Digital Twin Technology Enables the Construction of Zero-carbon Parks

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Abstract. In response to the national "carbon peak, carbon neutral" dual-carbon strategy, the park transformation and upgrading, to create a zero-carbon park is imperative. This paper studies the successful cases of zero-carbon parks in China and other countries, and summarizes the application of "digital twin", a cutting-edge technology in the construction of zero-carbon parks, which provides a digital solution for the intelligent operation and management of zero-carbon parks. In addition, this paper also collected and sorted out the existing domestic zero-carbon park policies related to digital twin technology, extracted the relevant zero-carbon park construction standards and regulations, so as to better play the advantages of digital twin technology and provide reference and demonstration for the construction of similar zero-carbon parks.

Keywords. Digital twin technology, zero-carbon parks, low carbon development, dual-carbon construction rules

1. Introduction

At the United Nations General Assembly's 75th session in September 2020, China's president, Xi Jinping, stated that the carbon neutrality of country will reach by 2060 and peak its carbon dioxide emissions by 2030. The achievement of the "dual carbon" goal is one of the most important goal in China to encourage the transition to a low-carbon economy and achieve high-quality development. At present, China's industrial parks contribute approximately 30% to the national economy, but industrial energy consumption accounts for about 66% of the total energy consumption in the country, and industrial carbon emissions account for 68% of China's total carbon emissions. Therefore, it is urgent to accelerate the transformation and upgrading of parks and build zero carbon parks. Digital twins, as a promising emerging technology, have played a important role in multiple fields. Effectively leveraging the role of digital twins in the construction of zero carbon parks can greatly promote the "dual carbon"

ICPDI 2023, September 01-03, Chongqing, People's Republic of China

DOI 10.4108/eai.1-9-2023.2338814

process and achieve green and sustainable development. This article summarizes the significance of digital twin technology in building zero carbon parks by studying successful cases of zero carbon parks both domestically and internationally.

2. Background and path to zero-carbon parks under support of digital twin

Park is the core unit of industrial agglomeration and development, the main carrier of industrial activities with a high concentration of advanced elements and flourishing innovation activities, and also the most important and extensive spatial carrier for China's promotion of new-type urbanization and the implementation of the strategy of manufacturing a strong country, which has become the focus of attention for China's realization of the goal of "dual-carbon". Zero-carbon parks are built on the basis of intelligent parks fully empowered by digitalization, and digital means are used throughout the entire process of building and running carbon-neutral parks. Therefore, digitalization and intelligence have become the most basic features of zero-carbon parks.

The construction of a zero-carbon smart park is a complex systematic project, which requires the integration of the concept of "carbon neutrality" in the whole life cycle of planning, construction and management of the park. Besides, the realization of a zero-carbon smart park cannot be achieved without the support of energy saving, emission reduction, carbon sequestration, carbon sinks and other means[1]. In addition, self-balancing of carbon emission and absorption inside the park must be accomplished by low-carbon industrial development, the use of green energy, facility aggregation and sharing, recycling of resources, and intelligent management of carbon elements, so as to realize the deep integration of production, ecology, and life.

Digital twin, as an emerging technology, can provide strong support for the construction of zero-carbon park. According to Deng Yao (2022), digital twin is a technological concept to restore the real world 1:1 to the digital world, and the digital twin divides every thing into two parts: one is the entity in the physical world, and the other is the digital twin of the entity that exists in the digital world[2]. The twin is a digital representation of the entity in which physical and digital worlds can coordinate information from the physical world and interact with physical world objects[3]. Digital twin technology has fully demonstrated its value in industrial manufacturing, smart cities, engineering and construction, and has become an important means of digital transformation. Simply put, a digital twin is a device or system based on the creation of a digital version of the "clone". The idea to deploy Digital Twin technology for security and health maintenance of aerospace aircraft was first put out by the U.S. Department of Defense. First of all, in the digital space to establish a model of the real aircraft, and through the sensor to achieve a complete synchronization with the real state of the aircraft, so that after each flight, according to the structure of the existing situation and past loads, timely analysis and assessment of the need for maintenance, whether it can withstand the next mission loads and so on.

