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Olympic Sports Selection Model Based on Multi-Criteria Decision Making

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Abstract:

This paper develops a comprehensive mathematical model for evaluating sports at the Brisbane 2032 Olympic Games by combining six key factors that meet the IOC criteria. The model is a three-dimensional 'Classification - Entropy Weighting TOPSIS' framework, which evaluates each unique or non-specialized sport by determining the target weights from the three dimensions of popularity, environmental impact, and fairness through the entropy weighting method, followed by the TOPSIS method of composite ranking. The model was also tested on historical Olympic data, analyzing recently added/removed sports (2020-2028) and traditional core sports (in existence since 1988). The model can successfully explain the continued creation of new sports. Based on the model analysis, we predict that Rugby Union and Roker could be added to the Brisbane Olympics in 2032 and that eSports and Paragliding could be included in the Olympic program after 2036. The model balances traditional Olympic sports and modern sporting trends well and can guide Olympic program decisions.

Keywords: Multi-criteria decision making; TOPSIS-Entropy weight method; Olympic sports selection; Sensitivity analysis.

1. Introduction

1.1 Problem Background

Recent changes in Olympic events reflect their evolution with the times: in 2020, modern sports like skateboarding, sport climbing, and surfing were introduced; the 2024 Paris Olympics will remove Karate but add Breaking (breakdancing); the 2028 Los Angeles Olympics will add flag football, lacrosse, and coastal rowing, while baseball and softball will return to the Olympics after a 20-year absence.

These changes reflect the Olympics' attitude of pursuing innovation while maintaining traditions. Still, they also bring a series of challenges: How can we scientifically evaluate whether a sport is suitable for the Olympics? How can we find the balance between tradition and innovation? How can we ensure that new additions attract audiences and uphold the Olympic spirit? To address these issues, we must establish a scientific evaluation system, develop mathematical models to assess sports, verify the model's reliability using existing events, and ultimately provide reasonable recommendations for the 2032 Brisbane Olympics.

Fig. 1 SDEs

1.2 Restatement of Questions

We developed a six-factor evaluation model for Olympic sports, which was validated through testing on recent Olympic changes and used to assess potential sports for Brisbane 2032, completing a bit of task-solving:

Task 1: Identify Assessment Factors.List and explain all essential factors for evaluating Olympic sports.

Task 2: Develop Evaluation Model. Create a mathematical model to evaluate whether SDEs are suitable for the Olympics.

Task 3: Test the Model. At least three recently added/removed SDEs (2020, 2024, 2028 Olympics). Validate the model by evaluating diverse sports to explain their current Olympic status.

Task 4: In order of priority, recommend three new SDEs for the 2032 Brisbane Olympics and explore potential sports for future inclusion.

Task 5: Test model stability, analyze factors leading to high scores, and evaluate whether these factors represent model strengths or weaknesses.

Task 6: Submit a concise proposal to the IOC, explaining the model's evaluation results and specific recommendations in plain language. Include an overview of model principles, analysis of sports evaluation results, and justified suggestions for adding or removing events.

1.3 Main Work

Considering the background, we analyze and solve the problems step-by-step.

1. For task 1: We developed a comprehensive six-factor evaluation system based on the IOC's evaluation criteria to assess Olympic sports. These factors were selected for data accessibility and direct correspondence to the IOC's core standards. The system includes metrics for global participation, geographical diversity, gender equality, integrity measures, environmental adaptability, and innovation appeal; each quantified through specific formulas to ensure objective evaluation.

2. For task 2: The International Olympic Committee (IOC) faces a multi-dimensional decision-making challenge in selecting sports for the 2032 Brisbane Olympics. Therefore, we have developed an evaluation model using a multi-level" Classification-Entropy Weight-TOPSIS" strategy. First, we categorized the evaluation indicators into three dimensions: Popularity (number of participating countries and continents), Environmental Friendliness (environmental impact score), and Equality (gender equality indicator and sanction violations). This classification ensures comparability among similar indicators while avoiding the potential irrationality of direct comparisons between indicators of different natures. Within each category, the entropy weight method is used to determine the weights of indicators, fully utilizing the objective information reflected in the data and reducing bias from subjective judgments. Finally, the TOPSIS method is applied to conduct comprehensive evaluations for each dimension, and the final evaluation results are obtained through the arithmetic mean of the three-dimensional scores, providing quantitative criteria for the IOC's sports selection.

