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News

Green technologies behind the Beijing 2022 Olympic and Paralympic winter games

The world's first known Olympics games took place some 3000 years ago. The historical carbon footprint - a measure of the amount of carbon dioxide released into the atmosphere because of a defined set of activities – is not known, but the current emissions represent no small number. According to the International Olympic Committee[1], the games were accountable for more than 60,000 tons of CO_2e per year in 2018, but this has been decreasing recently. However, for the first time in the history of the Olympic Games, the Beijing 2022 high-tech Olympic and Paralympic Winter Games (henceforth "Beijing 2022") achieved Carbon Neutrality. Among hundreds of technologies that were developed and applied in pursuit of net zero carbon emissions, a dozen "*Green innovations*" deserve to be in the spotlight both for their innovativeness and to inspire others around the world seeking to host *sustainable* sport events. Let's take a closer look at some of these technologies.

Evaluation techniques for the sustainability of the winter olympics

Assessing sustainability first requires defined criteria for evaluation. On this aspect the Beijing 2022 event has created a legacy for scientific evaluation of sustainable sporting and events through the formulation and publication of two key documents that serve as examples to the world. First, based on their practical experience, Beijing 2022 organizers have developed the *Guidance for Event Sustainability Evaluation*[2] (hereafter referred to as *Guidance*). This document by referencing the framework and content of relevant ISO standards[3–5] has filled an important method gap: defining evaluation criteria for sporting event sustainability. The Guidance lays out the content, methodologies, and provides a step-by-step process for event sustainability evaluation. One of the general requirements is that the Guidance requires a team of examiners be formed. Thereafter, multiple evaluations can be conducted ad hoc, with the last one necessarily carried out after event completion. This Guidance specifies seven criteria for evaluation of event sustainability: facilities and venues (Q1), sourcing and resource management (Q2), ecological and environmental protection and management (Q3), traffic and transport (Q4), low carbon and climate change (Q5), staff and the public (Q6) and, intelligent and innovative practices (Q7). The Guidance can serve as model guidelines for scientifically evaluating future similar events.

Secondly, Beijing 2022 also published an *Evaluation Standard for Green Snow Sports Venues*[6] (hereafter *Standards*) separately. The purpose of this *Standards* was to evaluate the green design, construction, and operation of newly-built, renovated, or expanded snow sports venues. The evaluation system comprises indicators across three dimensions: ecological environment, resource conservation, and health and culture. Together these documents can be regarded as an evaluation system, with potential application to the sustainability evaluation of sports events at national, intercontinental, and even global levels, as well as events of other types.

New ice-making age: the debut of green CO_2 cooling system

The fact is that Olympic games require massive cooling systems. The cool fact is, for the first time in the history of Olympics, Beijing 2022 applied natural carbon dioxide (CO_2) refrigeration systems at four venues for making ice. The core technology of this climate-friendly ice-making system - transcritical carbon dioxide direct cooling (TCDDC) - is an important step in implementation of large-scale sustainable ice-making solutions. Not only is this system climate-friendly, it is better than conventional freon gas systems too with a cooling efficiency that is 1.2 times higher in comparison.

So, how does this technology work? The TCDDC system applies high pressure on the gaseous CO_2 and converts it from gas to fluid state. When this liquid CO_2 is transported to the area that needs to be cooled, it is decompressed and during this process it evaporates by absorbing heat from the outside and as a result cools the area. Ice-making equipment applying the TCDDC technology can assure high-quality frozen surfaces by accurately controlling the temperature, humidity, and stability of the ice while consistently maintaining the surface temperature difference below 1 °C. And, all of this in a record time of 33% faster than the IOC standard! In only 2 h, TCDDC cooling achieves a fast and effective ice surface transition (for different games) on the short-track speed skating. The system also has an inbuilt heat recovery device that allows no energy to be

[1] https://olympics.com/ioc/sustainability/climate-positive-commitment.
[2] DB11/T, Guidance for Event Sustainability Evaluation, 1892d2021, 2021 [S]. Beijing.
[3] ISO, Event Sustainability Management SystemseRequirements with Guidance for Use, 2012. ISO 20121.
[4] ISO, Environmental Management Systems d Requirements with Guidance for Use, 2015. ISO 14001.
[5] ISO, Voluntary Guidance Standard on Social Responsibility, 2010. ISO 26000.
[6] DB11/T 1606d2018, Evaluation Standard for Green Snow Sports Venue [S], 2018. Beijing.