With the continental development of digital twin technology, it has changed a range of different fields. First of all, in the field of intelligent manufacturing, digital twin technology is used to create virtual factories, components, or production line models that can be simulated and optimized in a digitalized environment, thereby improving production efficiency and reducing production costs[4]. Besides, digital twin technology can help doctors diagnose diseases more accurately, improve cure rates, and allow patients to receive treatment faster, shortening treatment time. For example, by establishing a digital twin of the patient, doctors can analyze the condition in a virtual environment and develop more precise treatment plans. Moreover, digital twin technology can digitally model various supporting facilities, transportation facilities, and livelihood facilities in cities, combined with real-time data analysis, to provide comprehensive feedback on the city's operating status and decision-making support for city managers, further optimizing the construction and operational management of urban infrastructure. Additionally, it can help drivers better control vehicles and avoid accidents. By establishing a digital twin of the transportation system, various traffic scenarios can be simulated to optimize traffic flow and improve road safety. In the construction of zero-carbon parks, digital twin technology also plays an important role.

As the first zero-carbon smart park in Europe, the zero-carbon smart park in Berlin's Oerlikon House, Germany, empowers the construction of a zero-carbon smart park with energy transformation, realizing the transformation from a century-old gas plant to a zero-carbon smart park, and achieving the climate protection goal of CO2 emission reduction by 2050 set by the German federal government in 2014. The Water Tower Café in the park, equipped with an intelligent energy management system, uses a small cogeneration energy center for heating, cooling and power supply. Biogas made from agricultural waste from the state of Brandenburg is transported to the park's energy center through the natural gas pipeline network, where it can be combusted to generate 2 megawatt-hours of electricity per year, enough to meet the electricity needs of 1,300 households. The waste heat from the power generation heats water to 90 degrees Celsius, which is used to meet the heating needs of the park through 2.5 kilometers of heating pipes. As a result of these measures, 80 to 95 per cent of the park's energy is already obtained from renewable sources.

In recent years, the construction and development of zero-carbon parks in China has been carried out in an orderly manner. Taopu Smart Park, located in Putuo District, Shanghai, focuses on the research of big data and artificial intelligence technology, and leads the park's economic green, low-carbon and recycling high-quality development by focusing on digital transformation, supplemented by energy transformation. In terms of digital transformation, based on its advanced Internet of Things platform, the Smart City focuses on building an intensive and efficient smart park management system, promoting the development of related strategic emerging industries and urban digital construction, and assisting in the construction of Shanghai's science and technology innovation center and the higher quality development of the Yangtze River Delta; in terms of energy transformation, the Smart City makes use of the smart energy management system to enhance the energy laddering utilization and improve the efficiency of energy utilization, which has effectively improved the efficiency and economy of the park's energy utilization. In terms of energy transformation, WICC utilizes an intelligent energy management system to enhance energy ladder utilization and improve energy use efficiency, which effectively improves energy utilization efficiency and economy in the park.

Based on the successful cases of zero-carbon park construction at home and abroad, combined with the park’s characteristics , this paper summarizes that the construction path of zero-carbon park should be roughly divided into the following three steps.

The first step is to clarify the sources and the total amount of carbon emissions in the park. The first step is to carry out a carbon inventory, define organizational boundaries, clarify the types of greenhouse gases, and build a carbon emission management platform to provide real-time supervision of energy and carbon emission management for all types of emission sources. The second step is to develop medium- and long-term planning goals. The goal planning is shown in Table 1.

Table 1. Goal Planning in Three Stages.

Short-term goal planning	inventory and set carbon neutral targets
Medium-term goal planning	Increase in the proportion of renewable energy use
	Energy optimization and efficiency
	Green buildings and non-mechanical consumption reduction
	Promote green operations and green work practices
Long-term goal planning	Design sustainable products
	Adoption of downstream green logistics services
	Decarbonize by linking the supply chain carbon footprint sharing approach
	Assist upstream customers to achieve their Scope 3 decarbonization

The third step is to formulate carbon reduction measures targeting emission sources. Promote the use of new and renewable sources of energy and encourage the use of renewable energy utilization facilities, including distributed photovoltaic power generation systems, wind-solar hybrid street lamps and smart charging piles, in buildings and living facilities[5].

It has also reformed the park's heating, air-conditioning, hot water supply, lighting, electrical appliances and other infrastructure to improve energy utilization efficiency. In addition, the digital transformation of the park should be strengthened, a carbon monitoring system should be constructed, a statistical monitoring platform for energy consumption and carbon emissions should be set up, basic data statistics on the park's industry, buildings, transportation and electricity consumption should be strengthened, and a sound enterprise carbon emissions data management and analysis system should be established to support scientific planning and precise deployment by park managers.

