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Sustainable land use and green ecology: A case from the Beijing 2022 Winter Olympics venue legacy

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According to the Olympic Charter, the construction of new permanent venues or infrastructure for the purposes of the organization of the Olympics shall only be considered on the basis of sustainable legacy plans. However, as time passes, the Olympic legacies grow increasingly unsustainable and create conflicts between humans and nature. This perspective examined the spatial distribution of the Beijing 2022 Winter Olympics venue legacy. We presented a spatial assessment of Olympic venues' legacy experience in terms of construction and sustainability. The findings indicate that the Beijing 2022 Winter Olympics venues incorporated sustainable land management and green ecology concepts from the Olympic Movement, and that the legacy could serve as an example for future development of Olympic infrastructure, natural sites, and resource management.

KEYWORDS

Olympic Games, Olympic movement, Agenda 2030, spatial distribution, urbanization, ecology

Introduction

In the Legacy Strategic Approach, IOC states "Olympic legacy is the result of a vision. It encompasses all the tangible and intangible long-term benefits initiated or accelerated by the hosting of the Olympic Games/sport events for people, cities/territories and the Olympic Movement" ([International Olympic Committee, 2017](#)). As the scale and influence of the Olympics have grown, however, the sustainability of the Olympic Games has been decreasing between the Barcelona 1992 Summer Olympics and the Tokyo 2020 Summer Olympics ([Müller et al., 2021](#)). Construction of new Olympic venues has caused pollution and ecological damage ([Chappelet, 2008](#)), and land exploitation for the Winter Olympics poses a larger threat to the environment than for the Summer Olympics. Few modern cities have convenient access to the alpine terrains required to stage winter Olympic events. As a result, the three recent Winter Olympics have all necessitated extensive natural land exploitation in mountainous regions, whose ecosystems are more fragile than those in typical metropolis. Human activities such as the creation of artificial snow and the carving out of alpine skiing courses result in the overuse of natural water resource and the alteration of biodiversity ([Song et al., 2018](#)).

Prolonged artificial snow cover alters mountainous vegetation, and permanent infrastructure projects such as transportation and supplementation facilities could have even more lasting environmental effects (Huang et al., 2019). Environmental assessments of the Winter Olympics exposed environmental degradation and even irreparable ecological damage. Venues of the Sochi 2014 Winter Olympics are located in a world heritage site. During the construction period, mountains and hydrological systems in the Caucasus Nature Reserve were devastated by illegal waste dumps (Müller, 2015). Mount Gariwang's 500-year-old forest was destroyed in order to build an alpine skiing center for the PyeongChang 2018 Winter Olympics, wreaking havoc on the surrounding ecosystem and biodiversity (Lee, 2019). These examples demonstrate that resolving the conflict between winter Olympic venues and ecologically sensitive land use is a priority for the sustainability of the Olympic Movement, which becomes more fragile nowadays than it might be seen (Chappelet, 2021).

Since the Nagano 1998 Winter Olympics, IOC has adopted a policy for environmental protection, bringing sustainable land use to a new level of strategic importance (Cantelon and Letters, 2000). However, IOC's efforts for environmental sustainability have not been met by the organizers (Geeraert and Gauthier, 2018). Meanwhile, many cities incorporated bids for the Olympics into their development plans, with the intention of leveraging the Olympics to accelerate urbanization (ESSEX* and Chalkley, 2004). When the recent Olympic Games are reviewed, it becomes clear that managing land is not as straightforward as one may believe. While Sochi has been regarded as the second-most expensive Olympics in history (Müller, 2014), its Olympic venues are more symbolic than functional, and almost all of the legacy commitments made in the bid book have not been met (Azzali, 2017). Numerous venues in the Rio 2016 Olympic Park have been outsourced or demolished, leaving others in critical disrepair and disarray (Drehs and Lajolo, 2017), while imbalanced urban growth has exacerbated socioeconomic inequalities within the local population (Azzali, 2019). Likewise, the construction projects associated with the PyeongChang 2018 Winter Olympics were too costly to sustain economically and ecologically (Lee, 2021), and the legacy venues did not promote widespread participation in winter sports or provide lasting economic benefits for the local economy (Lee, 2019). The concept of sustainable land use transcends the Olympic cycle, which is especially important for the Winter Olympics, when legacy venues will either generate socioeconomic spillover or become undesirable loads.

