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A sudden surge: The impact of hosting the olympics on national energy consumption (1970–2022)

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ABSTRACT

This study examines the short-term impact of hosting the Olympic Games on national per capita energy consumption from 1970 to 2022. Using cross-national panel data from 78 countries and a difference-in-differences approach, the analysis isolates change in energy use during the year before, the year of, and the year after Olympic hosting. Results reveal a significant increase in per capita energy consumption during both the preparation year and the hosting year, with no statistically significant change observed in the year following the event. These findings suggest that the energy surge is primarily driven by large-scale infrastructure development, including the construction of venues and transportation networks, as well as heightened operational demands and the influx of visitors during the Games. However, energy consumption does not fully return to pre-event levels post-hosting, indicating potential lasting changes in energy systems or economic activity. These may include the continued utilization of infrastructure, increased energy demand in newly developed regions, or broader shifts in economic patterns linked to the event. The study underscores the need for host countries to anticipate these temporary surges and implement targeted sustainability strategies—such as flexible energy solutions and demand management practices—to mitigate environmental impacts effectively.

1. Introduction and background

The intersection of mega-events and sustainability has become a critical concern in contemporary environmental policy. As global attention increasingly focuses on climate change and resource management [1–3], the environmental implications of large-scale international events have come under scrutiny. Among these events, the Olympic Games represent one of the most resource-intensive and globally visible mega-events, creating both opportunities for sustainable development and significant environmental challenges for host countries. Understanding how these events affect national resource consumption patterns is essential for informed policy decisions about hosting such prestigious but resource-demanding events.

Mega-events like the Olympic Games require massive infrastructure investments and generate substantial increases in resource consumption. The preparation and hosting phases typically involve extensive construction of stadiums, transportation networks, and accommodation facilities, alongside dramatic increases in visitor numbers and associated services [4]. While proponents highlight economic benefits including job creation, foreign investment, and tourism revenues [5,6], these gains come at considerable environmental cost. The energy implications are particularly significant, as Olympic hosting creates acute spikes in electricity, fuel, and water demand through venue operations, transportation systems, and hospitality services. These surges strain existing

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infrastructure and can exacerbate environmental pressures, raising fundamental questions about the sustainability of such events [7,8]. As countries increasingly commit to carbon reduction targets and sustainable development goals, understanding the energy footprint of mega-events becomes essential for responsible hosting decisions.

Although considerable research exists on the economic and social dimensions of Olympic hosting (e.g., [9]), systematic examination of environmental impacts has been limited and fragmented. While recent studies have begun documenting environmental challenges at mega--events—such as organizational barriers to sustainability initiatives [10], weak environmental governance mechanisms, and modest greening outcomes despite substantial efforts [11]—most research has focused on individual cases or single countries through qualitative assessments. Recent work by Ceccon et al. [12] represents an important step forward, providing cross-national evidence that carbon emissions rise during Olympic preparation and hosting years before returning to baseline levels. However, it remains uncertain whether similar patterns occur for other fundamental environmental indicators, particularly per capita energy consumption—a critical measure that reflects overall resource demand and is directly influenced by the infrastructure development, transportation surges, and operational intensification characteristic of Olympic hosting. This study addresses this question by providing a systematic, cross-national analysis of how Olympic hosting affects national energy consumption patterns, using a comprehensive dataset of 78 countries from 1970 to 2020 under a Difference-in-Difference approach and a parallel trend model to better capture the causal relationship between hosting the Olympics and changes in energy consumption trends. Specifically, we analyze energy consumption trends during three critical periods: pre-hosting, hosting, and post-hosting years, compared to non-hosting countries. The findings contribute to a deeper understanding of the resource management challenges posed by mega-events and offer critical evidence for policymakers seeking to balance economic benefits with sustainability objectives.

Hence, this article is structured as follows: Section 2 reviews studies on economic and environmental impacts of hosting mega-events and develops the hypothesis. Section 3 outlines data, sample selection, and methods for analyzing energy consumption in 78 countries (1970–2020). Section 4 presents findings on energy trends before, during, and after the Olympics. Section 5 discusses sustainability implications, policy recommendations, and future research directions.

2. Literature Review and hypothesis

2.1. The Impacts of Hosting Mega-events on Environmental Sustainability

The Olympic Games have drawn significant scholarly attention for their socio-economic and environmental impacts on host countries. While there is a consensus that hosting mega-events promotes economic growth through increased tourism, job creation, and enhanced international visibility [9], these benefits are often accompanied by substantial costs. These include the financial burden of large-scale infrastructure projects, such as stadiums and transportation networks [13], and the post-event underutilization of these facilities, which can result in "white elephant" projects with little long-term value [14].

Research on the environmental performance of mega-events reveals a persistent gap between sustainability goals and actual outcomes, particularly in the context of case studies of a particular mega-events. While there is growing awareness and initial efforts to implement sustainability initiatives [15], most events achieve only modest success in mitigating their environmental impacts. For instance, the 2008 International Children's Games faced organizational barriers that limited the effectiveness of its sustainability practices [10]. Similarly, despite the International Olympic Committee's long-standing focus on sustainability, weak enforcement mechanisms often prevent host cities from fulfilling their environmental commitments. The 2010 FIFA World Cup in South Africa further underscores this issue, as innovative local greening projects were undermined by insufficient national leadership, poor co-ordination, limited funding, and inadequate communication, leaving a significant carbon footprint [11]. These examples highlight the critical role of governance, resources, and organizational capacity in bridging the gap between sustainability rhetoric and actual outcomes.