3. Regulations for the construction of zero-carbon parks in relation to digital twin

The regulations related to zero-carbon parks collected and sorted out in this paper mainly come from two documents - Carbon Neutral Evaluation Methods for Industrial Parks and Technical Specifications for the Creation and Evaluation of Zero-Carbon Parks.

3.1. Digital twin in Carbon Neutral Evaluation Methods for Industrial Parks

The evaluation indicators for carbon neutrality in industrial parks in the "Carbon Neutral Evaluation Methods for Industrial Parks" are constructed around six dimensions: energy system cleaning, production and manufacturing low-carbon, infrastructure greening, resource utilization recycling, digital operation and management, and low-carbon management systematization. The maximum score is 100 points. Among them, digital operation and management plays an important role, and the specific evaluation indicators are shown in Table 2.

Table 2. Digital Operation and Management in Carbon Neutrality Evaluation Indicators for Industrial Parks.

<table>
<tr><td rowspan="3">Digital Evaluation of Operations Management (10 points)</td><td rowspan="2">15</td><td rowspan="2">Establishment of a carbon emission management platform (5 points)</td><td>The carbon emission management platform has basic carbon emission management functions, such as real-time collection, processing, analysis, and traceability of energy consumption and carbon emission data of the main emission sources in the park</td><td>The park has established a carbon emission management platform with basic functions, 3 points will be given</td></tr>
<tr><td>The carbon emission management platform has good automation level and visibility, which helps to improve the refined management level of energy use and carbon emissions in the park, and has produced quantifiable energy-saving and carbon reduction effects[6]</td><td>The platform operation has produced quantifiable energy-saving and carbon reduction effects, 2 points</td></tr>
<tr><td>16</td><td>Enterprise access rate (5 points)</td><td>The enterprise access rate refers to the ratio of the number of enterprises already connected to the carbon emission management platform to the total number of enterprises in the park</td><td>If this indicator is not less than 20%, 1 point will be given. Afterwards, for every 20% increase, 1 point will be added, with a maximum score of 5 points</td></tr>
</table>

The total score for the same type and evaluation of industrial parks shall be calculated according to formula:

$$D = \sum_{i=1}^{20} X_i$$

D---Total score of carbon neutrality evaluation for industrial parks

Xi---Score of the i-th evaluation indicator

Based on the total score of carbon neutrality evaluation in industrial parks and the completion of annual carbon offsetting in industrial parks, the carbon neutrality level of industrial parks is comprehensively evaluated. The evaluation level is shown in Table 3.

Table 3. Carbon Neutrality Assessment Levels for Industrial Parks

Total evaluation score D	Carbon neutrality assessment level of industrial parks	
	Incomplete annual carbon offsetting	Complete annual carbon offsetting
60≤D<80	Low carbon industrial park	Carbon Neutrality Industrial Park
D≥80	Near zero carbon industrial park	Carbon Neutrality Demonstration Industrial Park

3.2. Digital twin in Technical Specifications for the Creation and Evaluation of Zero-Carbon Parks

The Technical Specification for the Creation and Evaluation of Zero-Carbon Parks proposes measures for the creation of zero-carbon parks, in which digital technology plays a pivotal role. The specific specifications are listed in the Table 4 below.

Table 4. Technical Specifications for the Creation and Evaluation of Zero-Carbon Parks and the role of Digital Twin Technology

System	Measure	Digital Twin related
Infrastructure system	Centralized facilities, leveraging the advantages of intensification, efficiency, and ease of deployment	Construction and use of centralized management facilities on digital platforms
	Taking into account multiple factors comprehensively, reducing redundant construction, renovation and renovation	
	A vegetation system that conforms to the local ecological climate characteristics, improves greening rate, and increases carbon sequestration	Intelligent technology controls lighting
	Energy saving lamps and intelligent induction control technology, renewable energy lamps	
Architecture system	The site selection should consider the regional energy resource endowment and comply with the principles of low-carbon, green, and sustainable development	Digital assisted site selection