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Fig. 1. Ice surface in the "Ice Ribbon"was made by TCDDC technology (authorized of using by Visual China Group).

wasted. The waste heat recovery device efficiently recovers waste heat generated by this system and channels it for multiple purposes, such as heating, water supply, dehumidification, and ice melting. The debut of the TCDDC system is the key factor behind the reduced carbon footprint of Beijing 2022.

Faster response and more controllable power delivery technology

Perfection is a pursuit that never ends for an athlete. The Beijing 2022 games took a page or two from competitive athleticism itself and applied it to their power grids to achieve 100% green power supply to the venue – yet another first in the history of the Olympics. The side benefit from this initiative has been the continued 14 billion kWh of clean electricity transmission to the Beijing-Tianjin-Hebei region every year after the event. Let's take a closer look at their green power revolution.

The Zhangbei Flexible Direct Current (Flexible DC) power grid project is the world's first major pilot for DC power grid networking. This project operating at a voltage level of 500 kV is also the highest in the world. This next-generation technology is similar to high-voltage DC transmission in structure and consists of converter stations and DC transmission lines, much like the conventional systems. However, the converters here make a world of difference. While high-voltage DC uses voltage-source converters based on high-frequency modulation technology, flexible DC uses current-source converters based on phase-controlled commutation technology. Turn-off devices are the biggest feature of voltage-source converters. They enable the separate control of output active power and reactive power by adjusting the output voltage amplitude of such converters and the power angle difference with the system voltage. In this way, through the manipulation of converter stations at both ends, the mutual transmission of active power between two alternative current (AC) networks can be achieved. In other words, the Flexible DC power grid has the following advantages: first, no reactive power compensation and low harmonic levels, second, no phase change failure problem, and third, suitable for supplying power to isolated islands.

The Flexible DC transmission is highly suitable for urban power grid capacity expansion and DC power supply. With loads on urban power grids increasing worldwide, this technology can meet the rising needs for both scale and quality of power supply. Further, by continuously optimizing materials, such as improving the insulation and heat resistance properties of encapsulation materials, Flexible DC transmission has the potential to completely replace traditional AC/DC interconnected transmission for long-range, high-capacity transmission. The green electricity generated was also used for electrolytic hydrogen production. At the opening ceremony of Beijing 2022, instead of natural gas or propane, hydrogen was used for the domestic torch relay and the cauldron ignition, making Beijing 2022 also the first Olympic event whose torches had zero carbon emissions! Iconic indeed.

A multi-technology integrated data base construction method

Olympics events involve massive landscaping efforts and construction. Beijing 2022 sought to address the issues associated with habitat loss through development of a process-wide landscape restoration data base, integrating a range of data collection technologies, and laid a data-driven foundation for the ecological restoration of the ecological corridor park in the Zhangjiakou competition zone. Technologies incorporated into this venture included Beidou ground-based augmentation system, unmanned aerial vehicle (UAV) tilt photography, UAV multispectral remote sensing, etc. Using this data base, the work team can locate and mark typical plants, and stay informed of vegetation coverage changes, leaf area index, biomass, nitrogen content, and chlorophyll content among other parameters.

