Analysis of Carbon Emissions and Carbon Reduction Strategies in Sponge City Design

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Abstract. With the policy orientation of national carbon peak and carbon neutrality, the design and construction of sponge cities should inevitably have corresponding responses. This article discusses the types of carbon emissions, carbon emission boundaries, and difficulties in quantitatively calculating carbon emissions from LID facilities in sponge city construction. It analyzes the path of carbon reduction in sponge cities and also explores carbon sink asset management for colleagues to explore.

Keywords: Sponge City, LID facilities, carbon emission, boundary, quantitative analysis, emission reduction pathway, carbon sink assets

1 Introduction

The "Opinions of the CPC Central Committee and the State Council on Fully, Accurately, and Comprehensively Implementing the New Development Concept to Achieve Carbon Peak and Carbon Neutrality" propose to strengthen the guidance of green and low-carbon development planning. Green and low-carbon requirements should be fully implemented in all links of urban and rural planning, construction, and management. The "Action Plan for Carbon Peak Before 2030" issued by the State Council calls for the acceleration of green and low-carbon development in urban and rural construction, with urban renewal and rural revitalization both implementing green and low-carbon requirements. Advocating for green and low-carbon planning and design concepts enhances the climate resilience of urban and rural areas, which is directly related to the construction of sponge cities.

Sponge cities, as a new generation of urban stormwater management concepts, refer to the ability of cities to adapt to environmental changes and respond to natural disasters brought about by rainwater, much like a sponge, also known as "water resilient cities."

How to design sponge cities on a low-carbon basis, how to construct LID facilities based on the concept of low impact development, and how to manage the carbon sink of LID facilities are all hot and difficult topics in the industry. Starting from the stages

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and components of carbon emissions from LID facilities, this article qualitatively analyzes the path of carbon reduction in sponge city facilities, identifies the objective difficulties in quantitatively analyzing carbon emissions, and explores the direction of carbon sink management in sponge city cities for colleagues to explore.

2 Carbon Emission Analysis of LID Facilities

2.1 Stages of Carbon Emissions from LID Facilities

Carbon emissions can be calculated by emission type, dividing them into direct and indirect emissions, or by phase. This paper refers to the life cycle segmentation method of the "Building Carbon Emission Standard" GB/T51366-2019, dividing the carbon emissions of LID facilities into three stages[1]:

1) Carbon emissions in the production and transportation of LID facility materials, including various building materials such as permeable paving materials, soil conditioners, vegetation, etc. The production process and transportation process of these materials will produce carbon emissions.

2) Carbon emissions during the construction and demolition of LID facilities, including energy consumed in construction processes and demolition activities. The construction process consumes energy in the form of indirect emissions, including the production and transportation of on-site construction, various LID facilities, civil construction, electrical equipment, water supply and drainage pipelines and accessories installation, etc. LID facility demolition: The demolition of facilities will use mechanical equipment and energy, and the carbon emissions produced are generally calculated as a certain proportion of the carbon emissions of facility construction.

3) Carbon emissions during the operation and maintenance of LID facilities, including hydraulic energy consumption, biological processes, and maintenance management. Some LID facilities, such as rain gardens and wetlands, may require hydraulic equipment such as pumps to assist in drainage or maintain water levels during operation. The operation of these devices consumes electrical energy, resulting in carbon emissions. Biological processes such as vegetation and microorganisms in LID facilities absorb and purify rainwater while also carrying out life activities such as respiration, which produce a small amount of carbon emissions. However, compared with the carbon emissions during the construction and maintenance of facilities, this part of the carbon emissions is usually small. Maintenance management: LID facilities require regular maintenance and management during use, such as vegetation trimming, soil testing, facility cleaning, etc. These maintenance activities also produce a certain amount of carbon emissions, although less than the construction process, but the accumulation over a long period cannot be ignored[2].