The United Nations Sustainable Development Goals and Agenda 2030 promote sustainable land use as a global objective (United Nations Development Programme, 2015). The focus of the Olympic legacy research is gradually shifting toward ecosystem conservation, environmental protection,

sustainable development, and legacy management (He et al., 2020). Legacy infrastructure is not a one-time endeavor, and more rational solutions are required to properly exploit the legacy for the sustainable human future. Environmental geography explores the spatial facets of interactions between humans and natural, as well as the environmental effects of urbanization. Therefore, this perspective evaluated the land planning and utilization of the Beijing 2022 Winter Olympics venue.

Chinese land management of Olympic venues

Figure 1 depicts the layout of the Beijing 2022 Winter Olympics venue (Beijing Organising Committee for the 2022 Olympic and Paralympic Winter Games, 2022a). Nine of the 41 venues are inherited from the Beijing 2008 Summer Olympics, while four are legacy venues from the Beijing 2008 Summer Olympics land use (Liu and Gui, 2021). Beijing Olympic Park, Shouti Stadium Complex, Wukesong Sports Centre, and Shougang Park are home to 27 venues. The four regional locations are clustered northwest of Beijing, with a highly asymmetric distribution from north to south. All of them are concentrated in the city's north, with the majority in the Haidian District. The Olympic Park has the most dense distribution of venues, while the rest venues are dispersed around the district.

This spatial layout was planned in order to maximize the usage of existing land and people for new purposes. First, this ensures that the Olympic legacy is fully utilized. Only the new National Speed Skating Oval is part of the Olympic Park; the remainder has been renovated to maximize the usage of the Olympic legacy while also taking into account Beijing's overall urban development. The Olympic Park is distributed symmetrically along the central axis, forming a spatiotemporal dialogue between the present and the history with the Forbidden City on the central axis, and constituting a major structure in Beijing's dual Olympic city (held both summer and winter Olympics). The three dual Olympic sites, National Stadium (Bird's Nest), National Indoor Stadium, and Wukesong Sports Centre, yield uninterrupted socioeconomic values (Jinxia, 2010) and ensure the legacy venues are utilized in a sustainable manner following the Olympic cycle.

Second, the development and operation of the post-Olympic venue acts as a key indicator of the performance of the Beijing 2022 Winter Olympics venue legacy. The operation and legacy sustainability of Olympic venues are based on the previous venue's experience. Between 2012 and 2019, the Wukesong Sports Centre hosted 542 cultural and athletic events, attracting millions of visitors annually with an average of more than 200 days of use and around 80% arena occupancy (Beijing Organising Committee for the 2022 Olympic and