Mega-events hosted by China, especially the 2008 Beijing Olympic Games, have been well-documented for their sustainability outcomes. Wu & Zhang [16] highlighted Beijing's achievements in reducing greenhouse gas emissions through industrial restructuring, technological innovation, renewable energy adoption, and ecosystem restoration. Between 2001 and 2006, Beijing reduced per unit GDP energy consumption by 33.3 % and CO_2 emissions by 32.4 %, demonstrating a successful balance between economic growth and environmental sustainability. Similarly, Wu et al. [17] estimated that the 2008 Beijing Olympics reduced approximately 10.46 million tons of CO_2 emissions through clean energy adoption, energy efficiency improvements, and temporary air pollution controls. Short-term air quality control measures during events like APEC 2014 and the 2015 Military Parade also significantly improved Beijing's air quality, reducing pollutants such as $PM_{2.5}$, PM_{10}, and NO_2 [18]. However, these outcomes were not uniformly positive. Long et al. [19] noted that while Beijing's environmental efficiency improved during and after the 2008 Olympics, neighboring cities experienced negative effects, likely due to the relocation of pollution-intensive industries.

In addition to these case studies, Ceccon et al. [12] provided important cross-national evidence showing that carbon emissions rise significantly during both the preparation and hosting years of the Olympic Games, before returning to baseline levels afterward due to the scaling down of event-related activities, such as transportation, hospitality, and operational demands, lead to a reduction in resource use. Their findings highlight the short-term dynamics of emissions associated with the large-scale infrastructure development and operational demands of hosting, but they also underscore the need for further research on other environmental indicators, such as energy consumption, to provide a more holistic understanding of the environmental impacts of mega-events.

2.2. Literature gap and contribution

Despite the growing body of research on the environmental impacts of hosting mega-events, much of it remains fragmented and heavily focused on individual case studies, particularly those centered on Beijing. For example, studies like Wu & Zhang [16] and Wu et al. [17] emphasize Beijing's industrial restructuring, adoption of renewable energy, and clean energy initiatives as effective strategies for reducing greenhouse gas emissions during the 2008 Olympics. Similarly, Ma et al. [18] and Long et al. [19] document short-term improvements in air quality during and immediately after the Games. While these findings provide valuable localized insights into the environmental consequences of hosting mega-events, they do not offer a broader, cross-national understanding of how such events impact national-level sustainability metrics, such as per capita energy consumption.

Among the limited cross-national studies, Ceccon et al. [12] stands out as the first to provide systematic evidence of the environmental impacts of hosting the Olympics. Their analysis reveals that carbon emissions rise significantly during the preparation and hosting years before returning to baseline levels. However, while their study demonstrates the temporary nature of emissions surges, it focuses exclusively on carbon emissions and does not explicitly assess per capita energy consumption. This omission is significant because energy consumption provides a more direct measure of the resource-intensive processes associated with hosting mega-events, including large-scale infrastructure development, increased transportation demands, and heightened operational activities during the Games.

Most existing studies treat energy consumption as a secondary or background factor, often inferred through related metrics like carbon emissions or localized air quality changes, rather than analyzing it as a primary indicator of sustainability. For instance, while Ceccon et al. [12] document emissions increases, they do not delve into the specific trends in energy usage that underpin these emissions. This leaves a critical gap in understanding how hosting the Olympics affects energy consumption patterns, which are directly tied to infrastructure projects, transportation systems, and operational demands.

Addressing this gap requires systematic, cross-national research that explicitly evaluates the impact of hosting the Olympics on per capita energy consumption. Such an approach is vital for determining whether hosting the Games results in sustained increases in energy use or if the observed surges are confined to the preparation and hosting phases. Moreover, analyzing energy consumption across countries allows for meaningful comparisons, taking into account variations in energy systems, governance capacities, and sustainability policies. This study directly addresses this gap by focusing on the relationship between Olympic hosting and national per capita energy consumption, offering critical insights into the broader environmental challenges and sustainability implications of mega-events.

Hence, this study makes several key contributions by directly analyzing per capita energy consumption, offering a more precise measure of resource demand during mega-events compared to prior research that emphasizes carbon emissions as a proxy. By examining data from 78 countries over five decades, it moves beyond localized case studies to provide a global perspective, enabling meaningful comparisons across diverse contexts with varying energy systems, governance capacities, and sustainability practices. The study also identifies distinct energy consumption patterns during the preparation, hosting, and post-hosting phases, highlighting both the short-term surges and potential long-term implications of hosting the Olympics. Furthermore, the findings reveal the persistence of elevated energy consumption post-hosting, challenging assumptions that energy use fully returns to baseline levels, and emphasizing the need for targeted sustainability strategies to mitigate long-term environmental impacts. By addressing these gaps, the study contributes to a deeper understanding of the environmental challenges posed by mega-events and provides actionable insights for balancing their economic benefits with sustainability goals.

2.3. Mechanism and hypothesis development

Building on the mechanism identified by Ceccon et al. [12]—where temporary surges in resource use are driven by large-scale infrastructure development and heightened operational demands—this study examines whether similar patterns apply to per capita energy consumption. Mega-events like the Olympics require host countries to undertake extensive construction projects, including the building of stadiums, transportation networks, and accommodations, which result in significant energy demand during the preparation phase. These activities involve energy-intensive processes, such as industrial production, the manufacturing of construction materials (e.g., steel and cement), and the operation of heavy machinery, all of which collectively drive-up energy consumption [13]. Additionally, preparatory work often includes upgrades to utilities, roads, and public transportation systems, further exacerbating energy use. These resource-intensive activities are critical to ensuring that the infrastructure is ready for the Games [19]. This aligns with Ceccon et al.'s [12] findings on carbon emissions, where emissions rise sharply during the pre-event period due to the scale of construction efforts. Given the substantial energy demands of infrastructure preparation, we hypothesize:

H1: Hosting the Olympics is associated with a significant increase in national per capita energy consumption during the year prior to the Games.