The integration of data collection technologies effectively circumvents shortfalls of using single technology. For example, the BeiDou ground-based augmentation system ad hoc network coupled with UAV tilt photography reaches areas that are inaccessible to humans, but it can only acquire surface information and cannot support image modeling of landscapes obscured by vegetation such as tall trees, low shrubs, or grass. Such deficiencies can be compensated by integrating complementary technologies for monitoring such as high precision 3D laser scanning. Specific integration actions applied at Beijing 2022 were in order: First, rapid survey foundation modeling was done using UAV tilt photography and BeiDou ground-based enhancement system ad hoc network. Next, field status mapping, survey sampling, multispectral remote sensing, laser scanning, and other technologies were applied for collecting above-ground and subterranean data. Real-time data were also obtained from sensors, high-definition cameras, and through setup of Internet of Things (IoT) facilities in the experimental area. Collectively from these different sources of data, a cross-scale, multi-precision dataset was constructed. This method of data collection has the potential to be extended and applied in similar projects elsewhere, especially in alpine, arid, and other vulnerable regions tasked with hosting such events or faced with natural disasters or other risk factors for habitat loss.

Unlocking ultra-low-energy buildings (ULEBs)

The design and construction of ULEBs is another green highlight of Beijing 2022. ULEBs are constructions integrated with systems capable of adapting to local site conditions. By using 'passive design' strategies, ULEBs have a minimized demand for heating, air conditioning, and lighting. In addition, use of renewable energy and energy-efficient equipment also lower their energy consumption. Beijing 2022 built ULEB projects in various scenarios, such as polyclinics, athlete's apartments, and sports centers.

A great example for one such ULEB is the Wukesong Ice Sports Center that has become one of the largest ultra-low-energy sport centers globally using several energy-saving technologies in parallel. For instance, the ice rink contains the liquid desiccant dehumidification system that could lower energy use by 77.1% compared to conventional electrothermal rotary-wheel dehumidification. Insulation needs of the Wukesong center were met by high-

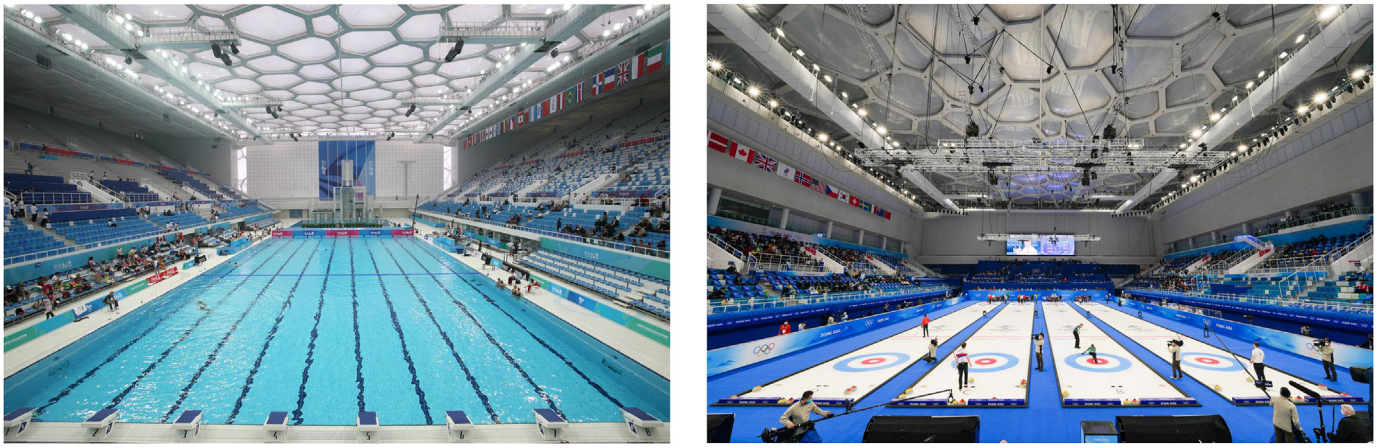

Fig. 2. Renovation of National Swimming Center. The left image shows the National Swimming Center, a boutique venue for the 2008 Beijing Olympic Games; The right image shows the curling venue of the 2022 Beijing Winter Olympics, which was renovated from the National Swimming Center (authorized of using by Visual China Group).

performance curtain walls with a heat transfer coefficient (K) of less than 1.0 W m^{-2} K^{-1}. And the ULEB's lighting comes from a total of 1958 pieces of crystalline silicon PV modules with a combined capacity of around 600 kW expected to generate an average of about 700,000 kWh of clean electricity per year. The energy savings from this technology alone results in savings equivalent to 252 tons of coal and reduced CO_2 emissions by about 697.8 tons!