3. For task 3: We implemented a bidirectional validation approach to test our model's reliability. That included analyzing recent Olympic changes (2020-2028), evaluating traditional core sports, and using a comprehensive bidirectional identification method to verify the model's explanatory power for recent IOC decisions and its consistency

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with fundamental Olympic principles.
4. For task 4: Through model analysis, we identified Breaking, Rugby Union, and Roque as priority recommended sports for the 2032 Brisbane Olympics. Meanwhile, emerging sports like Esports and Paragliding may appear in the Olympics beyond 2036.
5. For task 5: We conducted sensitivity analysis by adjusting weights at different levels and observing changes in model results. The study shows that recommended sports like Breaking maintain high rankings under different weight combinations, confirming the model's robustness.
6. For task 6: We drafted a recommendation letter to the IOC detailing the model's construction logic, evaluation process, and recommended results. The letter emphasizes how our recommended sports align with the Olympics' modernization needs.
To better arrange our process for solving problems, the flow diagram of our work is shown in Figure 2.

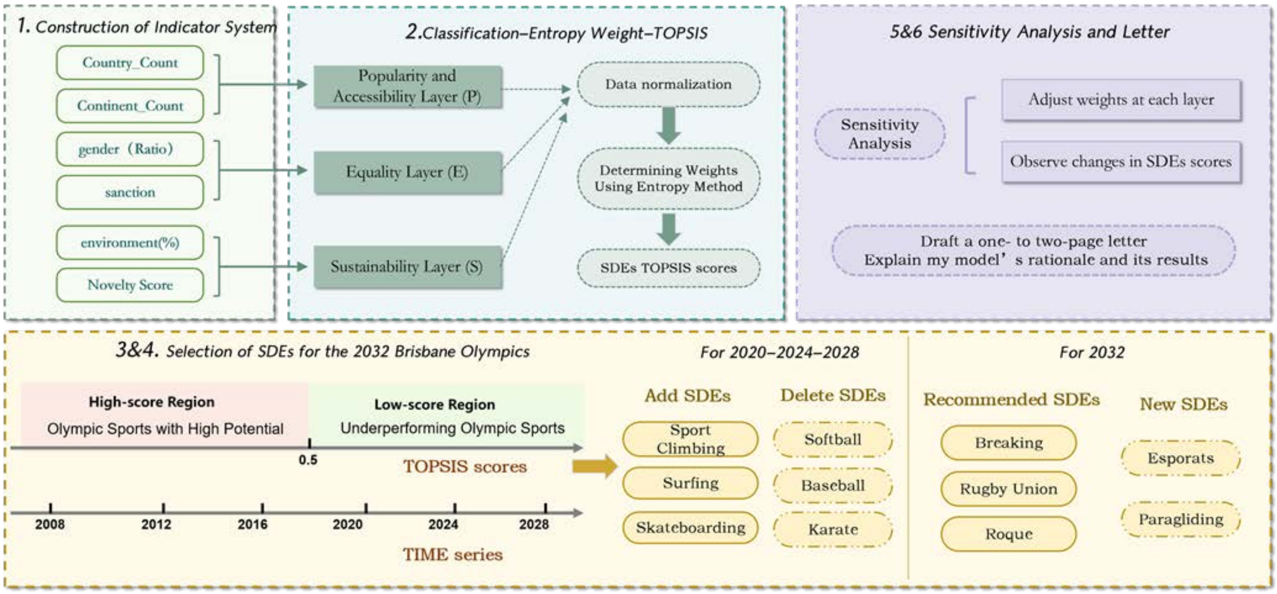

Fig. 2 The flow diagram of the main work

2. Assumptions and Justifications

Several assumptions and justifications are listed below to simplify the problem,
Assumption 1: Data Completeness Assumption: All input data is assumed to be accurate, complete, and highly relevant to the research problem.
Assumption 2: Independence of Criteria Assumption: Each evaluation criterion is assumed to be independent, with no significant correlations or dependencies between them.
Assumption 3: Temporal Static Assumption: The evaluation standards used in the model are assumed to remain relatively stable over time, making the analysis applicable for future Olympic evaluations.
Assumption 4: Balanced Weight Allocation Assumption: The weights calculated through entropy-based methods are assumed to genuinely reflect the importance of each criterion in the decision-making process.

3. Notations

Note: The following table presents selected notation explanations, while additional symbols are defined within the context of the main text.

Table 1 Notations used in the paper and explanations

Notation	Explanation
C	The sum of unique participating countries
G	The sum of active continents
D	Total number of recorded doping violations
E	Environmental adaptability score
N	Novelty score

P	Popularity and accessibility layer
P1	The ratio of participating countries
P2	The ratio of continents covered
N0	Total number of IOC member countries
N1	Number of participating countries
T1	Number of ban incidents
yij	Standardized value for positive indicators
xij	The original value for indicators
xij'	Transformed value for indicators

4. Key Factors Assessment and Considerations

As the Olympic Games evolve, the IOC must maintain traditional values while adapting to modern sports development trends, necessitating a scientific and objective evaluation system. Therefore, we have transformed IOC's evaluation criteria into quantifiable and comparable specific indicators. Our team has identified six key evaluation factors based on the evaluation criteria provided by the International Olympic Committee (IOC). These factors not only possess excellent data accessibility but also directly correspond to IOC's core evaluation criteria.

