Research on the Framework of the Carbon Neutrality Standard System for Urban Underground Space

Lina Ye*, Min Qi, Kaiguo Jia, Rong Yi, Zheng Zhang, Yuguo Cai, Yun Qing, Huaibin Li

Mineral Resources Research Institute, China Metallurgical Geology Bureau, Beijing 101300, China
Lina Ye and Min Qi contributed equally to this work and should be considered co-first authors

*609243920@qq.com

Abstract. To implement the strategic deployment of carbon peaking and carbon neutrality, and in accordance with the requirements of the *Implementation Plan for Establishing and Improving the Standard Measurement System for Carbon Peaking and Carbon Neutrality*, this paper proposes the construction framework and implementation path of the carbon neutrality standard system for urban underground space. Adhering to the principles of completeness, coordination, and dynamics, the system covers four sub-systems: basic standards, technical standards, monitoring standards, and management standards, spanning the entire lifecycle of planning, construction, operation, and maintenance of various urban underground spaces such as urban underground transportation, municipal utilities, and public services. By clarifying the core content and technical focus of each subsystem, this research aims to provide top-level design support for formulating relevant standards, facilitating the achievement of net-zero balance between regional greenhouse gas emissions and removals.

Keywords: Urban Underground Space; Carbon Neutrality; Standard System; Carbon Emission Reduction; Carbon Removal.

1 Introduction

With the accelerating pace of urbanization, the scale of urban underground space development has been expanding rapidly. Statistics show that the annual newly developed area of urban underground space in China has exceeded 200 million square meters in recent years. The energy consumption and carbon emissions generated throughout its full lifecycle—spanning planning, construction, operation, and maintenance—account for approximately 8%–12% of the total urban carbon emissions [1]. For instance, a single underground comprehensive transportation hub can produce 30,000–50,000 tons of CO_2 equivalent during the construction phase, with its annual operational emissions reaching around 5,000–8,000 tons; among these, lighting, ventilation, and air conditioning systems contribute to over 70% of the total operational emissions[2]. Studies have demonstrated that the application of low-carbon technologies

Y. Xu et al. (eds.), *Proceedings of the 2026 5th International Conference on Engineering Management and Information Science (EMIS 2026)*, Advances in Computer Science Research 130,
https://doi.org/10.2991/978-94-6239-652-4_25

under the guidance of a standardized system can reduce the lifecycle carbon emissions of underground spaces by 25%–40%[3].

As a critical component of urban carbon neutrality initiatives, the low-carbon development of urban underground spaces is confronted with multiple challenges, including inconsistent carbon accounting standards, non-unified technical application specifications, and incomplete monitoring systems. Against this backdrop, constructing a scientific, practical, and verifiable carbon neutrality standard system is imperative. Such a system will serve to regulate the low-carbon development of underground spaces, improve energy efficiency, and accelerate the adoption of low-carbon technologies in this field. Guided by GB/T 1.1-2020 *Directives for Standardization—Part 1: Structure and Drafting Rules for Standardization Documents* and tailored to the unique characteristics of underground space utilization, this paper systematically establishes a carbon neutrality standard system. By providing a methodologically rigorous framework—backed by logical analysis and feasible validation pathways—this research aims to address the aforementioned gaps and offer guidance for the formulation and implementation of relevant standards.

2 Core Concepts and Basic Principles

2.1 Definition of Core Terms

Carbon neutrality in urban underground space is defined as achieving a net-zero balance between greenhouse gas emissions and removals across all artificially developed subsurface spaces within urban administrative jurisdictions. This goal is accomplished through a synergistic combination of strategies, including optimizing energy structures, improving energy efficiency, adopting low-carbon technologies, promoting resource recycling, and implementing carbon removal measures. The proposed standard system comprises four interconnected subsystems—Basic Standards, Technical Standards, Monitoring Standards, and Management Standards—forming a hierarchical, integrated framework characterized by clear division of functions and mutual interdependence.