Sustainable renovation of old venues

Sustainable renovation describes a series of structural or functional changes made to existing buildings, to realize their social, economic, and environmental sustainability (see Fig. 1). The renovation projects for Beijing 2022 were committed to sustainable development by aiming to maximize energy conservation while reducing emissions. Such projects for Beijing 2022 were of three types. First of these sustainable renovations involved functionally renovating existing venues for multi-functionality. The National Swimming Center (also known as the 'Water Cube') was built for Beijing 2008 summer Olympic Games. In 2022, this 'summer' Olympic legacy building was successfully renovated into a Winter venue (Fig. 2). The Water Cube is a comprehensive venue for not only swimming events, but also ice events, and large cultural events. Next in the lineup of sustainable renovations was the delivery of green and low-carbon sports events through technology rethinking. A prominent transformation in this category was the upgrade of the ice-making system in the Capital Indoor Stadium using the TCDDC approach. Third in the sustainable renovations was transformation of old industrial bases to residential blocks. The obsolete silos and storage bins used to store iron ore in Shougang Park were renovated into green office areas for the Beijing 2022 Organizing Committee. This not only witnessed reuse of industrial relics but also prevented carbon emissions from new constructions.

Intelligent energy solutions: smart energy management platform

Smart energy platforms are designed to help identify energy inefficiencies, reduce wastage, and increase energy efficiency. These platforms, based on 5G, real-time interoperability, and two-way communication technologies, function as a comprehensive service platform and support a variety of mobile terminals for energy management. As a result, they provide a variety of capabilities including real-time monitoring, security analysis, transaction management, operation and maintenance management, and decision analysis. Further, with the support of artificial intelligence (AI) and IoT, these platforms can further promote energy data interconnection, upgrade energy structures, and enhance energy efficiency.

Within the Beijing 2022 setup, the Yanqing Integrated Transportation Service Center (YITSC) provides a good example for the adoption of smart energy platforms to achieve renewable energy management and CO_2 emission reduction. YITSC combined terminal equipment with green energy-saving technologies and provided various services including asset management, remote control, intelligent maintenance, and energy efficiency monitoring. Through this initiative, Beijing 2022 eliminated 1723 tons of CO_2 emissions and saved 658 tons of coal equivalent annually at YITSC alone.

Wildlife and habitat conservation in competition zones

The Winter Olympic Games usually require the construction of competition venues in natural environments, which is a challenge to the conservation of wildlife and their habitats. Beijing 2022 carried out a series of approaches in parallel to protect the habitats on which wildlife depended. Wildlife conservation in the construction zone was carried out in three stages. In the pre-games research stage, an expert team conducted an investigation on wildlife species, distribution, and habits by using DNA-based identification methods, and put together a wildlife conservation and habitat construction plan. Special training was also offered to help construction workers to enhance professional knowledge and technical expertise in wildlife identification and conservation. In the construction phase, strict restrictions were set for construction work (such as preventing construction at night and mechanical operations in streams and rivers), and compensation approaches were introduced for wildlife's activities, migration, treatment, and reproduction (such as building ecological corridors and artificial habitats). During the competition stage, non-intervention wildlife monitoring was adopted. More than 200 infrared motion sensor cameras were set up in competition zones and their surrounding areas to monitor wildlife footprint. In 2021 alone, more than 14,000 photos (including videos) were taken in the Yanqing competition zone through continuous monitoring. The pre- and post-comparison results indicated that, surprisingly, the competition zones attracted the immigration of new species. Instead of being forced to relocate by construction, wild animals continued to ramble around the competition zone, and on instaces greater variety of species than before were spotted. The competition zone had

through its wildlife conservation approach successfully created a situation featuring harmony between man and wildlife.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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