4.1 Number of Participating Countries (Country Count)

The Number of Participating Countries is a crucial metric for evaluating Olympic sports, directly addressing the IOC's inclusivity requirements and measuring global accessibility. With its clear unit of measurement in country count, this quantitative factor provides concrete evidence of a sport's international reach and popularity, making it an essential consideration in the evaluation process. Count the unique number of participating countries in the sport:

$$C = \sum \text{UniqueCountries} \quad (1)$$

4.2 Number of Continent covered (Continent Count)

The Number of Participating Continents complements the country count by ensuring true geographical diversity in Olympic sports. This factor explicitly addresses the IOC's representation requirement across at least four continents, safeguarding against regional concentration and promoting genuine global participation in the Olympic movement. Count of continents where the sport is officially practiced:

$$G = \sum ActiveContinents \quad (2)$$

4.3 Gender Participation Ratio (Gender)

Gender equality is one of the core objectives of the modern Olympic Games and corresponds to the criterion of "gender parity." An SDE with a ratio of men to women close to 1:1 indicates a high degree of gender inclusiveness; an imbalance in the gender ratio may suggest that the SDE has limitations in attracting athletes of different genders. Therefore, sex ratio data was chosen to assess gender equality in each program quantitatively.

To address gender balance issues, we can define an "equilibrium score" to measure how close the male-to-female ratio is to ideal. The ideal male-to-female ratio is 1, so we can use the following formula to calculate this score:

$$EquilibriumScore = \frac{1}{|MaleFemaleRatio - 1| + ?} \quad (3)$$

4.4 Historical Doping Cases

Historical Doping Cases in SDEs represent the number of doping violations detected in each sport, discipline, or event throughout Olympic history. This quantitative metric, measured by the accumulated number of confirmed doping cases, is a crucial indicator of the integrity challenges within specific Olympic events.

$$D = \sum DopingCases \quad (4)$$

4.5 Environmental Adaptability of SDEs (Environment)

This factor determines the immediate and long-term viability of event organization and directly affects the sustainable implementation of SDE.

E=Geography(1-5)+Climate(1-5)+Cultural(1-5) (5)

4.6 Novelty Score of Sports (Novelty Score)

The Novelty Score is a comprehensive indicator evaluating the innovation and appeal of Olympic sports, rated on a 1-5 scale. This metric considers several aspects: the modernization level of sports rules, spectator appeal of

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competition formats, attraction to young audiences, and alignment with contemporary sports development trends. A higher novelty score indicates strong innovative vitality and market potential, aligning with the IOC's strategic goals of attracting new generations of viewers and maintaining the Olympics' continued vitality.5-point scale evaluation (1=low, 5=high):

$$N=RuleModernization(1\text{-}5)+SpectatorAppeal(1\text{-}5)+YouthAttraction(1\text{-}5)+TrendAlignment(1\text{-}5) \quad (6)$$

Based on the evaluation criteria provided by the International Olympic Committee (IOC), our team identified six key evaluation factors, as shown in Figure 3.

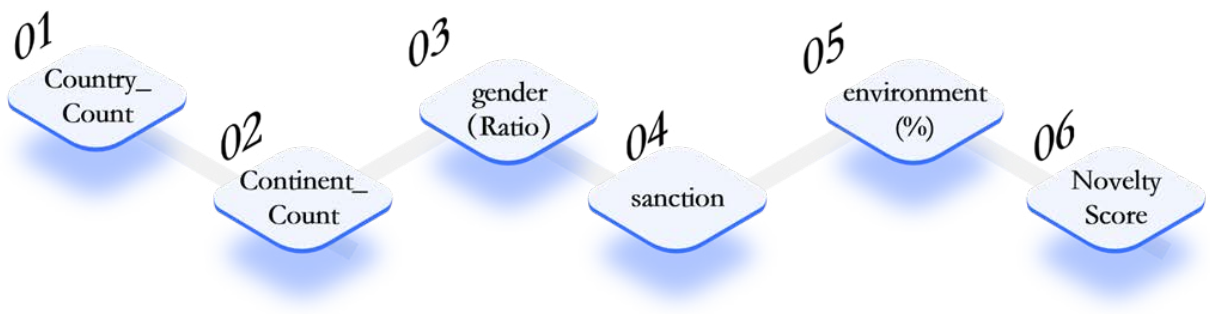

Fig. 3: The key evaluation factors

These factors provide a quantitative scientific basis to effectively support the IOC in selecting and optimizing SDEs aligned with the Olympic Games' core values. The model we have constructed based on these factors will be used to further quantitatively analyze the suitability of the SDEs and provide decision support for selecting projects for the Brisbane 2032 Olympic Games.

