

# Sustainable Adaptive Reuse of Industrial Heritage for Urban Resilience: A Multi-objective Collaborative Optimisation Framework and Place-Value Enhancement Mechanism

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**Abstract**—The post-industrial cities are experiencing serious resilience challenges due to globalization, deindustrialization, and climate change. The adaptive reuse of industrial heritage as a critical carrier of urban memory and spatial structure is not only about cultural conservation but also one of the most important ways of improving urban resilience and attaining sustainable development. Nonetheless, there are examples of modern adaptive reuse practices that tend to extreme ends of the scale, either being limited to commercialisation only or static preservation, ignoring social equity, i.e., the displacement of original residents in the process of gentrification, and environmental costs, i.e., the high amount of embodied carbon emissions. In order to fill this gap, this paper suggests that a low-cost and reproducible decision-making and assessment framework can be adopted to combine multi-criteria analysis with place-value improvement. First, an evaluation indicator system of resilience-oriented reuse is developed based on the Entropy-Weight TOPSIS approach that considers five dimensions: economic, social, environmental, infrastructure and institutional resilience. Second, rather than depending on costly field experimentation or parameter-intensive algorithm optimization, a clear scenario-based trade-off analysis is applied to assess carbon impacts of life cycles and socio-cultural value across different retrofit alternatives. Lastly, the discussion of how social innovation facilitates territorial innovation is explored by combining the Analytic Hierarchy Process and SWOT into A'WOT and by simplifying spatial and governance analysis. The case-based application shows that the overall reuse plan has a better-balanced performance than the commercial-development and ecological-conservation plans, and it is possible to enhance the environmental and social resilience by keeping the existing buildings, increasing the number of people involved in the process, and adopting inclusive governance. This paper gives a practical and repeatable decision-making instrument of industrial heritage conservation in the context of everyday research and planning, providing theoretical support that balances environmental advantages and social justice in urban regeneration and resiliency construction.

**Keywords**—Industrial heritage, Adaptive reuse, Urban resilience, Scenario-based evaluation, Entropy-Weight TOPSIS, Place value, Embodied carbon

## I. INTRODUCTION

The process of urbanisation is taking place at a faster pace and therefore cities have to deal with more complicated

external challenges and internal stressors. The projections by the United Nations indicate that by the year 2050, there will be 70 percent of the global population living in cities, whereas today urban areas already use two-thirds of the world energy and produce over 70 percent of the greenhouse gases and half of the solid waste [1]. In this context, promoting urban resilience, which can be described as the capacity of an urban system to retain, alter, and change as it continues to fulfill its main roles in the face of disturbances [2] [3], has become a key concern of the Sustainable Development Goals (SDGs).

Since the post-industrial cities are arranged in space, many industrial heritage sites are now abandoned or poorly utilised and have been identified as key nodes in the process of urban regeneration. The old production machines represent valuable historical and cultural content and huge material resource pools. Nonetheless, industrial heritage is usually confronted with two difficulties in the current context of urban regeneration. First, it can be seen as a barrier to urbanisation and therefore demolished to the last brick and this does not only wipe out the urban history but wastes a significant amount of resources and emits high level of carbon [4]. Second, it can be over-commercialized, and while these kinds of interventions provide short-term financial benefits, they tend to cause gentrification, displacing or alienating the people of the initial community and destroying the community and cultural identity of the area [5].

There is broad acknowledgment of adaptive reuse as one of the best ways to address the stated challenges [6]. It adds further value to historic structures by providing them with a new purpose, thus prolonging their functional lifespan and reducing the significant environmental expenses that would be incurred through new constructions. However, in the face of both global climate change and social equity, a scientifically assessed and optimized reuse plan of the industrial heritage is an acute problem. The available researches are inclined to one-dimensional evaluations either in the form of purely economic feasibility analysis or qualitative discussion of cultural value and do not have a quantitative decision-making structure that considers environmental benefits (e.g., embodied carbon emissions) and social equity and economic vitality at the same time [7].