During the event itself, national per capita energy consumption is expected to remain elevated due to heightened operational demands across various sectors, especially transportation and hospitality. Transportation systems are a key driver of this surge, as the influx of millions of international visitors places unprecedented pressure on public and private transit networks. Increased fuel consumption for buses, trains, and airplanes, as well as additional electricity demand for metro systems and other public transit infrastructure, contributes significantly to energy consumption [4].

In addition to transportation, the hospitality industry also exerts a significant influence on energy consumption during the Games. Visitors indirectly drive demand through their reliance on hotels, restaurants, and entertainment venues, all of which require substantial energy inputs for electricity, heating, cooling, and other utilities. Olympic venues—including stadiums, arenas, media centers, and broadcasting facilities—add to this demand, requiring extensive energy inputs for lighting, air conditioning, and broadcasting technologies. These energy-intensive operations are essential for the smooth execution of events and the global broadcast of the Games [17]. Yet, Ceccon et al. [12] further emphasize how mega-events like the Olympics amplify resource use across sectors such as tourism and lodging, placing additional strain on the host country's energy systems. Combined, these factors illustrate how the extraordinary operational demands associated with hosting the Olympics result in a significant increase in national per capita energy consumption during the event year. Thus, we hypothesize:

H2: Hosting the Olympics is associated with a significant increase in national per capita energy consumption during the year of the event.

After the Games conclude, energy consumption is expected to stabilize as the extraordinary demands associated with hosting subside. Construction activities, which drive significant energy use during the preparation phase, are completed, and the operational intensity required to accommodate millions of visitors diminishes. This aligns with Ceccon et al. [12], who found that carbon emissions typically return to baseline levels after the event, suggesting that energy use may follow a similar trajectory. The cessation of event-specific activities, such as the operation of Olympic venues and the expanded transportation schedules, further contributes to the normalization of energy consumption patterns.

However, while immediate energy consumption may decline, the potential for sustained impacts due to newly constructed infrastructure and expanded capacities remains a consideration. Scandizzo & Pierleoni [14] argue that post-event underutilization of facilities can lead to inefficiencies, but such "white elephant projects" may not significantly increase national energy consumption due to their limited operational use. Furthermore, Wu et al. [17] emphasize that sustainability measures implemented during the Games, such as clean energy adoption and efficiency improvements, can help offset any prolonged energy demand. These factors collectively support the expectation that energy consumption in the post-event year normalizes without significant deviations from pre-hosting levels. Based on this understanding, we hypothesize:

H3: There is no significant change in national per capita energy consumption in the year following the hosting of the Olympics.

This set of hypotheses reflects the expected temporary nature of energy surges observed during the preparation and hosting phases and the stabilization of resource use patterns following the conclusion of the Olympics. Each hypothesis is grounded in the mechanisms driving energy demand during specific phases of hosting, providing a clear framework for understanding the relationship between mega-events and national energy consumption.

3. Methods

3.1. Study Focus

This study employs a cross-national time-series (CNTS) analysis to examine the effects of preparing for and hosting the Olympic Games (both Summer and Winter) on national per capita energy consumption. As such, the analysis spans 78 countries from 1970 to 2022. The starting year, 1970, was chosen due to the availability of comprehensive and reliable data for key covariates, such as the Globalization Index and World Bank indicators, while 2022 reflects the most recent year for which complete and consistent data were available at the time of analysis. Many data sources, particularly World Bank indicators, extend through 2022, ensuring the dataset's robustness and accuracy.

3.2. Variables

The dependent variable, coded as Energy Per Capita, is sourced from the Energy Institute [20] and measures primary energy consumption in exajoules per country-year. This focus on per capita energy consumption accounts for differences in population size across countries, ensuring a standardized and comparable measure of energy demand at the country level. The dataset includes 78 countries, encompassing all G20 and OECD members, as well as other UN member states with significant energy markets.

The selection of these 78 countries—regardless of whether they have hosted the Olympics, be it the Summer or Winter Games—is based on the availability of consistent data necessary for panel analysis. The dependent variable, coded as Energy Per Capita, is sourced from the Energy Institute [20] and measures primary energy consumption per capita in exajoules per individual. We focus on per capita energy consumption, rather than total national energy use, to account for differences in population size across countries and to provide a more comparable measure of energy demand at the individual level. This approach ensures that our analysis captures changes in energy consumption that are not merely driven by population size variation, in line with existing studies (e.g., [21]). The Energy Institute [20] dataset covers 78 countries, including all G20 and OECD members, as well as numerous other UN member countries with significant energy markets. However, a key limitation is that the dependent variable's coverage excludes many developing countries, including a few that have previously hosted the Olympics, such as Bosnia and Herzegovina, due to country coverage is excluded in the dataset. This omission may limit the generalizability of the findings to all Olympic host countries, particularly those with less comprehensive energy reporting or underdeveloped data collection systems.

The key explanatory variables in this analysis capture three critical periods related to hosting the Olympics: (1) the year prior to hosting (Pre-Host Year), (2) the year of hosting (Hosting Year), and (3) the year following the event (Post-Hosting Year). Each of these periods is represented by a dummy variable coded as 1 for the respective country-year and 0 otherwise. The binary classification is based on historical data from the International Olympic Committee [22], where the author has categorized one year before and one year after the event as the Pre-Host Year and Post-Hosting Year, respectively.