5. Modelling of assessment

5.1 The Characteristics of IOC Evaluation Criteria

Through observation of the IOC's evaluation criteria, we find that these standards exhibit characteristics of multiple criteria, indicator heterogeneity, and dynamism, specifically as follows:

1. Multi-criteria nature: The IOC's evaluation standards involve various dimensions:

(1) Popularity dimension: Need to consider the global development of sports

(2) Equality dimension: Need to assess gender equality and competitive fairness

(3) Sustainability dimension: Need to consider environmental impact and social responsibility

2. Indicator heterogeneity: Various assessment indicators have different units of measurement and properties:

(1) Quantitative indicators: The number of participating countries, continents covered, etc.

(2) Qualitative indicators: Such as degree of gender equality, environmental friendliness, etc. (requiring quantification)

3. Dynamism: The development of sports has a temporal dimension

(1) Historical continuity: The preservation value of traditional sports

(2) Innovation: Development potential of emerging sports

5.2 Construction of Hierarchical Entropy Weight TOPSIS Evaluation Model

In evaluating SDEs, multiple-dimensional indicators such as popularity, competitiveness, and spectator appeal must be considered simultaneously, with hierarchical relationships between these dimensions. Therefore, this paper adopts the hierarchical entropy weight TOPSIS method to construct the evaluation model, which automatically determines the importance of each indicator based on actual data, avoids subjective judgments, and provides reasonable comprehensive evaluation results.

5.2.1 Construction of Indicator System

Based on the above observations, we constructed a hierarchical indicator system:

1. Popularity and Accessibility Layer (P)

In this layer, we measure the global influence of SDEs, $P = \{P_1, P_2\}$. P_1 represents the number of participating countries (Country Count); P_2 represents the number of continents covered (Continent Count).

The specific quantification method is as follows:

$$P_1 = \frac{N_1}{N_0} \times 100\% \quad (7)$$

$$P_2 = \frac{N_2}{5} \times 100\% \quad (8)$$

N_0 represents the total number of IOC member countries, N_1 represents the number of participating countries, and

N_2 represents the number of continents covered.

2. Sustainability Layer (S)

Our definition of sustainability combines environmental impact and novelty, where:

$$S = \omega_1 S_1 + \omega_2 S_2 \qquad (9)$$

S_1 represents the degree of environmental impact (environment); S_2 represents the novelty score of the sport; ω_1 and ω_2 are the weights determined by the entropy weight method. Environmental and novelty impact scoring (S_1) uses a 1-5 scale, as shown in Table 2:

Table 2 Sustainability Layer Scoring Scale

Score	Novelty Level	Environmental Level
1	Traditional sports, no modernization	Extremely high environmental impact
2	Traditional sports, minimal innovation	High environmental impact
3	Mixed traditional and modern elements	Medium environmental impact
4	Modern adaptations dominant	Low environmental impact
5	Highly innovative with youth appeal	Minimal environmental impact

3. Equality Layer (E)

Consider gender equality and competitive fairness E = {E_1, E_2}, where E_1 represents the degree of gender equality (gender), and E_2 represents competitive fairness (sanction), considering ban incidents in the past five years. The specific formulas are as follows:
Gender equality measurement:

$$E_1 = \frac{min(E_m, E_f)}{max((E_m, E_f)} \times 100\% \qquad (10)$$

$$E_2 = (1 - \frac{T_1}{T_0}) \times 100\% \qquad (11)$$

E_m represents the number of male participants, N_1 represents the number of female participants, T_0 represents the total number of competitions, and T_1 represents several ban incidents.

5.2.2 Intra-layer Weight Calculation

Based on IOC's multi-dimensional decision requirements, we adopt a "Classification-Entropy-TOPSIS" hierarchical evaluation strategy and calculate weights through the following steps:
(1) Data Standardization:
For positive indicators (e.g., Country Count, Continent Count):

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} ?x_{ij}^2}} \qquad (12)$$

For indicators requiring positive transformation (e.g., environmental impact, sanction count):

$$x_{ij}\bar{i} = \max_i ? x_{ij} - x_{ij} \qquad (13)$$

(2) Entropy Weight Calculation:
For indicators j in Popularity(P) layer (Country Count, Continent Count), Sustainability(S) layer (environment), and Equality(E) layer (gender, sanction):

$$e_{kj} = -\frac{1}{ln(m)} \sum_{i=1}^{m} ? p_{ij} ln(p_{ij}) \qquad (14)$$

$$w_{kj} = \frac{1 - e_{kj}}{\sum_{j \in layerk} ?(1 - e_{kj})} \qquad (15)$$

(3) Inter-layer Weight Balance:
Each layer is assigned an equal weight (1/3) to ensure balanced consideration of Popularity, Sustainability, and Equality dimensions in the evaluation.
Therefore, the final weight for each indicator is:

$$W_{kj} = \frac{1}{3} \times w_{kj} \qquad (16)$$

5.3 Comprehensive Evaluation Model

Based on the IOC's multi-dimensional decision requirements for the 2032 Brisbane Olympics, we construct a TOPSIS-based evaluation model that integrates popularity, sustainability, and equality factors; the flowchart of the comprehensive evaluation model is shown in Figure 4, which includes seven key steps:

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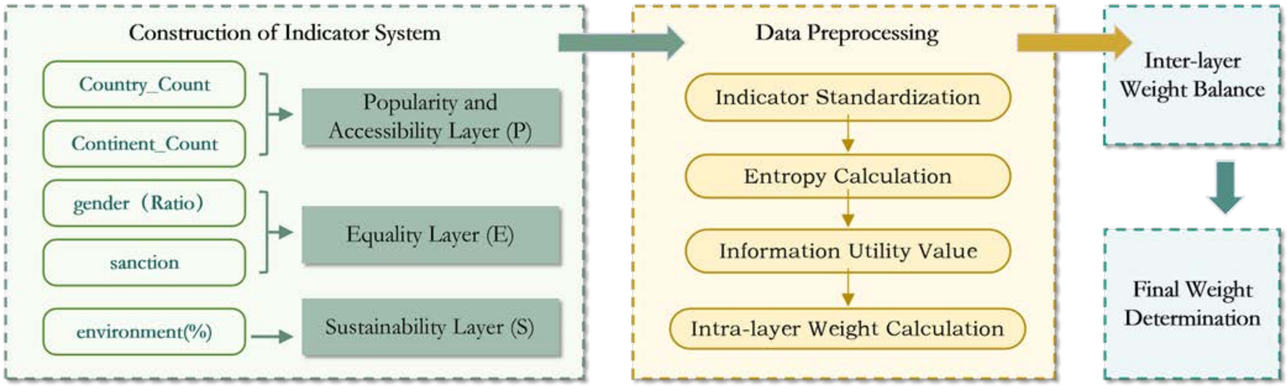

Fig. 4 The flowchart of the Comprehensive Evaluation Model

(1) Calculate weighted normalized values for each SDE indicator:

$$v_{ij} = W_{kj} \times y_{ij} \tag{17}$$

(2) Determine ideal reference points:

$$\begin{aligned} &\text{Positiveidealsolution(bestcase)}: v_j^+ = \max_i ? v_{ij} \\ &\text{Negativeidealsolution(worstcase)}: v_j^- = \min_i ? v_{ij} \end{aligned} \tag{18}$$

Which represent the hypothetical best and worst SDEs against which actual sports are compared.

(3) Calculate distances for each SDE:

$$\begin{aligned} &\text{Distance to best case}: D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \\ &\text{Distance to worst case}: D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \end{aligned} \tag{19}$$

(4) Calculate the final evaluation score:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{20}$$

The evaluation score C_i (ranging from 0 to 1) comprehensively measures each SDE's alignment with Olympic values through global accessibility, environmental sustainability, and competitive fairness, where a higher score indicates better overall suitability for Olympic inclusion.

5.4 Comprehensive Evaluation Results of Olympic SDEs

Finally, as shown in Figure 5, the left side features a pie chart using the Morandi color palette to display the distribution proportions of six weight indicators. In contrast, the right side presents a bar chart comparing TOPSIS scores, with the data divided into two groups (Top 5 SDEs and Bottom 5 SDEs).

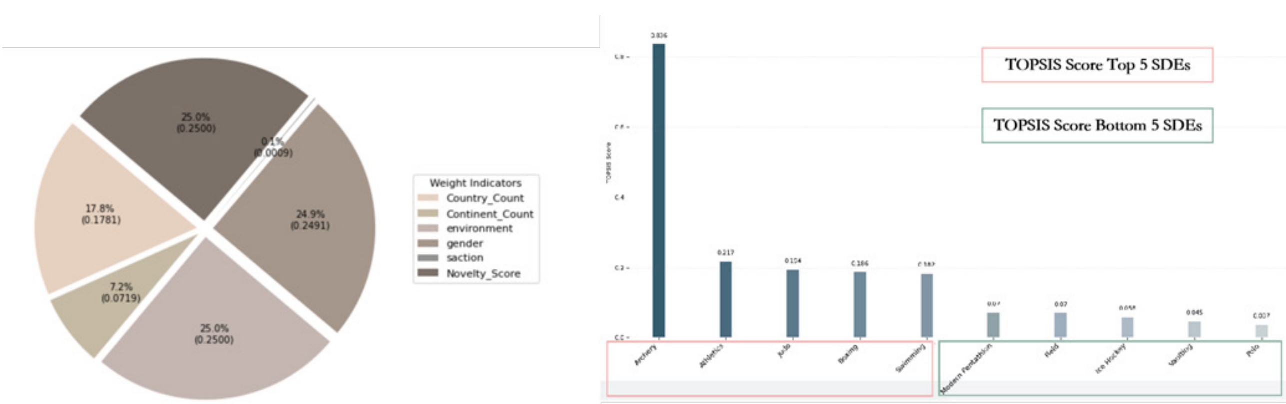

Fig. 5 Weight Indicators Distribution and TOPSIS Score Comparison

The TOPSIS model's weight distribution shows that environmental adaptability (0.25), gender equality (0.2491), and innovation (0.25) dominate the evaluation system, aligning closely with the IOC's strategic goals of promoting Olympic sustainability, gender equality, and youth engagement. That is followed by the number of participating countries (0.1781), reflecting the importance of global participation. The relatively low weights of continental distribution (0.0719) and sanctions (0.0009) indicate that geographical spread and violations are not primary considerations.