	GB/T50378, GB/T50878 two star and above standard construction, GB 55015 calculation of building carbon emissions, reducing carbon emission intensity per unit building area	
	Multiple passive and active building energy-saving technologies	Standardized calculation of carbon emission data
	Solar photovoltaic (solar thermal), wind solar complementary, renewable energy and building integrated system	
	Three-dimensional green buildings to increase carbon sequestration	
Transportation system	New energy public transportation vehicles, new energy sanitation vehicles	Optimizing the distribution of public transportation network points through digital technology
	Optimize bus stops, shuttle bus stops, and shared bicycle networks to achieve low-carbon public transportation	
	Charging station facilities, low carbon travel for employees	Digital integrated transportation system
	The logistics site is close to the transportation hub, with environmentally friendly and energy-saving logistics transportation equipment and vehicles; Social comprehensive transportation system	
Energy system	Optimize and upgrade the clean and zero carbon energy structure with resource endowment; Renewable energy and hydrogen and biomass power generation systems	Intelligent microgrid systems utilize resource endowments to optimize and upgrade the clean and zero carbon energy structure
	Intelligent microgrid, energy storage system, multi energy complementary system, distributed energy, energy cascade utilization and other technologies	
	Residual heat/pressure/energy recovery and reuse	
Production system	Energy efficient equipment, products, and technologies, energy-saving technology products	Linkage control between production system and energy

	Process upgrading and replacement, zero carbon emission or low Carbon footprint raw materials/parts/products	system[8]
	Linkage control between production system and energy system to improve system energy efficiency level	Digital supports research and development of energy-saving technology products
	Comprehensive reuse of waste, improving material utilization rate, and reducing carbon emissions during raw material production process	
	Collaborative governance technology for pollution reduction and carbon reduction, eliminating or reducing the generation and emissions of waste, pollutants, and greenhouse gases	
Waste treatment system	Main pollutant emission source monitoring system	Monitor pollutant emission , with the main pollutants being traceable and controllable
	Advanced low-carbon sewage treatment process, sludge reduction and resource utilization work	
	Source control of VOCs, improvement of VOCs control measures, and adoption of more efficient processing equipment	
Park management system	Zero carbon creation management organization; Carbon emission management system; Special funds for zero carbon development	The carbon emission management platform timely grasps the carbon emission situation of the park
	Zero carbon creation strategy, implementation plan, specific measures, and strategies for maintaining zero carbon in the park	
	Carbon emission management platform; Environmental awareness devices	
	Carbon emission inventory (accounting); Supervision and assessment of enterprise carbon emissions	Dynamic visualization of carbon emission verification
	Building a green factory according to GBT 36132 standard, adopting carbon capture, utilization, and storage technology according to local conditions	

Project emission reduction offset/credit offset	Emission reduction projects and carbon sinks for new Energy development such as photovoltaic and wind power	Carbon sink development
	Centralized procurement and bulk procurement to purchase green electricity	
	Internationally recognized CER or nationally recognized CCER; Government approved, registered or recognized carbon inclusive projects to reduce emissions; Government certified carbon reduction for energy-saving projects	

Four key steps can be taken in order to enable "dual carbon" using digital technology: data analysis, prospect projection, clear path identification, and enforcement adjustment. Digital twin, 5G, Big Data, AI, and other technologies have all been significant contributors to this process. Smart agriculture, smart energy, smart transportation, smart manufacturing and smart cities are just a few of the new industrial forms that have been developed as a result of integrating artificial intelligence and digital technology with traditional industries[7]. Diverse factor resources are successfully integrated while creating new values, resulting in precise factor input, precise process management, and effective supply and demand matching.This has led to energy conservation and consumption reduction Improving efficiency and recycling play a crucial role.

Calculation Method for Evaluation Score of Zero Carbon Park Creation(1):

$$S_{ZCE}=\sum_{1}^{i} 100 \times \frac{F_i}{F_{Li}} \backslash j \times \Omega_k \quad (1)$$

S_{ZCE}---Zero carbon park creation evaluation score;

F_i---The current status value of the i-th indicator element;

F_{Li}---Leading value of the i-th indicator element;

Ω_k---The dynamic variable weight corresponding to each first level indicator, k is taken as 1... 4;

J---The number of applicable tertiary indicators Fi included in each primary indicator layer, i is taken as 1... j.

According to the scores, parks can be divided into three different levels from fundamental to leading which are shown in Table 5 below.

Table 5. Zero Carbon Park Creation Rating.