Considering this, this paper seeks to come up with a cheap and repeatable Multi-objective Collaborative Decision-

making Model of Sustainable Adaptive Reuse of Industrial Heritage with Urban Resilience focus. The main contribution of this paper is three-fold: (1) it builds a framework of urban resilience assessment in five dimensions, i.e., economic, social, environmental, infrastructure, and institutional resilience through the Entropy-Weight TOPSIS approach to offer an objective foundation in scheme choice [8]; (2) it creates a clear-cut trade-off analysis of building life-cycle carbon emissions and local socio-cultural value based on well-defined parameter values and sensitivity tests; and (3) it investigates the interactive relationship between social innovation and territorial innovation and suggests pragmatic governance measures to avoid gentrification and improve place value.

## II. LITERATURE REVIEW

### A. Adaptive Reuse of Industrial Heritage and Sustainability

Adaptive reuse of industrial heritage is a common example of how circular economy principles are applied to the built environment. As Della Spina et al. (2023) stated, abandoned industrial heritage reuse strategies might successfully reactivate the natural, social, and cultural capital in vulnerable settings and act as a starting point of the sustainable urban transition [1]. The construction industry takes up about 39 percent of total world CO<sub>2</sub> emissions and in the fast developing China super-scale construction contributes to 50.9 per cent of the national carbon emissions. In the paper by Huang et al. (2025), it is highlighted that embodied carbon should be included in the assessment of industrial heritage retrofit plans; their comparative study shows that an empathetic adaptive reuse plan could decrease carbon emissions by some 75 percent compared to demolition and reconstruction [4]. Nonetheless, embodied carbon is often marginalized in contemporary evaluation systems, leading to a misjudgment of the environmental benefit of heritage conservation by decision-makers.

When it comes to effective heritage renewal, reviving historical industry structures by scientific adaptive reuse is the way to go in order to balance economic growth and cultural legacy. The main factors of heritage building renewal were summarized by Savoie et al. (2025) who noted that sensible change of function and involvement of the community are important to prevent unproductive restoration of industrial heritage [5].

### B. Urban Resilience Theory and Spatial Regeneration

The basis of the urban resilience theory is the social-ecological system analysis in ecology. Resilience has been described by Folke (2006) as the ability of a system to withstand disturbance and reorganize itself in order to maintain its original functions, structure and feedbacks [2]. Meerow et al. (2016) also broadened the idea to the urban context and stressed the fact that urban resilience is a process that involves several different pathways, such as persistence, transition and transformation [3]. In the context of spatial regeneration, the empirical research conducted by Tang et al. (2023) based on 110 prefecture-level cities of the Yangtze River Economic Belt shows that rationalization and industrial structure upgrading can have important implications in increasing urban resilience, and that the assessment system should consist of five aspects, i.e., economic, social, environmental, infrastructure, and institutional resiliency [6]. Locating industrial heritage reuse into an urban resilience paradigm means that retrofitting is not just the material

reconstruction of space, but a methodical endeavor to improve the strength of a society to withstand the threats of economic downturn and breakdown of society.

The current available literature on urban industrial renewal has also concentrated on the social and territorial value that comes with the regeneration of the heritage. Scaffidi (2024) confirmed that the regeneration of a heritage of industry may bring about positive social and territorial innovations, offering real support to urban resiliency renewal [9]. At the same time, the renewal of industrial heritage is also closely related to the sustainable development of the city over the long term. Mehan (2025) suggested that adaptive reuse of industrial heritage will be a significant driver of urban sustainable development beyond 2030, and it could end the single development mentality restricted by the SDGs [10]. Besides, the cross-regional case studies add value to the theoretical framework of industrial heritage regeneration and urban renewal. Chung and Lee (2023) used the industrial heritage example of Koreans and Taiwanese as the objects of study and identified the high level of mediation played by modern industrial heritage in the process of urban cultural revival and spatial renewal [11].

### C. Multi-criteria Decision-making and Optimisation in Heritage Conservation

Due to the contradictory requirements of various stakeholders involved in industrial heritage retrofitting, Multi-Criteria Decision-Making (MCDM) approaches have become a common phenomenon. Qiu et al. (2026) integrated both the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) in order to develop a multi-factor evaluation system of industrial heritage preservation in Hangzhou, which allows spatial visualization of value estimates [7]. Nevertheless, these spatial approaches might demand particular information and computer capability; hence, this paper will be based on their logic of indicators but in simpler tabular form that can also be applied using open records, simple field inspection and spreadsheets computation.