The decision to focus on the year immediately preceding and following the Olympic Games is a purposeful methodological choice, grounded in the observation that fluctuations in energy consumption are most pronounced during the final stages of event preparation and shortly after its conclusion. By restricting the analysis to this one-year interval, the study isolates the critical phases of heightened energy demand. In the preparatory year, energy consumption intensifies due to final construction activities, operational testing, and infrastructure expansions—processes that may span multiple years but typically peak in the months leading up to the Games. Extending the period of analysis beyond this interval would dilute these effects by incorporating years in which energy consumption does not yet—or no longer—fully capture the Olympic-related activities.

During the hosting year, energy use typically peaks as a result of continuous venue operations, substantial transportation requirements, and large-scale gatherings. In the subsequent year, energy use normalizes, although decommissioning temporary facilities and repurposing venues for legacy purposes can still exert an influence on overall consumption. Limiting the scope to a single post-hosting year thus establishes a clear demarcation between the heightened energy demands of the hosting period and the ensuing decline in consumption trends. Aligned with the approach proposed by Ceccon et al. [12], this design highlights three distinct periods: the year of acute anticipatory activities prior to the Games, the year of maximum consumption during the event, and the immediate post-Games interval. By delineating these phases, the study achieves a clearer understanding of the short-term impact of hosting the Olympics on national energy consumption.

In addition, we include a comprehensive list of control variables, detailed in Table 1 (along with their operationalization), to account for potential confounding factors noted in the existing literature. These variables include the level of economic development [23], the degree of globalization exposure [24], the amount of foreign direct investment, the level of democracy [21], population density, and the amount of oil reserves [25]. By incorporating these control variables, the analysis aims to reduce the risk that the observed effects of hosting the Olympics are driven by other underlying determinants of national energy consumption. This approach enhances the robustness of the study by isolating the specific impact of hosting the Olympics on energy use. Despite these efforts, we acknowledge that unobserved factors, such as regional energy policies or cultural practices, may still influence energy consumption and cannot be fully captured by variables that are easily available under the CNTS setup.

3.3. Empirical modelling

For the empirical analysis, we employ a Difference-in-Differences (DiD) approach to estimate the causal effect of hosting the Olympics on per capita energy consumption. In this framework, the country-year is the unit of analysis, enabling us to track changes in energy use within each country over time. The method compares changes in energy consumption between countries that host the Olympics (treatment group, consisting of 16 countries – see Table A2) and those that do not (control group, consisting of 62 countries – see Table A3) across the periods before and after the event. By incorporating country-specific fixed effects and year-specific fixed effects, the DiD framework controls for unobserved heterogeneity and common temporal shocks, ensuring robust and unbiased results.

From this analysis, we estimate the Average Treatment Effect on the Treated (ATET), which captures the average impact of hosting the Olympics on per capita energy consumption among host countries during the relevant periods. The ATET reflects the difference between the observed changes in energy consumption within treated country-years and the estimated counterfactual changes that would have occurred in the absence of hosting, as inferred from the control group. To minimize potential multicollinearity issues, the dummy variables for the Preparation Year (Pre-Host Year), Hosting Year (Host Year), and Post-Hosting Year (Post-Host Year) are included in separate regressions rather than simultaneously. This approach provides a clear and robust estimate of the individual effects of each period on per capita energy consumption.

The estimation strategy is represented by the following equation, where each period is estimated separately:

$$\mathrm{Y}_{it} = \alpha + \beta_k \mathrm{D}_{kit} + \gamma \mathrm{X}_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

where:

Table 1
Descriptive statistics.

Variable	Details	Mean	SD	Min	Max	Source
Energy Per Capita	Primary energy consumption per capita, measured in exajoules per individual.	140.4820	136.9871	0.9857	1143.3060	Energy Institute [20]
Pre-Host Year	Dummy variable equal to 1 if the Olympics was held in the country in the year prior to hosting, and 0 otherwise.	0.0079	0.0883	0.0000	1.0000	IOC (2025)
Host Year	Dummy variable equal to 1 if the Olympics was held in the country in the current year, and 0 otherwise.	0.0076	0.0866	0.0000	1.0000	IOC (2025)
Post-Host Year	Dummy variable equal to 1 if the Olympics was held in the country in the year after to hosting, and 0 otherwise.	0.0072	0.0848	0.0000	1.0000	IOC (2025)
Economic Development	GDP Per Capita in Current US Dollars (Logged).	8.7444	1.4747	3.1333	11.8034	World Bank [26]
Globalization	The overall globalization index encompasses economic, social, and political dimensions, with higher values indicating a greater degree of globalization.	63.4354	15.6362	18.3100	91.3100	Dreher [27]
FDI	Foreign Direct Investment relative to the national GDP.	0.5830	0.2995	0.0120	0.9220	World Bank [26]
Democracy	Measured using the electoral democracy index, which ranges from 0 (no electoral democracy) to 1 (full electoral democracy).	0.5830	0.2995	0.0120	0.9220	Coppedge et al. [28]
Population Density	De-facto population divided by national land area in square kilometers (Logged).	4.2516	1.5146	0.6931	8.9829	World Bank [26]
Oil Reserves	Proved reserves of crude oil represent the estimated quantities of all liquids identified as crude oil.	11.7160	36.0104	0.0000	297.7400	World Bank [26]

¨ Y_{it} is the per capita energy consumption for country i in year t.
¨ D_{kit} is one of the dummy variables—Pre-Host, Host, or Post-Host—included one at a time in each regression $k \in \{\text{PreHost}, \text{Host}, \text{PostHost}\})$.
¨ X_{it} is a vector of control variables as described above.
¨ $\mu_i$captures country fixed effects.
¨ λ_t captures year fixed effects.
¨ ϵ_{it} is the error term.

