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Sustainable Urban Development: Balancing Decarbonisation and Well-being Using GIS Scenario Analysis

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ABSTRACT

This research aims to propose sustainable urban development strategies that harmonise decarbonisation with urban residents' well-being through Geographic Information Systems (GIS) scenario analysis. Modern urbanisation enhances quality of life but escalates energy consumption, greenhouse gas emissions, and environmental degradation. In urban areas, CO2 emissions from transportation, industrial activities, and households significantly contribute to global warming, while overcrowding deteriorates living conditions and impacts health and well-being.

Decarbonisation is essential to address these environmental issues, but enhancing urban well-being is equally crucial. This study utilises GIS to explore urban development pathways that balance decarbonisation and well-being. Scenarios evaluate the impact of increased green spaces on CO_2 absorption, enhanced public transportation on reducing private vehicle usage, and energy-efficient buildings on lowering energy consumption and emissions.

The study includes practical interventions in The Nihonbashi Initiative Project, comparing sustainable measures such as greening projects, energy efficiency improvements, and well-being initiatives against a control office floor. Spatial analyses assess the environmental and well-being impacts, providing empirical data for sustainable urban planning. Building owners in the area collaborate to promote energy management, with an expected energy savings effect of approximately 10%. This collaborative effort aims to create a model for sustainable urban development that balances decarbonisation and resident well-being.

Expected outcomes throughout the investigation include the development of a new model for sustainable urban development that integrates renewable energy, green space enhancement, and low-carbon transportation. The study contributes a novel framework for GIS-based scenario analysis, advancing the understanding of achieving decarbonisation and well-being concurrently in urban environments, bridging theory and practice with evidence-based insights.

Keywords: Sustainable urban development, decarbonisation, Well-being, Geographic Information Systems (GIS)

NONMENCLATURE

Abbreviations	
GIS	Geographic Information Systems

1. INTRODUCTION

Urban decarbonisation and wellbeing have become pivotal focuses of contemporary urban planning, particularly in densely populated metropolitan areas such as Tokyo. As cities worldwide grapple with the dual challenges of reducing carbon emissions and enhancing the quality of life for their inhabitants, the intersection of these goals presents a critical research frontier. Tokyo, as one of the most populous cities in the world, offers a unique case study for exploring how urban design, technological innovation, and policy interventions can simultaneously address environmental and social objectives.

Urban areas in Japan are significant contributors to global carbon emissions, primarily due to high concentrations of transportation, residential, and industrial activities [4]. Consequently, urban decarbonisation strategies are essential for mitigating climate change. These strategies include enhancing energy efficiency, promoting the use of renewable energy, optimising public transportation, and implementing smart city technologies that monitor and manage energy consumption [8].

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With decarbonisation efforts, urban wellbeing is a crucial aspect of sustainable city planning. Wellbeing encompasses various dimensions, including physical health, mental health, social cohesion, and environmental quality. Factors such as air quality, green spaces, noise levels, and access to healthcare services significantly influence the overall wellbeing of urban residents. Addressing these factors not only improves the quality of life but also contributes to the resilience and sustainability of urban environments [6].

Nihonbashi, a historic and commercial district in central Tokyo, was selected for this study due to its unique combination of characteristics that make it an exemplary case for examining the interplay between urban planning, decarbonisation, and wellbeing. Nihonbashi's rich history and ongoing economic significance provide a dynamic environment to study the impacts of modern urban planning on both decarbonisation and wellbeing. Its diverse land use patterns, featuring a mix of residential areas, commercial establishments, and cultural sites, offer a unique setting to analyse how different land use types contribute to carbon emissions and influence residents' wellbeing.

Furthermore, Nihonbashi serves as a major transportation hub with extensive public transport networks, making it an excellent case to investigate the influence of transportation infrastructure on carbon emissions and accessibility [3]. The area has also been the focus of several innovative urban redevelopment projects aimed at enhancing sustainability and liveability [5]. The availability of comprehensive and high-quality datasets ensures a practical and feasible research environment [11]. Insights gained from this study can inform local government policies and contribute to national and international urban sustainability frameworks.