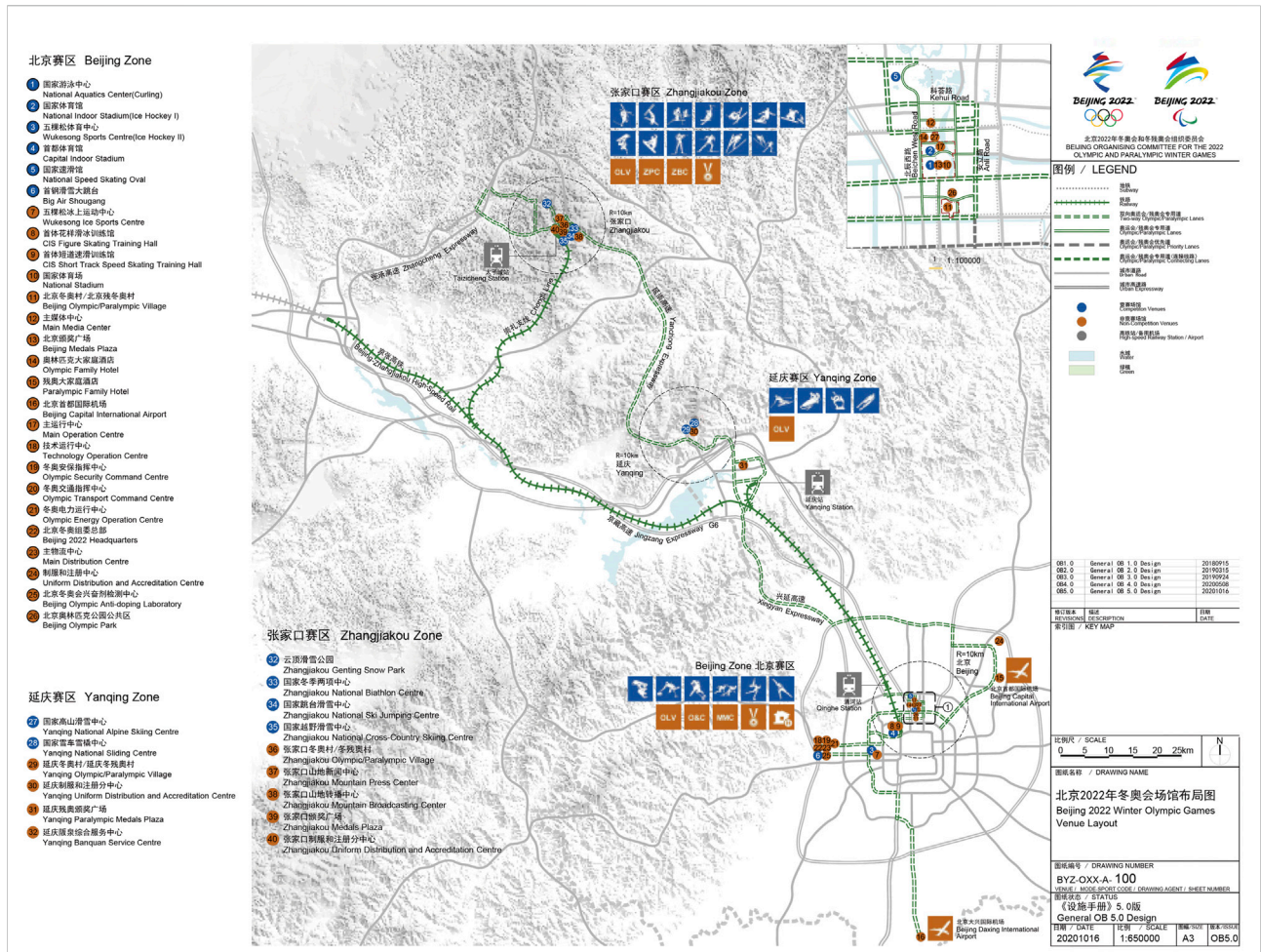


FIGURE 1 Beijing 2022 Winter Olympics venue layout. The photo was openly available from the Beijing Organising Committee for the 2022 Olympic and Paralympic Winter Games.

Paralympic Winter Games, 2022b). The Beijing 2008 Olympic venues enable for the organization of a variety of mega athletic events, non-sporting activities. Meanwhile, snow and ice sports and tourism are highly seasonally dependent. In the Chongli district, the artificial snow-making was available on 152–171 days from 1978 to 2017, and the natural snow skiing season was approximately 120 days (Chen et al., 2021a). The Olympic sites of the Beijing 2022 Winter Olympics demand precise management decisions. Venue managers and policymakers obtained an unparalleled wealth of expertise in operating all these athletic events, which becomes an intangible legacy of the Olympic venues for Beijing and China (Chen et al., 2021b).

Third, this enables the usage of industrial land resources. Shougang Group Co., Ltd. relocated to the Caofeidian District in Hebei Province prior to the start of the Beijing 2022 Winter Olympics to guarantee the games ran well. Given that demolishing the entire old park would be a waste of resources

and an environmental hazard, this idea adheres to the principle of conservation and utilization. The Olympics brand has transformed its former location into a new landmark for ice and snow sports, with the third ring road serving as the priority route for the Olympics and the northwest section of the fourth ring road serving as the exclusive route, ensuring that the Shougang Park is spatially connected to the other three regional venues *via* rational traffic organization. Shougang Park fully utilizes the Olympics opportunity to promote the creation of cultural scenery, and the ice and snow elements could offer a new depth to the area’s socioeconomic growth.