2.2 Life Cycle Boundary of Carbon Emissions from LID Facilities

The emission boundary for LID facilities can also refer to the figure below Fig. 1:

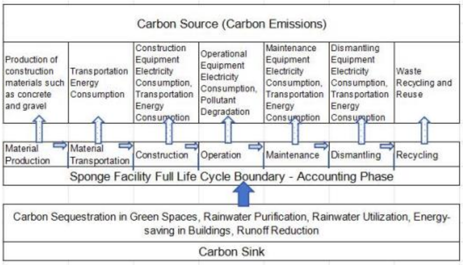

Fig. 1. Pic1 Carbon source(Carbon Emissions)[3]

2.3 Difficulties in Quantitative Carbon Emission Calculation of LID Facilities

There are multiple difficulties in the quantitative calculation of carbon emissions from LID facilities (Low Impact Development facilities), mainly stemming from the complexity of LID facilities themselves, the difficulty of data acquisition, and the diversity of calculation methods[4]:

1) Diversity of LID facility types: LID facilities include green roofs, rain gardens, permeable pavements, bioretention ponds, and other types. This diversity leads to the need for separate analysis and calculation for each type of facility when calculating carbon emissions, increasing the complexity and workload of the calculation.

2) Difficulty in data acquisition: There is a relative lack of basic data on the carbon emissions of LID facilities, such as the carbon emission factors in the production, transportation, installation, and later maintenance of various materials. This data is the basis for carbon emission calculations, but it is often difficult to obtain or of poor quality; it is also affected by climate conditions, usage frequency, management and maintenance, etc., increasing uncertainty.

3) Complexity of life cycle assessment: The calculation of carbon emissions from LID facilities usually needs to consider the carbon emissions throughout their entire life cycle, including material production, transportation, installation, use, maintenance, and demolition stages[5].

4) Limitations of technology and standards: Currently, the technology and standards for calculating the carbon emissions of LID facilities are not yet perfect. Although some places have introduced relevant calculation guidelines or standards, there are still many shortcomings, such as the accuracy of carbon emission factors, the scientific nature of calculation methods, etc., which need further research and improvement, making it impossible to fully calculate according to the "Building Carbon Emission Standard" GB/T51366-2019 requirements and data. At present, more use is made of the estimates of the United Nations Climate Committee, while also referring to the IPCC and China's relevant methods to study the carbon emission situation of the sewage treatment department in Chongqing.

5) There is a large deviation between the carbon calculation during the design phase of LID facilities and the accounting phase after construction. There are still many problems in the construction of sponge cities, with uneven construction and maintenance,

insufficient understanding of the concept of sponge city construction, unreasonable selection of sponge city plans, and LID facilities that do not fit the actual project, leading to difficulties in the normal operation of LID facilities, making it difficult to effectively control the total runoff and the removal of pollutants; poor management of rain gardens and other facilities in the later stage leads to environmental degradation, and even cancellation or repurposing, resulting in ineffective carbon sinks. These objective factors also cause a large gap between the carbon emission process in the design of LID facilities and carbon accounting[1].

2.4 Strategic Analysis of Quantitative Carbon Emission Calculation for LID Facilities

The strategies to solve the above problems are limited at this stage, and a large part requires system improvement. First, it is necessary to solve the problem of data and algorithms for LID facilities, and secondly, to solve the consistency problem between sponge city design and delivery.

1) Improve existing standards and specifications: The data on carbon emission factors in technical standards is not perfect, and there are plans for calculation methods but a lack of specific means, which are all issues that restrict us in calculating the carbon emissions of LID facilities in sponge cities. It is called for relevant standards, specifications, drawings, measures, and other technical regulations and tools to be updated and improved as soon as possible to meet the needs of the current project[1].

2) Temporary reference algorithms: Based on a comprehensive review of various literature, the use of life cycle carbon emission factor quota estimation method is still a simple and effective method. Based on the principles of the Intergovernmental Panel on Climate Change (IPCC) methodology, the net carbon emissions of sponge facilities are the sum of direct and indirect carbon emissions minus the amount of carbon sinks they can produce. In addition, emission factors can refer to the content of the "National Greenhouse Gas Emission Guidelines" released by the IPCC in 2006. This can serve as a strong supplement to the national standard "Building Carbon Emission Standard". Based on these conditions, it is possible to improve the local engineering general emission factor values and algorithm models in various regions and provinces and cities, which is worth referring to at this stage.