The coefficient β_k captures the effect of the relevant period (preparation, hosting, or post-hosting) on per capita energy consumption, while accounting for covariates and fixed effects. To validate the parallel trends assumption—a critical requirement for the DiD design—we conducted a Parallel Trends Visualization (Fig. 1), comparing the average energy consumption of treated and control groups within ±3 years of hosting the Olympic Games. This analysis highlights when shifts in energy consumption occur, offering insights into the timing and magnitude of these effects during the preparation, hosting, and post-hosting phases.

By distinguishing the effects of these periods, our approach improves the causal validity of the findings and minimizes the risk of results being influenced by statistical artefacts. Unlike prior research, such as Ceccon et al. [12], which relied on aggregated two-way fixed effects models (2WFE), we adopt a more granular approach by estimating separate regressions for each phase. This avoids conflating time-specific impacts and provides a clearer picture of the temporal dynamics of energy consumption. Furthermore, our methodology addresses limitations of traditional 2WFE models, including susceptibility to biases from heterogeneous treatment effects or staggered event timing. By isolating and analyzing each period independently, we ensure a more robust and reliable evaluation of how hosting the Olympics affects energy consumption. These findings offer policymakers practical insights into the timing and scale of energy impacts associated with hosting large-scale events.

4. Results

As shown in Table 2, the results for the Average Treatment Effect on the Treated (ATET) across the three models indicate distinct patterns in per capita energy consumption associated with different Olympic

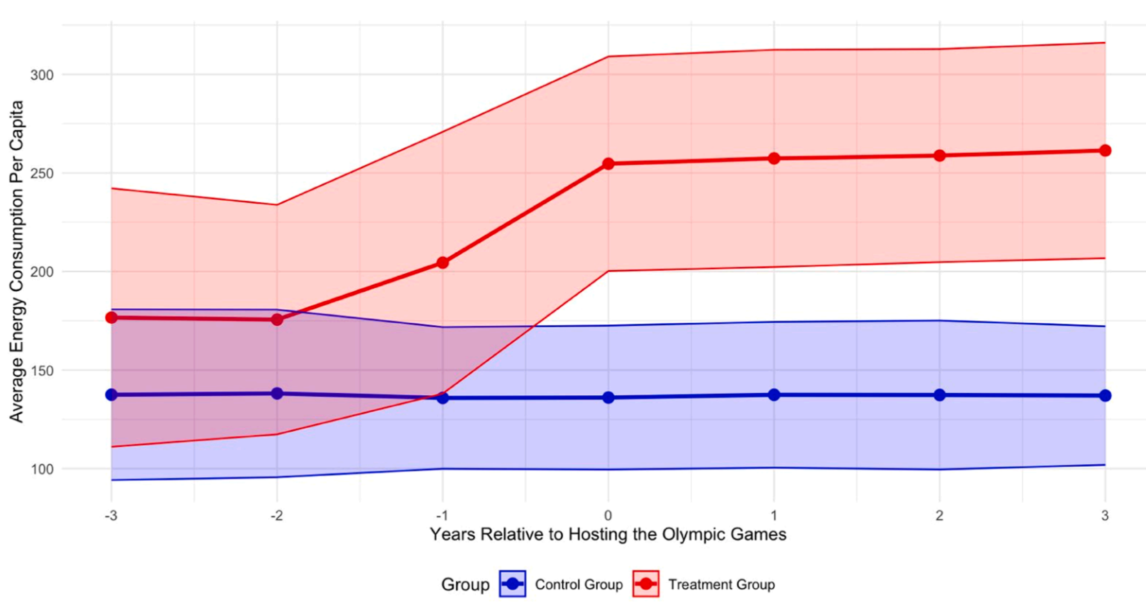

Fig. 1. Energy consumption trends: ±3 years relative to hosting the olympic games.

Table 2
DiD results of olympics host variable on energy consumption per capita.

	Model 1	Model 2	Model 3
Pre-Host Year	6.5135**		
	(3.2355)		
Host Year		5.1823*	
		(3.0785)	
Post-Host Year			4.4581
			(2.8909)
Economic Development	22.7246**	22.7483**	22.7608**
	(9.5769)	(9.5712)	(9.5709)
Globalization	−0.2493	−0.2472	−0.2473
	(0.7665)	(0.7662)	(0.7662)
FDI	−2.9593	−2.9684	−2.9585
	(2.1316)	(2.1324)	(2.1311)
Democracy	−11.2231	−11.2640	−11.2287
	(20.6658)	(20.6428)	(20.6431)
Population Density	79.0154***	79.0403***	79.0401***
	(17.3958)	(17.3935)	(17.3935)
Oil Reserves	0.0597	0.0598	0.0599
	(0.2012)	(0.2011)	(0.2012)
Countries	78	78	78
N	3177	3177	3177

$p < 0.01$***, $p < 0.05$**, $p < 0.1$*. Standard errors are in the parathesis.

periods. Interpreting the coefficients in marginal terms, the results indicate that hosting the Olympics is associated with notable increases in per capita energy consumption. Specifically, in Model 1, the estimated coefficient of 6.51 for the pre-host year implies that, on average, countries experience a 6.51 unit increase in per capita energy consumption (measured in exajoules per individual) during the year prior to hosting the Olympics, compared to non-hosting years and countries. In Model 2, the coefficient of 5.18 for the host year suggests a marginal increase of 5.18 units in per capita energy consumption in the year the Olympics are held. In Model 3, the coefficient of 4.46 for the post-host year indicates a similar, though statistically insignificant, marginal increase in per capita energy consumption in the year following the event. These estimates reflect the average treatment effect on the treated (ATET), representing the additional energy consumption attributable to the Olympics during each respective period, holding other factors constant.