The spatial distribution characteristics of the Beijing zone display the following pattern. All four districts are positioned along the policy-oriented, third and fourth ring roads. The Beijing municipal government established such a dense distribution of venues in northern Beijing to account for aspects such as urban land use, post-Olympic usage, traffic

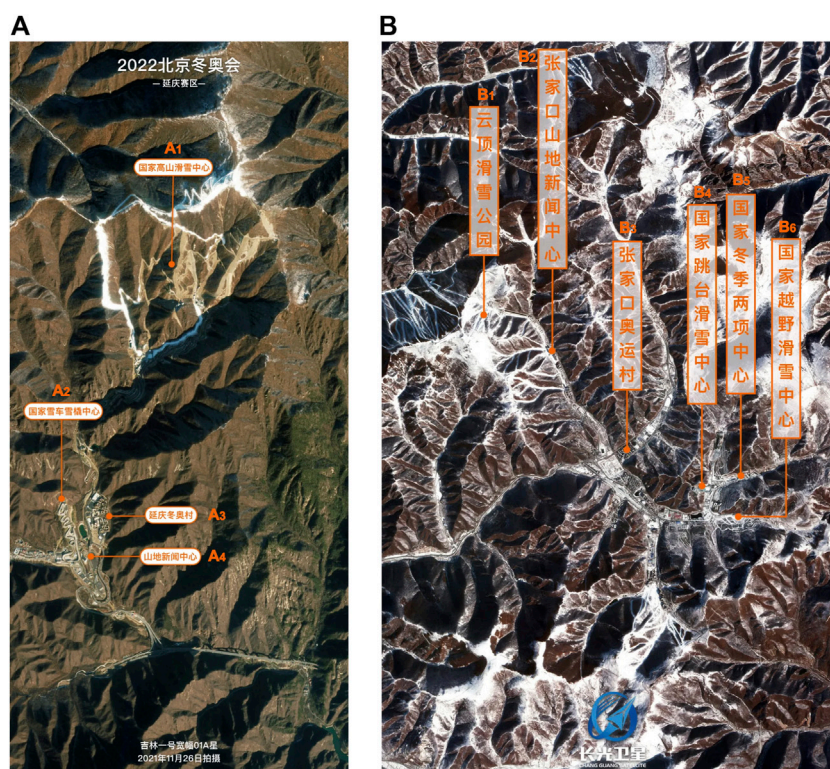


FIGURE 2

Satellite images of the Beijing 2022 Winter Olympics venues. **(A)** Yanqing zone: A1, Yanqing National Alpine Skiing Centre; A2, Yanqing National Sliding Centre; A3, Yanqing Olympic/Paralympic Village; A4, Yanqing Mountain Press Center; **(B)** Zhangjiakou zone: B1, Zhangjiakou Genting Snow Park; B2, Zhangjiakou Mountain Press Center; B3, Zhangjiakou Olympic/Paralympic Village; B4, Zhangjiakou National Ski Jumping Centre; B5, Zhangjiakou National Biathlon Centre; B6, Zhangjiakou National Cross-Country Skiing Centre. The photos were openly available from the QQ.com.

circumstances, history, and culture. This pattern is also predominately concentrated in economically developed areas. In 2020, Haidian and Chaoyang districts were ranked top and second in terms of GDP per capita in Beijing (QQ.com, 2021c). Economically developed areas have adequate capital and a large market to ensure that venues could be constructed, renovated, and repurposed post Olympic Games.