The scoring results reveal that archery leads significantly (0.836), likely due to its excellent performance in key dimensions such as environmental adaptability, gender equality, and innovation. Traditional core sports like athletics, judo, boxing, and swimming maintain stable scores in the 0.18-0.22 range, reflecting their foundational status in the Olympics. Meanwhile, sports like modern pentathlon, field hockey, and equestrian scoring below 0.07 align with their practical limitations in global popularity and innovation potential, providing quantitative evidence for understanding why certain sports might be adjusted or removed from the program.

6. Model feasibility validation

After establishing our evaluation model based on the Entropy Weight-TOPSIS method, model validation becomes crucial for ensuring model reliability. By testing two representative groups of sports: recent changes (such as Karate and Sport Climbing from 2020-2028) and traditional core sports (those existing before 1988, like Athletics and Swimming). We can comprehensively validate the model's explanatory and predictive power. This dual validation approach verifies whether the model accurately reflects the IOC's modern decision-making logic (through recent changes) and the Olympic core values (through traditional sports).

Based on the distribution characteristics and trends of model scores, we adopted a bidirectional identification method to discover SDEs for addition or removal. For the high-score region, we focus on non-Olympic sports with comprehensive scores close to existing Olympic sports, indicating strong potential for inclusion. For example, Breaking, as a sport reflecting modern culture, has shown a steady upward trend in scores since its 2020 evaluation, demonstrating strong development potential, which validates its introduction in the 2024 Paris Olympics. For the low-score region, we identify existing sports with scores significantly below average or showing declining trends, suggesting candidates for adjustment or removal. A typical example is Karate, despite being temporarily introduced as a traditional Japanese martial art in the 2020 Tokyo Olympics. Its score rapidly declined and remained low after its introduction, highly consistent with its exclusion from the 2024 Paris Olympics.

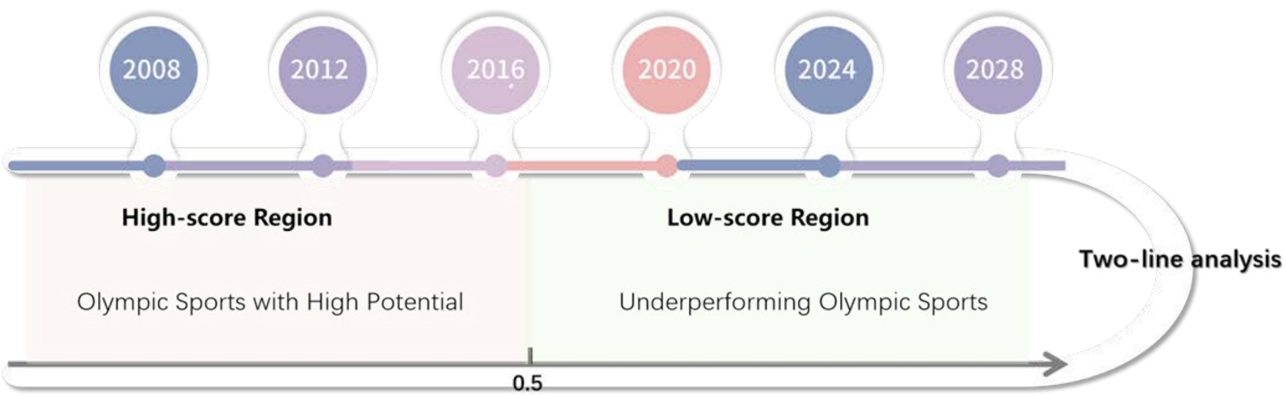

Fig. 6 Analysis of Olympic Sports Scoring

After obtaining standardized scores between 0-1 for each sport through TOPSIS calculation, we implemented a multi-layered visualization strategy: the main graph uses an area chart to display the score distribution curve for all sports in descending order; for key sports with recent changes (such as Sport Climbing, Surfing, Skateboarding added in 2020, removed Karate, and returning Baseball/Softball), we used small time series graphs showing their trajectories from 2008-2028, visually presenting the dynamic changes. Figure 7 presents a hierarchical visualization scheme that demonstrates the overall evaluation results and highlights the historical transitions of key sports.