In addition, Fig. 1 presents a parallel trends graph to test for pre-existing differences in trends between the treatment group (countries hosting the Olympics) and the control group (non-hosting countries). The graph highlights a noticeable divergence in energy consumption patterns, beginning in the pre-host year (1 year before the Olympics) and continuing into the hosting year. The treatment group experienced a significant increase in average per capita energy consumption, rising from slightly 150 exajoules to slightly >250 exajoules, while the control group consistently maintained its per capita energy consumption at around 130 exajoules. After the hosting year, the treatment group's energy consumption remained relatively steady at slightly above 250 exajoules in subsequent years. Together, these results demonstrate that per capita energy consumption rises significantly in both the year before and the year of hosting the Olympics. In contrast, the increase observed in the year following the event is negligible and suggests a potential chance that other —potentially unobserved factors may have influenced the sustained levels of energy consumption, rather than hosting the Olympics alone.

5. Discussion and conclusion

5.1. Reasons for the results

This study confirms that hosting the Olympic Games leads to temporary but significant increases in national per capita energy consumption during the preparation and hosting years, with no statistically significant change in the post-hosting year. These findings highlight the distinct mechanisms driving energy demand across the three phases and align with prior research on the environmental impacts of mega-events.

The 6.51 exajoule per capita increase in energy consumption during the preparation year reflects the resource-intensive nature of infrastructure development required for hosting the Olympics. Construction projects, including stadiums, transportation networks, and accommodations, rely on energy-intensive processes such as steel and cement production, heavy machinery operation, and material transportation. These demands are further exacerbated by upgrades to public utilities, roads, and urban infrastructure, which are often accelerated to meet the event's hosting deadlines. Statistically, the significant coefficient ($p < 0.05$) underscores the robustness of this result, consistent with research by Patel et al. [13] and Long et al. [19], who emphasize the increased energy demands associated with large-scale construction activities. This aligns with prior findings, such as Ceccon et al. [12], who observed similar surges in carbon emissions during Olympic preparation phases, driven by infrastructure development.

During the hosting year, energy consumption remains elevated, with a 5.18 exajoule per capita increase**,** driven by heightened operational demands across transportation, hospitality, and event management sectors. The influx of international visitors, athletes, and media personnel places significant pressure on public and private transportation systems, leading to increased fuel and electricity consumption for transportation systems. Additionally, Olympic venues, including stadiums, arenas, and media centers, operate at full capacity, requiring extensive energy inputs for lighting, air conditioning, broadcasting technologies, and security systems. These findings align with Baade and Matheson [4] and Wu et al. [17], who emphasize the critical role of event-specific activities in driving temporary energy surges. The hospitality sector also contributes significantly, with hotels, restaurants, and entertainment venues operating at or near full capacity to accommodate visitors. The magnitude of this statistically significant increase ($p < 0.1$) highlights the extraordinary scale of operational activity concentrated within a short time frame, confirming the hypothesis that hosting the Olympics leads to a significant rise in per capita energy consumption during the event year.

In the post-hosting year, energy consumption stabilizes, with a 4.46 exajoule per capita increase that is not statistically significant ($p > 0.1$). This suggests that while the extraordinary demands associated with hosting the Olympics subside, energy consumption does not fully return to pre-event baseline levels. Instead, the persistence of elevated energy consumption may reflect unobserved residual factors, such as infrastructure utilization, increased operational capacity, or broader economic trends stemming from the Games. These findings differ slightly from Ceccon et al. [12], who observed that carbon emissions typically return to baseline levels after mega-events as resource demands diminish. However, they align with Scandizzo and Pierleoni [14], who argue that newly constructed infrastructure, while often underutilized post-event (e.g., "white elephant" projects), may still contribute to modest ongoing energy demands. The parallel trends analysis (Fig. 1) confirms that the treatment group (host countries) and the control group (non-hosting countries) followed similar energy consumption trajectories before the pre-host year, validating the Difference-in-Differences (DiD) model. The divergence observed during the preparation and hosting years provides strong evidence that the increases in energy consumption are directly attributable to hosting the Olympics rather than external factors. The preparation year is characterized by energy-intensive construction and infrastructure upgrades, while the hosting year sees sustained increases due to heightened operational activity across transportation, hospitality, and event management sectors.

In the post-hosting year, while energy consumption stabilizes, the persistence of elevated levels suggests that hosting the Olympics may induce lasting changes in energy systems or economic activity. These could include continued utilization of infrastructure, increased energy demand in newly developed regions, or shifts in economic patterns directly or indirectly linked to the event [29,30]. These findings challenge the notion of a complete return to baseline energy consumption and highlight the broader implications of hosting mega-events. Overall, this study underscores the temporary but significant energy surges associated with hosting the Olympics, driven by large-scale infrastructure development and operational intensity. The failure to return to baseline level in energy consumption post-event emphasizes the importance of addressing unanticipated residual effects. Policymakers should focus on targeted sustainability strategies, such as optimizing infrastructure utilization, improving energy efficiency, and integrating renewable energy technologies, to mitigate the long-term environmental impacts of hosting mega-events.

5.2. Implications

5.2.1. Theoretical contributions

This study makes notable contributions to the theoretical understanding of how hosting mega-events like the Olympics influences energy consumption. By explicitly distinguishing between the preparation, hosting, and post-hosting periods, the analysis moves beyond aggregated models to provide a more granular understanding of the temporal dynamics of energy demand. This approach enables researchers to identify short-term energy surges and their subsequent normalization, offering insights into the predictability and timing of the energy impacts associated with such events. Furthermore, the study strengthens the causal validity of event studies by applying a DiD framework. By focusing on per capita energy consumption, the research ensures comparability across countries with diverse population sizes, addressing a critical gap in prior studies (e.g., [12]). The findings also contribute to the growing literature on sustainability and mega-events, emphasizing the challenges of balancing short-term economic and reputational benefits with long-term environmental considerations. At the same time, future studies can build on this theoretical framework by exploring heterogeneous effects across countries with varying levels of economic development, energy infrastructure, and environmental policies, as well as by extending the analysis to other types of mega-events, such as the FIFA World Cup or World Expos.