The Yanqing and Zhangjiakou zones, which were in charge of snow sports, are located in suburbs away from the Zhangjiakou city center, and the primary difference between them and the Beijing zone is that the venues are predominantly newly constructed on natural terrain. Yanqing zone consists of four venues (Figure 2A) (QQ.com, 2021a), which are divided by northern and southern sections by a bead chain layout on the mountain (Li, 2019). The north section is home to the National Alpine Skiing Centre, while the south section is home to the National Sliding Centre and the Yanqing Olympic/Paralympic Village. The Zhangjiakou zone contains 10 venues (Figure 2B) (QQ.com, 2021b). The Genting Snow Park was responsible for snowboarding and freestyle skiing events. The Central Chongli Prince Snow City encompasses all non-competition venues and

was responsible for the pre-, mid-, and post-Olympic logistics. The Southern Ancient Poplar Stadium Complex has three competition venues and one non-competition venue. The new sites are clustered in the same valley, enabling for the administration of the post-competition systematic restoration and environmental management.

The general pattern of Yanqing and Zhangjiakou consists of concave forms concentrated in valleys and convex forms concentrated on ridges, with the bulk of venues located in valleys (He, 2004). The valley has a modest temperature variation between day and night and a more stable temperature, which is conducive to snow formation and retention (Zhang et al., 2022a). The valley also has ample water resources and fertile soils that are essential for snow-making and subsequent ecological restoration. To reduce the impact on the mountain's natural environment, the site layout was tailored to local conditions, and buildings were distributed and developed in the valley of the mountain's slope, thereby minimizing construction and damage to the mountain and air pollution in the surrounding areas (Chu et al., 2022). Meanwhile, the Olympic transportation design in this region was conducted

with land sustainability in mind, which directly benefits the Beijing–Tianjin–Hebei coordinated development (Guo et al., 2022). In addition, the impact of transportation on carbon emissions was considered throughout the development of a bi-level programming model based on the minimal construction cost and the minimum overall trip time of the road network (Hong et al., 2022).

The long-term objectives of the past, present, and future are same, and for China, “clear waters and green mountains are mountains of gold and silver” (Kostka and Zhang, 2018), emphasizing the significance of ecological protection during the preparations for the Beijing 2022 Winter Olympics (Shi and Zhang, 2022) and in the cycle that follows. Before winning the Olympic bid, Chinese institutions initiated extensive scientific analyses of the vulnerable mountain regions’ ecological implications. Large-scale venue building must be balanced with ecological conservation (Zhang et al., 2021a), and contingency measures to recover the mountain forest have been devised (Liang et al., 2022). Therefore, attention was paid to the protection of flora and fauna throughout the design and construction of venues, and four types of ecological protection techniques are implemented to safeguard natural resources: avoidance, mitigation, reconstruction, and compensation (Beijing Organising Committee for the 2022 Olympic and Paralympic Winter Games, 2022a).

Because the construction of the Yanqing Olympic venues is the most ecologically challenging, wildlife protection is minimized by night construction, the installation of wildlife corridors, the arrangement of artificial nests, and the employment of infrared cameras and DNA analysis. Concerning wild plant protection, the type and distribution of plants in the area were investigated prior to construction, and some protected species were first considered for avoidance, then for *in-situ* protection, and those that could not be protected *in-situ* were considered for either *in-situ* or relocation protection. Five *in-situ* protection areas and one 300-acre relocation protection area were established, and 11,027 plants were protected *in-situ*. Ecological restoration areas of 2.14 million square meters and 454,000 square meters were completed in Yanqing and Zhangjiakou, respectively, to address ecological degradation caused by the construction process (Beijing Organising Committee for the 2022 Olympic and Paralympic Winter Games, 2022a). During the Olympic operation phase, the Zhangjiakou and Yanqing zones used surface water to construct a reservoir that could be used to draw water while also collecting rain and snow, ensuring that all snow and ice production was done with surface water. Intelligent snow-making was used to conserve water resource to the greatest extent possible. Meanwhile, the Zhangjiakou and Yanqing zones established a comprehensive sewage treatment system to collect and reuse sewage. Overall, the construction of Olympic venues, transportation, and other facilities led to a remarkable change in land use with minimal ecological damages and intensive reforestation activities, and the vegetation coverage continued to increase in the Zhangjiakou area (Zhang et al., 2021b), bolstering the belief that the Olympics will be held in a sustainable manner.