2. MATERIAL AND METHODS

GIS are critical tools for analysing spatial data and understanding the geographical context of various phenomena. GIS allows researchers to collect, manage, and analyse spatial and geographic data, making it possible to visualize patterns, relationships, and trends in a way that is not feasible with traditional data analysis methods [1]. In this study, GIS will be used to integrate and analyse multiple datasets related to carbon emissions, land use, population density, transportation networks, and environmental indicators in Nihonbashi.

QGIS, an open-source GIS software, will be employed for the spatial analysis in this research. QGIS is widely used due to its extensive capabilities, user-friendly interface, and the support for a wide range of data formats. It provides powerful tools for mapping, spatial analysis, and data visualization, making it an ideal choice for urban planning studies [10]. With QGIS, overlay analysis, buffer analysis, and hotspot analysis would be performed to examine the spatial relationships between urban planning, decarbonisation, and wellbeing in Nihonbashi. The use of QGIS ensures that the study is not only cost-effective but also accessible for future research and replication.

2.1 Data Collection

The first step involves gathering relevant datasets from reliable sources. Information on carbon emissions by sector, including transportation, residential, and commercial areas, will be sourced from the Tokyo Metropolitan Government's [11] environmental reports and open data portals. Detailed maps showing different types of land use, such as residential, commercial, industrial, and green spaces, will be obtained from urban planning departments and local government agencies. Population density data, detailing the distribution of the population within Nihonbashi, will be acquired from census data and demographic surveys. Additionally, transportation networks data, including maps of public transport routes such as bus lines, subway lines, bike paths, and pedestrian areas, will be sourced from transportation authorities and open GIS data repositories as OpenStreetMap [9], Geospatial Information Authority of Japan [2] and National Land Information Division [7].

2.2 Data Processing

Once the data is collected, it needs to be prepared for analysis. This involves ensuring data compatibility by converting all datasets to a common coordinate system and projection to ensure spatial alignment. Data cleaning will be conducted to remove duplicates, fill missing values, and correct any inaccuracies in the datasets. Additionally, data standardisation will be performed to ensure all datasets are in a consistent format and scale for ease of analysis.

2.3 Spatial Analysis

With the preprocessed data, various spatial analyses will be conducted to examine the relationships between urban planning, decarbonisation, and wellbeing. An overlay analysis will be used to combine multiple layers, such as land use, population density, and carbon emissions, to identify high-emission areas and their correlation with different land use types. Buffer analysis

will involve creating buffer zones around transportation networks and green spaces to study their impact on nearby emissions and wellbeing indicators. Hotspot analysis will be employed to identify areas with high concentrations of pollutants or wellbeing indicators using statistical techniques.

2.4 Visualisation and Interpretation

The final step involves visualising the analysis results and interpreting the findings. Detailed maps will be created to visually represent the spatial distribution of carbon emissions, land use, population density, and wellbeing indicators. Additionally, charts and graphs will be produced to illustrate key relationships and trends identified through the analysis. The visualisations will be analysed to draw meaningful conclusions about the impact of urban planning on decarbonisation and wellbeing, including identifying areas for potential improvement and providing recommendations for urban planners.

3. RESULTS

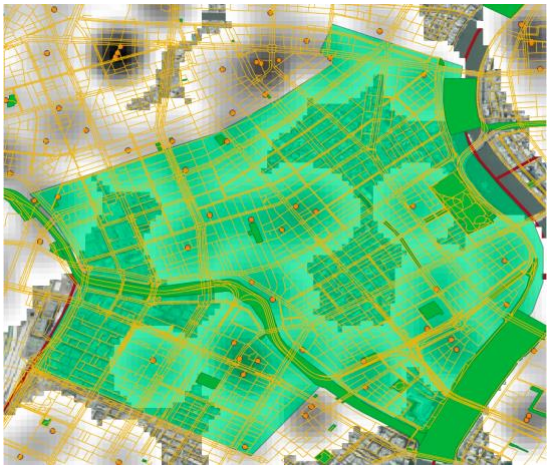

Fig. 1 Bicycle rent spatial sanalysis

The Figure 1 illustrates the spatial distribution of bicycle rental locations across the Nihonbashi district, with grey shaded areas representing the buffer zones surrounding each rental point. These zones highlight the areas within which bicycle rentals are readily accessible, indicating their potential impact on urban mobility and sustainability. The analysis suggests that the widespread distribution of rental locations can significantly contribute to decarbonization by reducing the dependence on private vehicles. As more data is integrated into future analyses, further insights will be gained into the relationship between bicycle accessibility, reduced carbon emissions, and improved urban well-being.