Entropy-weight TOPSIS approach is an experienced and objective comprehensive assessment model that has found its wide use in the assessment of urban development studies. It is an appropriate technique that has been applied in relevant studies to quantify the green development potential of coastal cities to come up with a full quantitative assessment framework of urban spatial benefits evaluation [8]. Besides evaluation models, GIS technology has also become more maturely implemented within the context of cultural heritage protection. The authors of Liu et al. (2024) have systematically reviewed the application trends of GIS in cultural heritage conservation, noting that spatial analysis technology can provide precise data support to heritage resource assessment, protection zoning, and renewal decision making [12].

However, in most cases, industrial heritage retrofitting using parameter-intensive algorithmic searches needs a careful set of input data, several calibrations, and expert calculations that can limit reproducibility during regular research situations. This paper therefore does not put algorithmic search as an essential empirical experiment but rather develops an explicit multi-objective trade-off model that presents decision makers with a reproducible scenario-comparison process.

### III. METHODOLOGY AND EVALUATION FRAMEWORK

The paper develops a two-tier model of decision-making that consists of macro-level assessment and micro-level comparison of scenarios. In the macro level, the Entropy-Weight TOPSIS approach is applied as a comprehensive ranking approach to the resilience contributions of alternative schemes whereas in the micro level a scenario based multi-objective trade-off analysis is used to compare carbon emissions and socio-cultural values with clearly documented parameter ranges and scoring rules. Figure 1 shows the general logic of the framework.

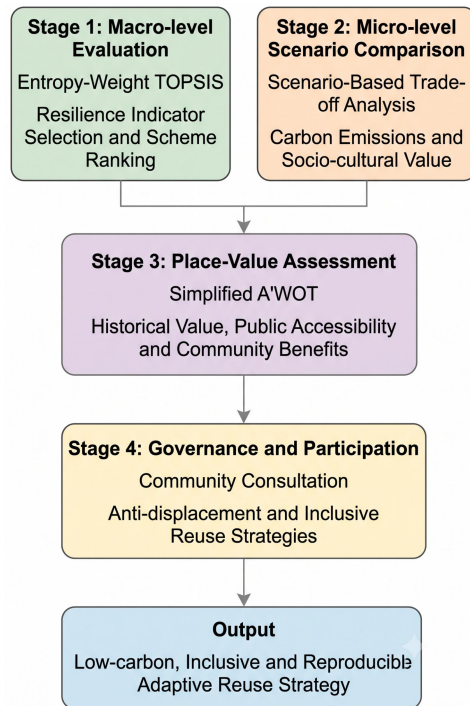


Fig. 1. The proposed low-cost and reproducible decision-support framework for the sustainable adaptive reuse of industrial heritage.

#### A. The Entropy-Weight TOPSIS Evaluation Model for Urban Resilience

According to the five-dimensional framework suggested by Tang et al. (2023) [6], this paper will choose eight core indicators, which are listed in Table I, to determine the extent of reuse schemes in promoting urban resilience. The indicators are chosen to make sure that every single item is rated based on information in publicly accessible planning documents, simple site observations, easily accessible project data or stakeholder surveys, so as not to use costly monitoring tools and complicated to replicate field studies.

In order to minimize the influence of subjective bias and enhance reproducibility, the Entropy-Weight approach is used to calculate the weight of every indicator. Considering  $m$  alternative plans and  $n$  assessment criteria, decision matrix  $X=x_{ijm}$   $\times$   $n$  is built with transparent scoring principles. Normalized matrix  $Y=y_{ijm}$   $\times$   $n$  is achieved after data standardization. Raw scores are normalized to the range of  $[0,1]$ , so it must be noted that each indicator has its own coding basis, which also needs to be reported alongside Table I. The proportion  $p_{ij}$  and the information entropy  $E_j$  of the  $j$ -th indicator are computed by:

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^m y_{ij}} \quad (1)$$

$$E_j = -\frac{1}{\lambda_{vm}} \sum_{i=1}^m p_{ij} \lambda_{vm} p_{ij} \quad (2)$$

The indicator weight  $W_j$  is then derived as:

$$W_j = \frac{1-E_j}{\sum_{j=1}^n (1-E_j)} \quad (3)$$

The TOPSIS approach calculates the distance between every plan and both the positive ideal solution  $D^+$  and the negative ideal solution  $D^-$  and finally provides the relative closeness coefficient  $C_i$  (which is between 0 and 1, and higher values indicate better plans):

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (4)$$

#### B. The Scenario-Based Multi-objective Trade-off Model

Once the preference of the scheme is determined, its design and operating parameters are compared by using an open and clear scenario based approach as opposed to expensive or hard to reproduce algorithmic optimization. The model establishes two possible conflicting aims.