3) Unification of carbon calculation and accounting: Strictly control the consistency of sponge city design and construction, and require sponge city projects in various places to be strictly accepted according to the drawings to avoid too much deviation. Of course, this is an ideal state. All carbon calculations are front-end, and to enter quantification, management, or even carbon trading, carbon accounting is ultimately required as a prerequisite condition. There will be deviations between carbon calculations and accounting, and models are needed to correct them. Establishing calculation models is also the content that our technical regulations and technical tools need to be improved and upgraded in the future.

3 Analysis of Carbon Reduction Pathways for LID Facilities

LID facilities can achieve carbon reduction mainly in the following aspects:

1) Reduce runoff pollution: LID facilities control rainwater runoff at the source, reducing the emission of pollutants in rainwater runoff, thereby reducing the load on urban drainage systems and water treatment plants. This helps to reduce the carbon emissions during the operation of these facilities, as the process of treating pollutants often requires a lot of energy consumption[2].

2) Improve energy efficiency and save energy and reduce emissions: By improving the urban microclimate (such as reducing the heat island effect) and improving building energy efficiency (such as the insulation effect of green roofs), LID facilities help reduce the city's dependence on air conditioning and heating equipment, thereby reducing energy consumption and carbon emissions. At the same time, green sponge facilities, such as green roofs, wall greening, water storage roofs, etc., can adjust indoor temperature, reduce air conditioning use, thereby saving electricity and reducing energy consumption. It is estimated that green roofs and three-dimensional greening can save more than 25% of energy, and saving 1 degree of electricity can reduce carbon dioxide emissions by 0.71 to 1.25 kilograms.

3) Promote low-carbon living: The construction and promotion of LID facilities also promote the formation of low-carbon lifestyles. Sponge cities build rainwater collection and treatment systems to collect rainwater for use in toilets, irrigation, and industrial water, thereby reducing dependence on tap water, and thus reducing carbon emissions in the production and transportation of tap water. According to statistics, saving 1 ton of tap water can reduce carbon dioxide emissions by about 0.91 kilograms[2]. Designs such as permeable pavements improve urban drainage efficiency, reducing traffic congestion and carbon emissions caused by urban flooding.

4 Carbon Sink Asset Management in Sponge City Construction

4.1 Content of Carbon Sink Assets in Sponge City Construction

1) Green space construction: Sponge cities implement "small sponge" construction within each unit plot in the community, building green spaces such as rooftop gardens, sunken green spaces, rain gardens, ecological grass ditches, and ecological landscape water bodies. These are not only facilities for controlling rainwater runoff and source reduction (household and ground source pollution) but also the main force in absorbing and digesting carbon dioxide. It is estimated that every square meter of lawn can absorb about 32 grams of carbon dioxide per day[2].

2) Carbon reduction benefits of ecological restoration and rainwater resource utilization: Sponge city construction improves the capacity for rainwater resources and comprehensive utilization level, reducing the city's dependence on tap water.

3) Comprehensive benefits: In addition to the direct role of carbon sinks, sponge city construction can also produce comprehensive benefits by alleviating urban flooding, improving water quality, and enhancing the urban ecological environment, thereby indirectly promoting carbon reduction.

4.2 Management of Sponge City Carbon Sink Assets

The management of sponge city carbon sink assets involves planning and management systems, technical standards and specifications, monitoring and assessment, policy incentives and guarantees, etc., with the main purpose of strengthening the publicity and education of sponge city construction and improving the public's understanding and participation in sponge cities and carbon sink assets. Due to the level of cognition, this part of the content is not discussed in this paper.

5 Conclusions

In summary, the construction of sponge cities has a very positive effect on responding to the country's carbon reduction. The setting of LID facilities can not only directly reduce the pollutants from non-point sources, reduce the operational review of sewage treatment facilities, reduce carbon emissions; the setting of rainwater regulation pools in some projects can improve the efficiency of rainwater resource utilization; at the same time, it can also help build green spaces, achieve ecological restoration, and ecological conservation. However, there are still difficulties in quantitative analysis. Due to the lack of technology and standards, the unevenness of sponge city construction, and the complexity of life cycle assessment, there are still differences and disputes in the quantitative analysis of carbon emissions, carbon reduction, and carbon sink assets during the construction and operation of LID facilities, which also poses greater goals and challenges for sponge city workers. Improving this chapter is of key significance to the construction of sponge cities and energy saving and emission reduction, and it is urgent for the industry to work together.

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