing the assessments discussed earlier at larger scales. This method provides detailed insights into carbon sequestration dynamics at a localized level, offering valuable supplementary information for comprehensive carbon accounting and environmental management strategies.

7. Conclusion

In conclusion, our study offers a comprehensive analysis of carbon dynamics in Shanghai's Nanhui New Town, emphasizing the pivotal role of vegetation and water bodies in carbon sequestration. By employing advanced methodologies such as remote sensing, UAV, and AI technologies, we have identified significant carbon stocks and fluxes, providing valuable insights for informed decision-making towards achieving carbon neutrality and promoting sustainable urban development. Shanghai's proactive measures towards peak carbon emissions and carbon neutrality, alongside the establishment of a carbon financial market, underscore the city's commitment to addressing climate change and fostering a low-carbon economy. Overall, our research contributes to advancing our understanding of carbon dynamics in urban environments and provides a foundation for implementing effective carbon management strategies to build greener, healthier, and more resilient cities.

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