2.2 Basic Principles for Construction

Build the basic principles: the Principle of Integrity, the Principle of Coordination and the Principle of Dynamism. Principle of Integrity: Cover the whole process of carbon emission and carbon removal in planning, construction, operation and maintenance management, and ensure that no key links are omitted; Principle of Coordination: Ensure that all standards are mutually coordinated and smoothly connected to form a complete standard chain; Principle of Dynamism: Make dynamic adjustments according to technological development and actual needs to maintain the timeliness and applicability of the standards.

3 Research Methodology and Process

The framework was developed through a multistage, iterative research process designed to ensure its comprehensiveness and relevance (see Fig. 1).

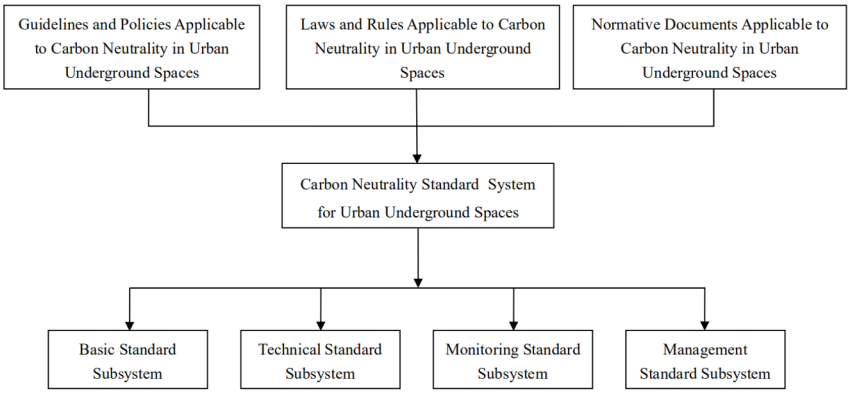

Fig. 1. Overall Framework of the Carbon Neutrality Standard System for Urban Underground Space.

3.1 Policy Review

A comprehensive analysis was conducted on domestic and international policies, regulations, and normative documents pertaining to carbon neutrality and urban underground space development, thereby establishing a solid legal and policy foundation for this research. Developed countries overseas launched the construction of urban carbon neutrality standard systems at a relatively early stage. Through a rigorous screening process, three highly relevant international standards and four domestic standards have been identified as follows:

(1) ISO 14064 Series Standards: Developed by the International Organization for Standardization (ISO), this series of international standards is designed to provide a consistent and transparent framework for the quantification, monitoring, reporting, and verification of greenhouse gas (GHG) emissions and removals.

(2) EN 15978:2011 *Sustainable Construction of Buildings and Civil Engineering Works - Sustainability Assessment of Buildings - Calculation Method*: Issued by the European Committee for Standardization (CEN), this standard is applicable to new buildings, existing buildings, and renovation projects. It specifies a full lifecycle assessment methodology for buildings, which can serve as a valuable reference for the sustainability evaluation of underground spaces.

(3) LEED for Cities and Communities: Developed by the U.S. Green Building Council (USGBC), this assessment framework transcends the scope of individual buildings and focuses instead on the overall performance of entire communities or cities. Its core assessment dimensions cover five key aspects: natural systems and

ecology, transportation and land use, water resource efficiency, energy and greenhouse gas emissions, and materials and resources.

(4) GB/T 51366-2019 *Standard for Calculating Carbon Emissions from Buildings*: This standard specifies a methodology for quantifying carbon emissions of buildings, which can be referenced for carbon emission accounting in underground spaces.

(5) GB 55015-2021 *General Specification for Building Energy Conservation and Renewable Energy Utilization*: It sets forth requirements for building energy conservation and renewable energy application, with partial applicability to underground spaces.

(6) GB/T 51153-2015 *Green Hospital Building Evaluation Standard*: Aimed at maximizing environmental protection and pollution reduction, this standard provides evaluation methodologies for green hospital buildings.

(7) DB11/T 1420-2017 *Technical Guidelines for Evaluation of Low-Carbon Buildings (Operation Stage)*: It stipulates the basic requirements, evaluation index system, assessment methods, and evaluation procedures for low-carbon buildings during their operational phase.