The evaluation results based on the Entropy Weight-TOPSIS model reveal evident hierarchical characteristics. In the main graph, scores gradually decrease from a maximum of approximately 0.8 on the left to near zero on the right, with most sports concentrated in the 0.1-0.2 score range, demonstrating the scoring system's good discriminatory power. Notably, the three sports added to the 2020 Tokyo Olympics - Sport Climbing, Surfing, and Skateboarding (cyan frames) - all show similar development trajectories: rapidly rising after the introduction and stabilizing at a moderate level of around 0.4, validating the IOC's decision to introduce these modern sports.

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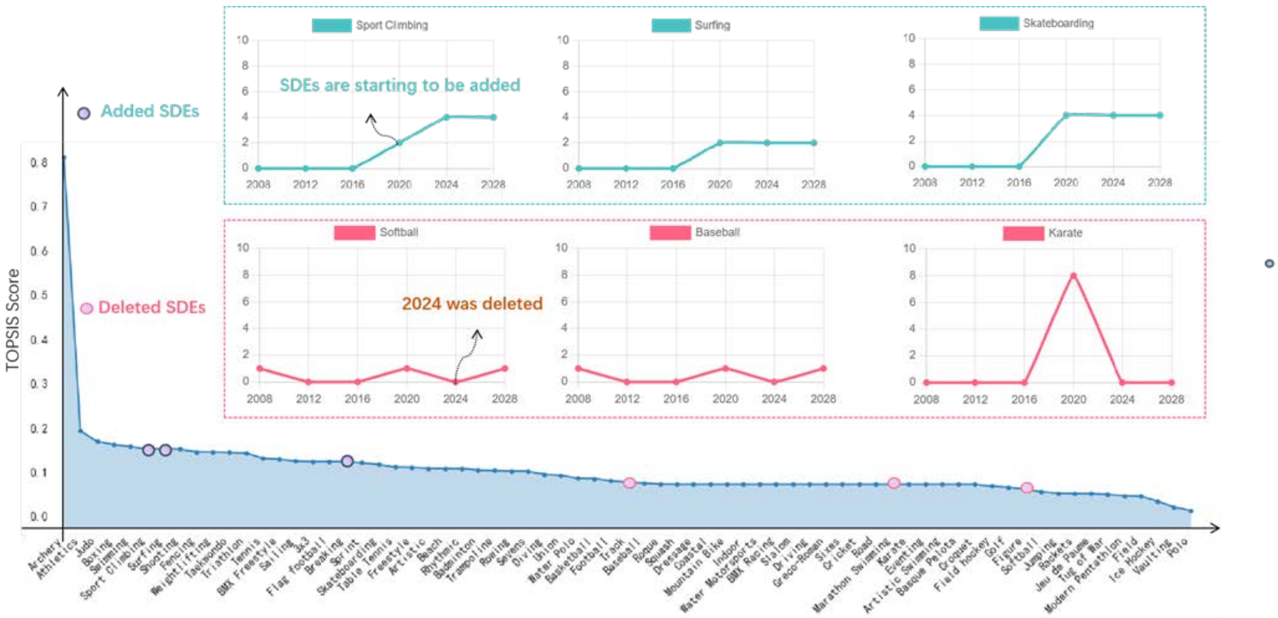

Fig. 7 Evaluation Results and Dynamic Analysis of Key Olympic Sports

Regarding exceptional cases (pink frames), Karate shows a "flash in the pan" pattern, with scores dropping sharply after its brief introduction in 2020, confirming its removal in 2024; in contrast, Softball and Baseball, despite lower scores, maintain stability, possibly supporting their return decision for the 2028 Los Angeles Olympics. These findings validate the model's predictive capability and provide an objective basis for future Olympic program adjustments.

Further analysis of the score distribution reveals several key insights. The exponential decay pattern in the main graph suggests a natural hierarchy among Olympic sports, with a select few achieving exceptional scores above 0.4. This distribution pattern effectively differentiates between high-performing and standard-performing sports, providing a clear framework for evaluation. The clustering of most sports in the 0.1-0.2 range indicates a stable baseline for established Olympic events.

The consistent trajectory patterns of newly added sports (Sport Climbing, Surfing, and Skateboarding) suggest a successful integration strategy by the IOC. Their rapid ascension and stabilization at the 0.4 score level may be a benchmark for evaluating future sports additions. Meanwhile, the contrasting patterns between Karate and Baseball/Softball highlight the importance of considering peak performance and long-term stability in program decisions.

7. Model evaluation results

7.1 The most suitable three SDEs for Brisbane 2032 New Sports

We exclude sports not included in the LA 2028 Olympic program and re-evaluate other SDEs using our three-layer TOPSIS model. The evaluation generates comprehensive scores based on Popularity (P), Sustainability (S), and Equality (E) criteria. Finally, we rank the sports based on their TOPSIS scores, recommending the top three for inclusion in the Brisbane 2032 Olympics.