Objective 1: Minimisation of life-cycle carbon emissions ( $f_{LCA}$ )

$$\mu \nu f_{LCA} = C_{embodied} + C_{operational} - C_{recovery} \quad (5)$$

where the first term corresponds to the carbon embodied in the material production and construction stages, the second term corresponds to carbon emissions during operation phase based on standard energy use assumptions, and the third term refers to carbon offset due to material recovery. Coefficients of all equations must be based on published carbon factors, design documents or explicit assumptions in order to allow the repetition of the calculation by other researchers.

Objective 2: Maximisation of local socio-cultural value (VSCV)

$$\mu \alpha \xi f_{SCV} = \sum_{k=1}^K \alpha_k V_k \quad (6)$$

Where  $V_k$  denotes the socio-cultural value indicators measured with the help of a simplified A' WOT procedure (e.g., accessibility of public space, retention rate of historical elements, and stimulation rate of community employment), and  $\alpha_k$  is the respective weight. In order to increase the degree of reproducibility, it is necessary to document rules of scoring, stakeholders classification and the weighting procedure in an additional scoring sheet or methodological note.

This paper does not apply fast non-dominated sorting and crowding distance computation, but instead it produces a restricted number of scenario combinations through modification of the key parameters across well-established intervals. Sensitivity analysis based on spreadsheet is subsequently employed to determine comparably balanced situations in terms of life-cycle carbon emissions and socio-cultural values thus enabling decision-makers to have transparent and reproducible set of trade-offs.

#### IV. CASE-STYLE APPLICATION AND MULTI-OBJECTIVE SCENARIO ANALYSIS

##### A. Case Background and Alternative Schemes

In order not to be dependent on the unattainable project information and expensive field experiments, this paper will be done in the form of a representative case-style application that is based on a typical Heavy Machinery Factory Site in a post-industrial setting. The site is supposed to have a large coverage area and to have faced similar issues like an ageing population of the surrounding community and poor infrastructure. Three standard retrofit schemes are set to compare and contrast them, including Scheme A (Comprehensive Reuse-oriented), which combines cultural and creative industries, community services and ecological restoration with a focus on low-carbon materials and social participation; Scheme B (Commercial Development-oriented), which includes high-density redevelopments into a high-end commercial complex with high economic returns but with a high-demolition rate; and Scheme C (Ecological Conservation-oriented), which involves minimal intervention to convert the site into an urban heritage park, where socio-economic vitality is also relatively low.

##### B. Resilience Dimension Evaluation Results

All three schemes are assessed relying on the Entropy-Weight TOPSIS model, and the weights and normalised scores of all indicators are shown in Table I. In order to enhance reproducibility, Table I must have a brief explanation of the scoring basis; ROI and job creation can be predicted based on planning or project documents; public participation, accessibility, green space ratio and policy support can be coded based on publicly accessible planning documents and community consultation documents; embodied carbon saving and energy efficiency can be calculated by published carbon factors and simple energy assumptions. As illustrated in Figure 2, Scheme A is found to be most balanced at indicative performance in the five dimensions of economic, social, environment, infrastructure and institutional resilience with the maximum relative closeness coefficient ( $C_i$ ), and hence is the chosen baseline scheme to be used in the future comparison of scenarios. Despite the fact that Scheme B is strong in the economic aspect, it has some obvious shortcomings in environmental and social aspects, especially concerning embodied carbon and public participation, whereas Scheme C is slightly less resilient economically. The findings ought to be seen as an open comparison between scenarios rather than as evidence of a massive experiment. Scenario Trade-off and Sensitivity Analysis

The low cost sensitivity analysis is performed using Scheme A on three easily observable and adjustable parameters, namely: the thickness class of building insulation materials, the retention rate of scrap steel and the proportion of public open space. The scenario-based trade-off frontier in Figure 3 is created based on the documented parameter ranges instead of 100-generation algorithmic iteration. Figure 3 illustrates that the scenario analysis indicates a non-linear trade-off between life-cycle carbon emissions and socio-cultural value. In lower-carbon scenarios, other socio-cultural functions may be reduced through stricter material-retention and function-control choices to achieve further carbon reduction; in higher-carbon scenarios, limited further socio-cultural value might come with extra spatial reconfiguration or facility intensity. A compromise scenario on the trade-off frontier can be chosen by decision-makers as per their real

budget limits, carbon emission goals and community tastes. It is important that all parameter ranges used to create Figure 3 are reported in the figure note or appendix so that the result can be reproduced.