Stage	Score	Level	trait
Stage 1	60≤Szce≤75	Fundamental	Characterizing that the park has a low-carbon development foundation, it is necessary to develop an accurate creation path.
Stage 2	75＜Szce＜90	Creating	The characterization park has reached a low-

			carbon park and can focus on breaking through weak links.
Stage 3	90≤Szce≤100	Leading	Characterize the high level of zero carbon creation in the park.

According to the evaluation results, after reaching the level of zero carbon park, zero carbon can be achieved by purchasing Carbon credit and other means, which is called "zero carbon park".

4. The actual situation of digital twin technology in the construction of zero-carbon parks

4.1. Application of Digital Twin in Logistics Parks

4.1.1. Packaging Material Management

New materials can be created with the aid of digital twin technology to lessen the waste and environmental damage caused by logistical packaging. This is even more important under the premise of the national "plastic restriction". It is of vital importance to research ways to produce packaging materials that are less harmful to the environment and more durable out of non-plastic resources as well. The digital twin also faces fundamental challenges in tracking and assessing the trajectory of recyclable packaging.

4.1.2. Cargo Tracking

To check whether the carrier has protected the products in line with the agreed-upon requirements, some high-value products can have their transit processes digitally tracked, with information on the temperature, humidity level, and impact and collision conditions of the commodities recorded throughout. In the event of cargo damage, there is also sufficient evidence to support the claims operation. Additionally, employing the actual ocean freighter as a digital twin for modeling and tracking aids in monitoring its timeliness and averting mishaps like vessel fires and breakdowns.

4.1.3. Path Planning

Digital Twin provides unheard-of prospects for digital logistics and supports the new generation of geographic information systems (GIS). A logistics-specific freight version of the map has been produced, revealing, among other things, the state of freight truck limits in each part of the city, and civilian maps have attained an unprecedented level of precision at the macro design level. This helps to develop more refined logistics planning programs. At the micro-operation level, the precise tracking of vehicles/cargoes also facilitates better decision-making in daily operations.

4.1.4. Logistics Infrastructure Management

In addition to the broader GIS, we can also build a twin model for a specific port/airport, where the digital twin monitors and analyzes its operation in real time, predicting the on-time performance of the shipping/airline schedules in the coming period, and so on. And, without having to build a physical structure, we can analyze the optimal reconstruction plan for the next 5-10 years.

4.1.5. Warehouse Management

The digital twin, supported by low-cost sensors and big data technology, allows us to know the application of each storage area of the warehouse at a glance and to build 3D models depicting them. Even if you are sitting at home, you can have a real-time overview of every shelf. For training purposes, we can also equip employees with virtual reality glasses that bring the digital twin warehouse to life.

4.2. Advantages

4.2.1. Better Help for R&D

The use of digital twins technology generates a huge amount of information about possible performance and outcomes which makes research and development more efficient. Organizations in related fields can utilize this data to receive more information about the real situation that can help them make appropriate product improvements timely before the start of production.

4.2.2. Higher Efficiency

During the production of new products, digital twins can help in monitoring and mirroring production systems with the aim of achieving and maintaining maximum efficiency throughout the manufacturing process[9].

4.2.3. Better Judgment of Product Life Cycles

Even helping producers make decisions about what to do with products that have reached the end of their useful lives and require final disposal through recycling or other methods is possible with the help of digital twin technology. They can assess what product materials can be extracted by employing digital twin technology.

4.3. Limitations

However, there are still some limitations in digital twin technology. First, the quality and accuracy of data are key to digital twin technology, as errors or missing data can lead to inaccurate models. Secondly, the real-time nature of digital twin technology requires data acquisition and processing to be fast enough, but current technology is still unable to meet this requirement. In addition, the interpretability and transparency of digital twin models are also an issue, as complex models are often difficult to understand and interpret. Finally, the application scope of digital twin technology is also limited, and can only be applied in specific fields and scenarios[10]. Despite these limitations, digital twin technology still has broad application prospects in many fields, and with the continuous development of technology, these limitations will gradually be addressed.

5. Conclusion

In conclusion, the digital twin technology has the potential to revolutionize the construction of zero-carbon parks. By optimizing energy consumption, predicting equipment failures, and enabling real-time monitoring and control, digital twin technology can help achieve the goal of carbon neutrality while improving overall park operations and reducing costs. As the technology continues to advance and become more widely adopted, it is likely to play an even more critical role in the future of sustainable urban development.

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