5.2.2. Managerial implications

The findings of this study provide actionable insights for Olympic organizers, host city managers, and infrastructure planners.

First, the significant but temporary increase in per capita energy consumption during the year prior to and the year of hosting highlights the importance of incorporating sustainability measures into Olympic planning. Governments and organizers should prioritize conducting comprehensive environmental impact assessments, mandating the use of renewable energy sources, and integrating energy-efficient technologies into construction and operational processes [31]. These measures can help mitigate negative environmental impacts while ensuring that hosting the Olympics delivers long-term economic and reputational benefits. Second, the results suggest that investing in permanent, large-scale energy infrastructure solely for Olympic-related needs may not be cost-effective. While energy consumption rises significantly in the preparation and hosting years, the increase observed in the year following the event is negligible. This indicates that energy demand largely returns to normal after the hosting year, and other potentially unobserved factors may influence any sustained levels of energy consumption. Consequently, host cities should adopt adaptable and temporary solutions, such as modular energy systems, rented backup generators, or mobile energy storage units, to address short-term surges in energy demand. Additionally, infrastructure development should focus on post-Games utility, ensuring that venues and facilities can be repurposed for community use or integrated into the local energy system. This approach would maximize long-term value and prevent costly "white elephant" projects.

Third, the predictability of energy surges during the preparation and hosting periods allows host governments and organizers to implement targeted demand management strategies to enhance energy security. Public awareness campaigns can encourage households and businesses to limit non-essential electricity use during peak Olympic events. Utilities could introduce time-of-use pricing to incentivize shifting commercial activities to off-peak hours. Organizers should also collaborate with key energy consumers, such as hotels, transport providers, and event venues, to schedule non-critical activities during low-demand periods. These proactive measures can reduce the risk of blackouts or grid disruptions while ensuring that essential services and Olympic operations continue smoothly. As such, by aligning energy planning with the observed patterns of consumption, host cities can better manage the temporary energy surges associated with the Olympics while avoiding unnecessary long-term investments in infrastructure that may not be fully utilized after the event.

5.2.3. Policy implications

The findings of this study have significant implications for policymakers, particularly in terms of sustainability and energy management during mega-events. First, policymakers should strengthen environmental regulations to ensure that future Olympic Games are hosted in a manner that prioritizes sustainability. For instance, governments could mandate green building certifications for all Olympic-related infrastructure and enforce strict carbon-neutral commitments for transportation, energy use, and construction projects. Such policies would help mitigate the environmental impacts of hosting the Olympics and align with global climate goals. Second, governments and practitioners should foster public-private partnerships (PPPs) to encourage collaboration between public institutions and private energy companies. These partnerships could lead to the development of innovative, sustainable energy solutions, such as smart grids, solar farms, and waste-to-energy facilities. By involving private sector expertise and investment, governments can reduce financial burdens while promoting technological innovation to address energy needs during and after the Olympics. Third, policymakers can use the lessons learned from the temporary energy surges associated with the Olympics to inform broader energy policies. Mega-events provide a unique opportunity to study how energy systems respond to large-scale, predictable demand shocks. This knowledge can be applied to design more resilient energy systems capable of handling future demand fluctuations caused by other factors, such as natural disasters or economic crises. By implementing these recommendations, policymakers can ensure that hosting the Olympics contributes not only to short-term success but also to long-term environmental, economic, and social benefits.

5.3. Limitations and future research

However, our study is not free from limitations. One limitation of this study is its reliance on national-level data, which may mask important regional or city-specific differences in energy consumption. The primary effects of Olympic hosting are likely to be concentrated in the host city and its immediate surroundings, where infrastructure development and event-related activities are most intensive. By focusing on national averages, the analysis may underestimate or overlook these localized surges in energy demand, as well as potential disparities in how different regions within a country experience the impacts of the Games. To address this, future research should utilize more granular, subnational, or city-level data to better capture the localized effects of Olympic hosting. By analyzing energy consumption patterns within host cities and comparing them to national trends, researchers can provide a more nuanced understanding of where and how the most significant energy impacts occur. This approach would help policymakers and planners target sustainability measures more effectively and ensure that strategies are tailored to the areas most affected by Olympic preparations and events.

A second limitation acknowledges the mismatch between certain specific Olympic contexts, such as China's 2022 Winter Olympics—-where facilities were completed by October 2021, yet the Games occurred in February 2022—and the strict one-year framework employed in this study. National energy consumption data are generally reported on an annual basis, reflecting cumulative energy usage over the course of a full year. As a result, sub-annual or event-specific analyses are often impractical in a cross-national study where consistency and comparability are paramount. Under these conditions, a one-year interval serves as a standardized and feasible unit of analysis, effectively capturing broader shifts in energy consumption across all 78 host countries represented in the dataset. Nonetheless, future research would greatly benefit from leveraging monthly national energy data—where such data can be widely obtained among hosting nations. This fine-grained temporal resolution would allow scholars to examine variations in energy use tied more directly to specific months of Olympic preparation, hosting, and post-event activities.