Overall, in contrast to the steady advancement of carbon neutrality initiatives in above-ground spaces, carbon neutrality in underground spaces is still in the preliminary stage of conceptualization, exploration, and planning. Currently, the relevant domestic standard system primarily focuses on traditional dimensions such as safety, functionality, and technical performance, while lacking sufficient consideration of carbon neutrality goals. A comprehensive and systematic industry-specific standard system for this field is yet to be established.

3.2 Framework Design

Guided by the national carbon peaking and carbon neutrality standard system framework and the specifications of GB/T 1.1-2020 *Directives for Standardization—Part 1: Structure and Drafting Rules for Standardization Documents*, a preliminary four-subsystem structure was established, encompassing the Basic Standards, Technical Standards, Monitoring Standards, and Management Standards subsystems.

3.3 Content Development

For each subsystem, specific standard categories were defined and delineated. The selection of technologies incorporated into the Technical Standards subsystem was determined based on three core criteria: (1) the frequency of mention and degree of emphasis in the reviewed literature and successful practical case studies[3,5,6]; (2) their verified potential to achieve substantial emission reduction or carbon removal effects throughout the full lifecycle of urban underground spaces; and (3) expert feedback on the technical maturity and applicability of such technologies under China's specific engineering and policy contexts.

3.4 Logical Integration

The interaction mechanisms and data flow pathways between the four subsystems were systematically mapped out. This process ensured that the Principle of Coordination, one of the core guiding principles of the standard system, was effectively translated into actionable and operational design arrangements.

4 Research on Structure and Content of Sub-Systems

4.1 Basic Standard Sub-System

As the cornerstone of the entire standard system, the basic standard sub-system provides general support for other categories of standards, mainly including terminology and definition standards, data quality standards, accounting and verification standards, and reporting and declaration standards. Terminology and definition standards: Standardize the relevant terminology of technologies, equipment, management and evaluation for carbon neutrality in urban underground spaces. Data quality standards: Specify the requirements for greenhouse gas data quantification methods, database construction and data quality control. Accounting and verification standards: Define the boundaries of carbon emission accounting and unify the accounting methodologies. Reporting and declaration standards: Standardize the declaration requirements for greenhouse gas emission accounting reports and low-carbon evaluation reports.

4.2 Technical Standard Sub-System

Focus on the standardization of key technologies for carbon neutrality in underground spaces, covering the technical links of the entire life cycle, including four parts: planning technology standards, construction technology standards, operation and maintenance technology standards, and carbon removal technology standards. The selection of technical standards is based on the current technological development trends of the industry, key emission reduction links in the carbon neutrality path, and the coverage gaps of the existing standard system, ensuring the pertinence and systematicness of standardization. Planning technology standards: Include standards for non-fossil energy utilization, clean utilization of fossil energy, low-carbon design for engineering investigation, and resource recycling; Construction technology standards: Involve standards for low-carbon construction equipment, processes, scales, procedures, and supply chain management; Operation and maintenance technology standards: Cover standards for low-carbon energy efficiency improvement and regional energy system optimization; Carbon removal technology standards: Include technical standards for carbon capture, utilization and storage (CCUS)[4], biological carbon sequestration, industrial carbon sequestration, building carbon sequestration, and carbon sink enhancement.

4.3 Monitoring Standard Sub-System

Establish a full-process monitoring standard framework to ensure the accuracy of carbon emission and carbon removal data, including four parts: planning monitoring standards, construction monitoring standards, operation and maintenance monitoring standards, and carbon footprint monitoring standards. The construction of the monitoring system aims to achieve full-process data controllability from the initial assessment to the later verification, providing a reliable basis for carbon management. Planning monitoring standards: Monitor the original vegetation carbon sink capacity, soil organic carbon storage, carbon emission baseline, and decomposition of carbon neutrality goals at the site; Construction monitoring standards: Track carbon emissions from building materials production and transportation, equipment energy consumption, construction carbon emissions, carbon loss from spoil, etc; Operation and maintenance monitoring standards: Cover carbon emissions from infrastructure energy consumption, indirect carbon emissions from personnel activities, and online monitoring requirements; Carbon footprint monitoring standards: Include monitoring of green space vegetation carbon sinks, carbon emission reduction from building materials recycling, soil carbon pool restoration, and storage reservoir leakage, etc.