TABLE I. THE ENTROPY-WEIGHT TOPSIS EVALUATION MATRIX FOR INDUSTRIAL HERITAGE REUSE SCHEMES.

Indicator	Weight	Scheme A (Comprehensive Reuse-oriented)	Scheme B (Commercial Development-oriented)	Scheme C (Ecological Conservation-oriented)	Data source and scoring rule
C1: Return on Investment (ROI)	0.15	0.85	0.95	0.5	Estimated from planning documents, comparable public cases or simplified project-cost assumptions. Higher expected economic return receives a higher normalised score.
C2: Job Creation	0.12	0.88	0.8	0.65	Estimated from the proposed functional programme, comparable employment-density data or local employment records. More stable and diverse job opportunities receive a higher score.
C3: Public Participation	0.14	0.92	0.5	0.85	Coded from community consultation records, questionnaires, meeting minutes or stakeholder interviews. Broader and earlier community involvement receives a higher score.
C4: Embodied Carbon Saving	0.18	0.8	0.4	0.95	Estimated using published carbon factors, building-retention ratio and material-reuse assumptions. Higher retention and lower demolition intensity receive a higher score.

C5: Energy Efficiency	0.1	0.85	0.6	0.9	Estimated from standard energy-use assumptions, simplified retrofit specifications or available energy-efficiency standards. Lower expected operational energy demand receives a higher score.
C6: Accessibility	0.1	0.82	0.75	0.6	Coded through site observation, public transport distance, pedestrian connectivity and entrance openness. Better public accessibility receives a higher score.
C7: Green Space Ratio	0.09	0.78	0.45	0.95	Calculated from the site plan, planning documents or publicly available satellite/map data. A higher proportion of accessible green space receives a higher score.
C8: Policy Support	0.1	0.9	0.7	0.8	Coded from local planning documents, heritage conservation policies and sustainability guidelines. Stronger consistency with current policy priorities receives a higher score.

<sup>a</sup>. Note: All scores are normalised to the interval [0,1]. The scoring process relies on publicly available planning documents, basic site observation, simplified project information and stakeholder consultation materials, so that the evaluation can be reproduced without expensive monitoring equipment or difficult-to-access experimental data.

Urban Resilience Dimension Assessment via Entropy-TOPSIS

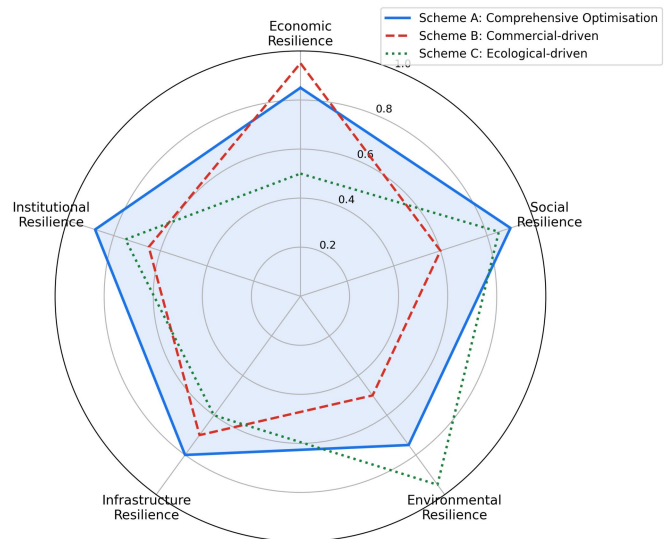


Fig. 2. Scenario-based comparison of the urban resilience dimensions of each scheme based on the Entropy-Weight TOPSIS method.