A third limitation concerns the degree to which the difference-in-differences framework can account for exogenous shocks or policy interventions that may coincide with Olympic years, potentially influencing energy consumption trends. Examples include substantial economic disruptions, evolutions in environmental policies, or global events such as the COVID-19 pandemic. Tokyo's 2021 Summer Olympic Games, for instance, were associated with a notably low carbon footprint of 2.73 Mt, largely attributable to pandemic-related curtailments in international travel, reduced spectator attendance, and scaled-back operations, alongside Japan's pursuit of carbon neutrality goals [32]. These factors collectively curtailed energy consumption by reducing transportation requirements and limiting the energy intensity of necessary infrastructure and operations in both the preparatory and hosting periods. Future work could expand upon the present analysis by incorporating a wider array of explanatory variables, including geopolitical developments, industrial activity, renewable energy uptake, and national legislation shifts. Integrating these factors would help to isolate the specific impact of hosting the Olympics, thereby bolstering causal inference and offering a more comprehensive insight into the broader environmental and societal implications of hosting mega-events.

A final limitation of our study is the restricted temporal and geographic coverage, which spans only from 1970 to 2022 and includes 78 countries, 18 of which have hosted either the Summer or Winter Olympic Games (or both). While this represents a substantial dataset, it excludes certain countries that have hosted the Olympics, such as Bosnia and Herzegovina, which hosted the 1984 Winter Olympics in Sarajevo. The omission of Bosnia and Herzegovina is primarily due to the lack of available data for the dependent variable, as the country is not included in the dataset used for the operationalization of energy consumption per capita. Additionally, many other countries—particularly those that are not G20 or OECD members and are often classified as developing countries—are also excluded from the dataset. This limitation means that the control group characteristics may not be fully representative of countries that have not hosted the Olympics. As a result, the findings may be biased toward trends observed in more economically developed countries with more robust energy data reporting. The exclusion of developing countries limits the study's ability to generalize its findings across a broader range of nations, particularly those with different economic structures, energy systems, and infrastructural capacities. To address these issues, future research - once it is available - should aim to expand the dataset to include a more diverse range of countries, particularly developing countries, to ensure that the control group better reflects global conditions. This could involve utilizing alternative data sources, such as satellite-based indicators of energy use. By expanding the geographic and economic diversity of the dataset, future studies can provide a more inclusive and representative analysis of the energy impacts of hosting the Olympics, offering insights that are applicable to a wider range of countries.

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CRediT authorship contribution statement

Jeremy KO: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anthony Chun-Fung CHEUNG:** Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Chun Kai LEUNG:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis. **Joseph Francis WONG:** Writing – review & editing, Validation, Project administration. **Wai-Kit MING:** Writing – review & editing, Supervision, Funding acquisition.

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.

Appendix

Table A1, Table A2, Table A3.

Table A1
Correlation Matrix.

	Energy Per Capita	Pre-Host Year	Host Year	Post-Host Year	Economic Development	Globalization	FDI	Democracy	Population Density	Oil Reserves
Energy Per Capita	1.0000									
Pre-Host Year	0.0466*** (0.0086)	1.0000								
Host Year	0.0491*** (0.0056)	−0.0078 (0.6615)	1.0000							
Post-Host Year	0.0516*** (0.0036)	−0.0076 (0.6683)	−0.0075 (0.6746)	1.0000						
Economic Development	0.6181*** (0.0000)	0.0519*** (0.0034)	0.0564*** (0.0015)	0.0608*** (0.0006)	1.0000					

(continued on next page)

Table A1 (*continued*)

	Energy Per Capita	Pre-Host Year	Host Year	Post-Host Year	Economic Development	Globalization	FDI	Democracy	Population Density	Oil Reserves
Globalization	0.3850***	0.0388**	0.0411**	0.0482***	0.8334***	1.0000				
	(0.0000)	(0.0287)	(0.0206)	(0.0066)	(0.0000)					
FDI	0.0998***	−0.0269	−0.0197	−0.0180	0.3112***	0.4367***	1.0000			
	(0.0000)	(0.1297)	(0.2677)	(0.3096)	(0.0000)	(0.0000)				
Democracy	0.1047***	0.0507***	0.0610***	0.0593***	0.5003***	0.6436***	0.1447***	1.0000		
	(0.0000)	(0.0043)	(0.0006)	(0.0008)	(0.0000)	(0.0000)	(0.0000)			
Population Density	−0.1376***	−0.0164	−0.0185	−0.0210	−0.0348***	0.0916***	0.1029***	−0.0223	1.0000	
	(0.0000)	(0.3548)	(0.2984)	(0.2377)	(0.0497)	(0.0000)	(0.0000)	(0.2082)		
Oil Reserves	0.2401***	0.0156	0.0145	0.0161	0.1063***	−0.0715***	−0.1215***	−0.2993***	−0.2217***	1.0000
	(0.0000)	(0.3786)	(0.4152)	(0.3633)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	

p-values are in the parathesis.

Table A2
List of countries belonging to the control group.

Algeria	Indonesia	Portugal
Argentina	Iran	Qatar
Azerbaijan	Iraq	Romania
Bangladesh	Ireland	Saudi Arabia
Belarus	Israel	Singapore
Belgium	Kazakhstan	Slovakia
Bulgaria	Kuwait	Slovenia
Chile	Latvia	South Africa
Colombia	Lithuania	Sri Lanka
Croatia	Luxembourg	Sweden
Cyprus	Malaysia	Switzerland
Czechia	Mexico	Thailand
Denmark	Morocco	Trinidad and Tobago
Ecuador	Netherlands	Turkey
Egypt	New Zealand	Turkmenistan
Estonia	North Macedonia	Ukraine
Finland	Oman	United Arab Emirates
Hong Kong	Pakistan	Uzbekistan
Hungary	Peru	Venezuela
Iceland	Philippines	Vietnam
India	Poland	

Table A3
List of countries belonging to the treated group.

Australia	Germany	South Korea
Austria	Greece	Spain
Brazil	Italy	United Kingdom
Canada	Japan	United States
China	Norway	
France	Russia	

Data availability

Data will be made available on request.

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