4.4 Management Standard Sub-System

Promote the implementation of carbon neutrality goals through management specifications and evaluation mechanisms, including three parts: low-carbon evaluation and management standards, carbon emission management standards, and carbon asset management standards. The design of management standards follows the logical chain of "evaluation - control - incentive" to promote the application of standards in actual projects. Low-carbon evaluation and management standards: Include evaluation standards for low-carbon technologies/equipment, systems, buildings, and energy systems, and clarify the classification of carbon neutrality levels; Carbon emission management standards: Standardize the requirements for energy consumption quotas, calculation, energy efficiency testing, and energy audits; Carbon asset management standards: Cover standards for the construction of carbon asset management systems, carbon finance, and carbon emission rights trading.

5 Conclusion

The construction of the carbon neutrality standard system for urban underground space provides a unified and systematic framework to underpin the low-carbon development of this critical urban sector. Through the synergistic operation of its four interconnected subsystems, the system achieves comprehensive coverage—spanning from basic definitions and technical specifications to monitoring, accounting, management, and evaluation. This study systematically expounds on the policy and theoretical basis of the system, as well as its core components including framework design, content development, and logical integration mechanisms, laying a solid foundation for practical application. Future research and practice should focus on the following key priorities:

(1) Dynamically optimizing the standard content in response to technological innovations, industrial development trends, and feedback from practical applications, ensuring the system's long-term timeliness and adaptability;

(2) Strengthening detailed coordination mechanisms between individual standards and across subsystems, preemptively identifying and resolving potential conflicts to enhance the system's internal consistency and operability;

(3) Promoting pilot implementation of the framework in typical urban underground space projects (e.g., underground transportation hubs, municipal utility tunnels, underground commercial complexes) to collect empirical data, verify its effectiveness and applicability, and refine the standards based on evidence-based insights;

(4) Fostering interdisciplinary collaboration among engineering technology, environmental science, policy management, and urban planning to ensure the standard system remains robust, holistic, and fully aligned with broader urban sustainability and national carbon neutrality goals.

By addressing these priorities, the proposed standard system can evolve into a powerful and practical tool, injecting standardized momentum into the realization of carbon neutrality goals for urban underground spaces and contributing to the overall achievement of the national carbon peaking and carbon neutrality strategy.

Acknowledgments

We are very grateful to the Journal Editor and journal reviewer for their patience and tolerance providing us this opportunity to study. This manuscript was supported fnancially by the Geological Surveying Project of Geological Survey Party sponsored by the National Key R&D Program of China (2017YFC0601304.

Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Birchall, S. J., MacDonald, S. and Slater, T.: Anticipatory planning: Finding balance in climate change adaptation governance. Urban Climate 37, 100859 (2021). https://doi.org/10.1016/j.uclim.2021.100859
2. Bobylev, N.: Mainstreaming sustainable development into a city's Master plan: A case of Urban Underground Space use. Land Use Policy 26(4), 1128-1137 (2009). https://doi.org/10.1016/j.landusepol.2009.02.003
3. Bobylev, N., Syrbe, R. U. and Wende, W.: Geosystem services in urban planning. Sustainable Cities and Society 85, 104041 (2022). https://doi.org/10.1016/j.scs.2022.104041
4. Jia, L. Q., Chen, X. J., Liu, Y. and Hao, Z. G.: Progress in carbon capture, utilization and storage of China Geological Survey and other geological exploration entities. China Geology 6(3), 541-544 (2023). https://doi.org/10.31035/cg2023068

5. Linton, S., Clarke, .and Tozer, L.: Technical pathways to deep decarbonization in cities: Eight best practice case studies of transformational climate mitigation. Energy Research & Social Science 86, 102422 (2022). https://doi.org/10.1016/j.erss.2021.102422
6. Wei, L. X., Guo, D. J., Ji, J. Y., Chen, Z. L., Hu, H. P. and Peng, X. L.: Optimization of spatial layouts for underground facilities to achieve carbon neutrality in cities: A multi-agent system model. Underground Space 19, 251-278 (2024). https://doi.org/10.1016/j.undsp.2024.03.005