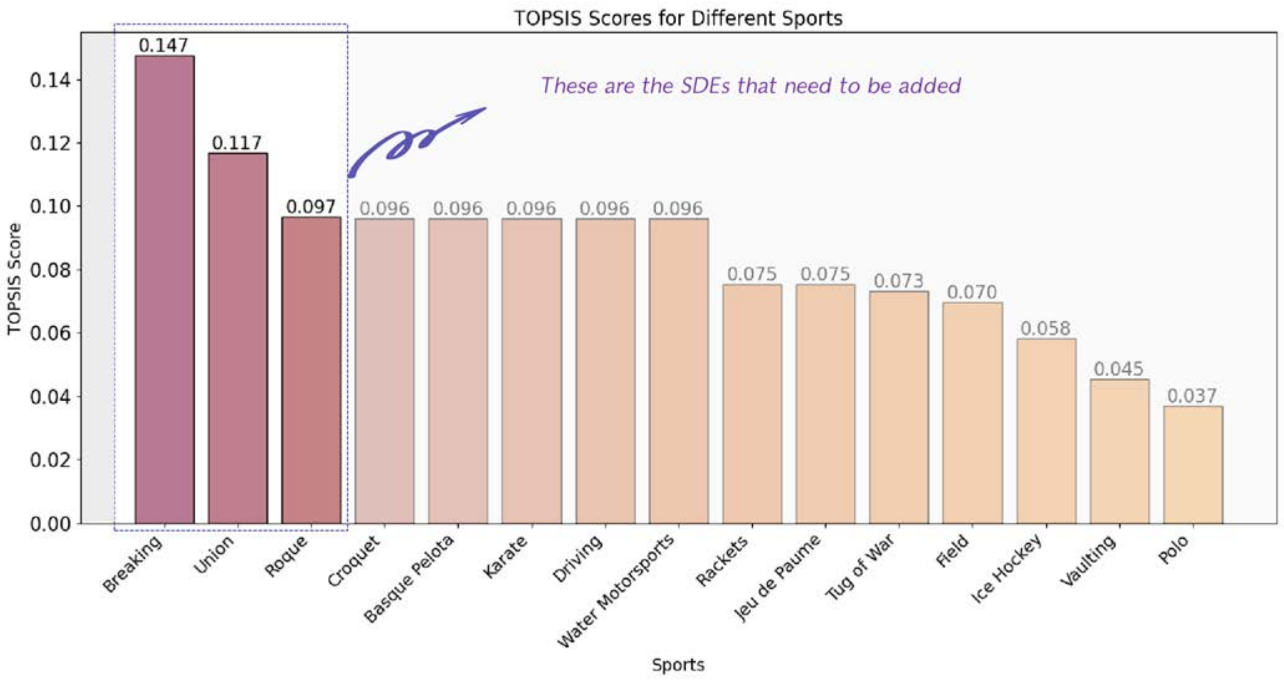

Figure 8: TOPSIS scores

Based on our TOPSIS evaluation of sports not included in LA 2028, we identified three top candidates for Brisbane 2032. Breaking leads with the highest score of 0.147, demonstrating strong performance across our evaluation criteria, particularly in youth appeal and cultural innovation. Rugby Union follows with a score of 0.117, benefiting from its established popularity in the Asia-Pacific region and strong international federation governance. Roque ranks third with 0.097, showing promise in environmental sustainability and gender equality, though with room for development in global participation.

7.2 Proposed New SDE for Brisbane 2032

Our analysis identified several promising candidates. Ultimate Frisbee, with its TOPSIS score of 0.173, demonstrates excellent performance in gender equality and environmental impact, making it a strong contender for Olympic inclusion. Similarly, Esports (TOPSIS score: 0.172) has shown remarkable potential, particularly in engaging younger audiences and offering accessible participation opportunities across geographical boundaries.

While Paragliding was also evaluated, its relatively low TOPSIS score of 0.104 and concerns regarding weather dependency, safety requirements, and venue limitations suggest it may not be optimal for Olympic inclusion.

8. Conclusion

This paper analyses the Olympic Movement regarding six key factors: participating countries, continental coverage, gender participation, historical doping cases, environmental adaptation, and sporting novelty. A multi-level 'Classification - Entropy Weights - TOPSIS' model was developed to assess traditional and emerging sports' popularity, ecological friendliness, and equality. The target weights determined through the entropy weighting method highlight the increasingly important role of global participation and environmental adaptability in sports evaluation. Traditional sports, such as archery, excelled in the TOPSIS ranking, scoring the highest in the assessment at 0.836; emerging sports, such as skateboarding and sport climbing, have excellent growth potential. The model was also used to forecast potential additions to the 2032 Brisbane Games. The model can guide Olympic programs to make the Games more sustainable and inclusive.

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