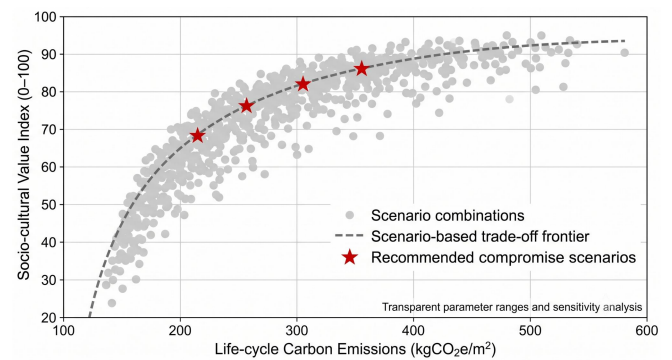


Fig. 3. The scenario-based trade-off frontier between life-cycle carbon emissions and socio-cultural value.

### V. PLACE-VALUE ENHANCEMENT MECHANISM AND DISCUSSION

#### A. Social Innovation Driving Territorial Innovation and Anti-gentrification Strategies

The research conducted by Scaffidi (2024) on 100 examples of the regeneration of industrial heritage in Europe validates the fact that the social innovation is the main pillar of territorial innovation and the ecosystemic regeneration model has the strongest influence [10]. In this context, Scheme A is an indication of bottom-up involvement of communities with the strong weight of the indicator being Public Participation (C3). Since the current study plans to prevent expensive intervention experiments, the anti-gentrification debate is designed as implementable governance but not as a presumed tested result. Two anti-displacement strategies are put forward. The first one is a mixed-ownership system, which involves implementing Community Land Trusts (CLTs) or cooperative ownership so that some of the revenue earned by the properties can be re-invested into the community. The second one is inclusive functional substitution, which entails keeping and improving the important community living-service facilities and affordable places and bringing in cultural and creative industries in a controlled and community-oriented fashion.

### B. Deep Integration of Circular Economy and Environmental Resilience

Physical stock of industrial heritage is an asset that has a significant material resource value. The situation comparison used in this paper is similar to the findings by Huang et al. (2025) who concluded that the inclusion of embodied carbon was the vital factor in assessing retrofit projects [4]. Adaptive reuse would release the stress of urban trash disposal and react to the global policy to counteract climate change by maximizing in-situ use of saved materials and replacing low-carbon construction materials whenever possible. It must be considered as a rational evaluation founded on clear assumptions and not as a consequence of expensive physical control.

## VI. CONCLUSIONS

The research builds a low-cost and repeatable multi-objective decision-support model to achieve the sustainable adaptive reuse of industrial heritage in response to resilience issues facing post-industrial cities. The overall conclusions are as follows. Firstly, the five dimensional evaluation system using the Entropy-Weight TOPSIS approach may assist in eliminating the short-sightedness of a particular commercial direction by filtering out balanced plans that take into consideration the economic dynamism, social fairness and environmental conditions. Secondly, the trade-off analysis based on the scenario shows the non-linear connection between the level of life-cycle carbon-emissions and socio-cultural value, offering the decision-makers a clear-cut list of alternative scenarios, not an expensive solution that depends on the algorithm. The potential of adaptive reuse in carbon reduction must be understood in context with available case studies and explicit assumptions and not as an experimental outcome applicable universally. Third, the reuse of industrial heritage is not just the reconfiguration of the material space, but it is an aspect in which social innovation leads to territorial innovation, and the creation of inclusive governance mechanisms is the basic guarantee against gentrification and the enhancement of the true value of place.

A drawback of this paper is that some socio-cultural indicators in the scenario-based trade-off model are measured based on rule-based scoring and restricted stakeholder contribution, implying some level of ambiguity. In future studies, objectivity could be increased even further in the form of repeated site observation, open-source plan data, inexpensive questionnaire and the open coding of multiple reviewers as opposed to using costly spatial-syntax software or massive big-data sentiment analysis. The framework can be applied in more typical project settings where all datasets, scoring sheets and calculation processes are fully disclosed.

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## AVAILABILITY OF DATA

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## AUTHOR CONTRIBUTIONS

Qiang Liu contributed to the conceptualisation of the study, literature review, case analysis and preparation of the original manuscript. Zhanyun Lu contributed to the methodological framework, evaluation model construction, data interpretation and manuscript revision. Both authors participated in the discussion of the research findings, approved the final version of the manuscript and agreed to be accountable for the content of the work.

## COMPETING INTERESTS

The authors declare no competing interests.

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