4. DISCUSSION

The spatial analysis of bicycle rental locations, as presented in Figure 1, provides crucial insights into the role of sustainable transportation in urban decarbonization efforts. The buffer analysis reveals a well-distributed network of bicycle rentals throughout the Nihonbashi district, ensuring widespread accessibility and encouraging eco-friendly mobility choices. The grey-shaded buffer zones surrounding these rental points demonstrate that large portions of the district are within a reasonable distance to bicycle rentals, which can significantly reduce reliance on private vehicles.

The distribution pattern of the rental stations supports the broader goal of reducing carbon emissions, as the close proximity to key transportation hubs and public spaces encourages seamless integration with other sustainable transport options, such as walking and public transit. The analysis shows that areas with higher rental density are likely to experience a notable reduction in vehicular traffic, lowering emissions from road transport, which remains one of the primary sources of urban carbon emissions.

As evidenced by the extensive coverage of the green-shaded areas, the current infrastructure also promotes well-being by improving air quality and reducing noise pollution. This aligns with the principles of sustainable urban development, where increased accessibility to non-motorized transport not only contributes to environmental goals but also enhances public health by fostering active mobility.

However, this preliminary analysis also suggests areas for future improvements. Incorporating additional datasets, such as real-time bicycle usage patterns, traffic flow data, and socio-economic factors, will enable a more comprehensive understanding of how bicycle infrastructure influences urban decarbonization and well-being. Future spatial analyses could focus on identifying underserved areas that would benefit from additional rental locations, as well as optimizing routes and connectivity between bicycle paths and public transport systems.

The expected outcome of integrating more granular data would be a more targeted approach in urban planning, enabling policymakers to implement data-driven interventions that promote decarbonization while improving the quality of life for residents. This analysis demonstrates that bicycle rentals can serve as a critical component in the broader strategy for reducing carbon footprints in dense urban environments like Nihonbashi.

5. CONCLUSIONS

The spatial analysis of bicycle rental locations in Nihonbashi offers valuable insights into the role of non-motorized transport in promoting sustainable urban development. By strategically distributing rental points across the district, the analysis shows that bicycle rentals can effectively reduce carbon emissions, decrease traffic congestion, and promote a healthier, more active population. This research highlights the potential of integrating sustainable transportation options into urban planning to balance decarbonization efforts with enhancing the well-being of residents.

The results emphasize that bicycle rentals are not merely a convenient mode of transport but a critical tool in achieving broader environmental and public health goals. By encouraging more eco-friendly modes of transport, cities can significantly reduce their carbon footprints, contributing to global decarbonization efforts while creating more livable urban environments. The buffer analysis in Figure 1 demonstrates that this infrastructure is accessible to a wide portion of the population, potentially reducing reliance on private vehicles and leading to long-term environmental benefits.

Future studies should aim to incorporate additional datasets, such as real-time usage, demographic information, and socio-economic factors, to further refine the understanding of how bicycle rental systems can be optimized for maximum impact. Moreover, expanding the analysis to include other forms of sustainable transport, such as electric scooters or car-sharing programs, could provide a more comprehensive view of how multi-modal transport systems contribute to urban sustainability.

This research provides a foundation for policymakers and urban planners to develop more effective, data-driven strategies to support both environmental goals and the well-being of urban populations. By continuing to invest in and expand sustainable transportation networks, cities like Tokyo can serve as models for the future of urban living—where decarbonization and well-being are not competing priorities but mutually reinforcing components of a thriving metropolis.

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