It is worth mentioning that, the Beijing 2022 Winter Olympics venues aimed prioritized renewable energy supply. The Zhangjiakou and Yanqing zones have abundant renewable energy resources (Zhang et al., 2022b). Zhangjiakou is influenced by winter monsoon, a strong winter monsoon from Siberia and Mongolian plateau, and is located at the junction of North China plain and dam plateau, which brings abundant wind and solar energies to the local area. The newly constructed energy infrastructures, such as the Zhangbei flexible DC grid (Li et al., 2020), show clearly that the Olympic Movement can leave a lasting legacy for the transition of the host nation to clean energy use through scientific land planning.

In 2021, China had 3.97 million sports venues, with a per capita size of 2.41 square meters (General Administration of Sport of China, 2022). This is significantly less than industrialized nations, such as the United States and Japan, where the sports venue area per capita exceeded 10 square meters years ago (Huang and Liu, 2020). Clearly, this does not align with the national fitness program’s objective of increasing the number of Chinese people who engage in daily fitness and sports, and the dearth of sporting venues is without debate. China’s Olympic venues are governed by a state-led, carefully planned investment model aimed at sustainability, which is now public welfare as a response to the Chinese public’s interest in snow and ice sports (An et al., 2019) and national fitness. The legacy of the Beijing 2022 Winter Olympics venues is significant in terms of societal value and resource scarcity in general (Chen et al., 2021b).

Discussion

Sustainable development is concerned with the human-nature relationship and their long-term viability. As the greatest human sporting event in the world, the Olympic Movement’s Legacy Strategic Approach is an urgent choice to address its own concerns (McBride and Manno, 2021). Olympic Games have expanded beyond traditional sporting competitions to encompass economic, political, cultural, and other spheres of sustainable development. Following the inclusion of sustainability as a foundational theme in the Olympic Agenda 2020 (International Olympic Committee, 2014), China promoted the concept of sustainable development and was the first Olympic Games to incorporate sustainability throughout the process. Among the 15 sustainability successes of the Beijing 2022 Winter Olympics, eight are related to the venues, covering pre-, mid-, and post-Olympic periods (International Olympic Committee, 2022).

Utilizing the polycentric and decentralized spatial distributions of the two cities and three competition zones, Beijing and Zhangjiakou collaborated to host the Beijing 2022 Winter Olympics. Geographically, the three competition zones represent a point-to-point spatial distribution, and the venue legacy was built based on the long-term benefits of Beijing and Zhangjiakou’s urban land use and natural topography. Beijing was primarily responsible

for ice events and possesses substantial humanistic and geographical advantages, particularly in the economy, culture, science and technology, transportation, and cultural legacy. Beijing has kept a significant amount of Olympic legacy as the host city of the Beijing 2008 Summer Olympics, and only one new National Speed Skating Oval was required to accommodate demand for ice events. Zhangjiakou and Yanqing were responsible for snow events due to their enormous natural resources, adequate wind and solar reserves, and favorable climatic and terrain characteristics. The advantages of the three zones complement one another, catalyzing a sustainable urbanization after the Olympics (Yeerkenbieke et al., 2021).

Sustainability is the way, ecological development is a prerequisite for sustainable development, and green ecology is synonymous with sustainable development. Olympic legacy should encompass long-term benefits for residents and cities (Suzuki et al., 2018), and the concept of managing the Olympics sustainably should be broadened to include the post-Olympic period. The contemporary Olympics are reaching a point where few city is willing to bid for the Olympics due to the prohibitively high cost (McBride and Manno, 2021). Few cities have hosted as many mega sporting events as Beijing, and the destiny of the dual Olympic city should not be only Beijing's. We should encourage more cities to bid for the Olympics. By leveraging existing venue legacy and the collective strength of city clusters to host the Olympics, the Olympics can foster the synergistic development of city clusters while accelerating the transition to a sustainable society. The Beijing 2022 Winter Olympics contributed to a Chinese solution for a green, urban economy development model driven by the Olympic Movement.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

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Conflict of interest

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