

Insuring Against Extreme Weather

Summary

As extreme weathers intensify, nearly half of the properties are uninsured. Moreover, insurance companies charge high premiums or are unwilling to underwrite. Therefore, we develop decision models for insurance companies, property developers, and community leaders.

First, to determine whether insurance companies should underwrite policies for properties, we propose the **EWUS** model. According to this model, the income of companies is derived from stocks, premiums, and investments minus claims when underwriting policies or solely from stocks when not underwriting. Companies will choose the option with the higher income of the two. The results show that companies in the **Maldives** benefit most with **18.98** billion dollars at **55** extreme-weather events and will not underwrite if annual extreme-weather events exceed **263** times. Companies in **Uruguay** benefit most with **140.3** billion dollars at **112** extreme-weather events and will not underwrite if annual extreme-weather events exceed **619** times.

Second, we employ **game theory** to simulate a negotiation among property developers, insurance companies, and residents to decide whether to build on certain sites. In each round, the developers improve the risk resistance of buildings, or the companies raise premiums. The game ends when the buildings can withstand the climate risk. We then use **non-linear optimization** equations based on the EWUS model to maximize the income of developers (**Equation 22**). The developers can build if the expected GDP per capita, a decision variable, is within $\pm 15\%$ of the actual value. The results show that developers can build in Maldives and Uruguay, where the difference between expected and actual GDP per capita is **12.5%** and **0.3%**, respectively.

Then, to value the buildings of communities and propose preservation measures, we select indicators of 127 communities from four aspects: economy, culture, society, and climate. Then the data is pre-processed by **KNN** interpolation and normalization. After that, we introduce the **ECS model**. It combines the **AHP** and **CRITIC** methods by the **Lagrangian multiplier** to obtain indicator weights (**Figures 8 & 9**) and calculates the Community Development Index (**CDI**) and Climate Risk Index (**CRI**) using these weights. The K-means algorithm determines thresholds for low, medium, and high levels of CDI and CRI to divide the **GE matrix** into nine regions, based on which we propose **five** preservation strategies (**Figure 10**).

Next, we apply the EWUS model and the ECS model to the **Mogao Caves**. The results show that insurance companies will underwrite policies if annual extreme-weather events are below **3135** times. Additionally, we use **GM(1,1)** to predict the indicators for the next **fifty** years and find the CRI of the community will increase from **0.383** to **0.509** with no preservation measures. Therefore, we write a **letter** to the community including a three-stage strategy, with distances to the optimal point being **0.526**, **0.381**, and **0.285** after each stage, respectively.

Finally, we analyze the strengths and weaknesses of the models and draw meaningful conclusions. In sensitivity analysis, we change the area of damaged buildings in the EWUS model and the weight of construction output in the ECS model and obtain **stable** results.

Keywords: extreme-weather events; EWUS model; game theory; ECS model; GE matrix

Contents

1 Introduction.....	3
1.1 Problem Background	3
1.2 Restatement of the Problem	3
1.3 Literature Review.....	4
1.4 Our Work	4
2 Assumptions and Justifications	5
3 Notations	5
4 Extreme-Weather Underwriting Strategy Model.....	6
4.1 Income of Insurance Companies.....	6
4.2 When to underwrite policies in Maldives and Uruguay?.....	8
5 Game for Property Development	10
6 Preservation Model for Community	13
6.1 Indicators Selection.....	13
6.2 Data Collection and Pre-processing.....	15
6.3 AHP-CRITIC for Community Evaluation	16
6.4 Preservation Measures Based on GE Matrix	18
7 Case Study of the Mogao Caves.....	20
7.1 Models Application.....	20
7.2 The three-stage strategy for Mogao Caves	21
8 Sensitivity Analysis	22
9 Model Evaluation and Further Discussion.....	23
9.1 Strengths	23
9.2 Weaknesses	23
9.3 Further Discussion	23
10 Conclusion.....	23
References	24
A Letter to Mogao Caves Community	25

1 Introduction

1.1 Problem Background

Climate change has led to a rise in extreme-weather events, and the interests of property owners and insurers around the world are at stake. **Figure 1** illustrates part of extreme weather events that can cause sudden and significant damage to property. Consequently, as shown in **Figure 2**, the global direct economic losses from extreme weather surged in 2015 and reached 2,140 million dollars in 2021.

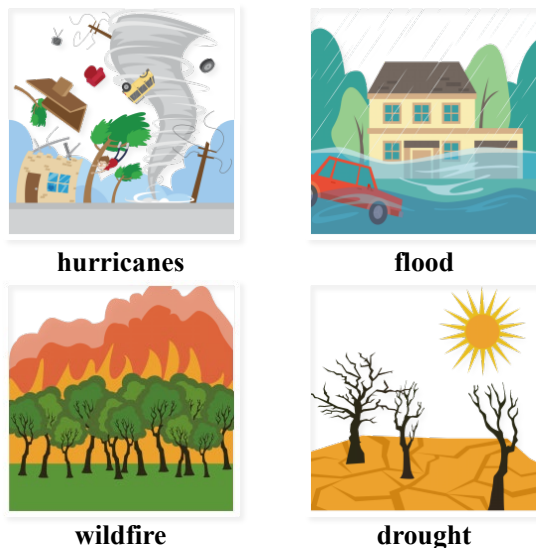


Figure 1: Extreme-weather events

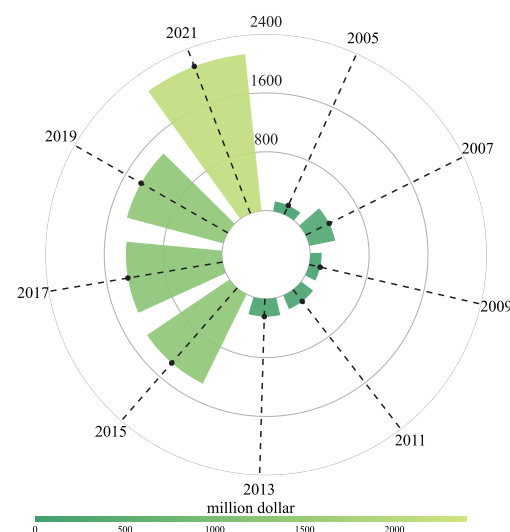


Figure 2: Direct economic loss ^[1]

Increasing property insurance coverage for extreme-weather events can help property owners cope with these risks. Therefore, we need to develop models to determine whether insurance companies should underwrite policies; to help communities assess property values, and then propose preservation plans.

1.2 Restatement of the Problem

To help Insurance of Catastrophes Modelers develop a sustainable property insurance deployment plan; and to help communities assess and preserve their properties, we need to accomplish the following tasks:

- Develop an insurance model that determines whether insurance companies should underwrite policies or not and apply it to two areas experiencing extreme weather.
- Adjust the insurance model to determine whether property developers should build certain sites in the future.
- Evaluate community development from economic and cultural aspects and propose preservation measures for community leaders.
- Apply the insurance model and the preservation model to a landmark, propose a timeline and cost for implementation of preservation measures, and write a letter to the local community.

1.3 Literature Review

Climate change has brought increasing extreme-weather events, which cause huge losses. Insurance can help property owners distribute and communicate risks. Therefore, property construction and insurance deployment need to be transformed to fit the laws of nature.

Regarding the impact of growing extreme-weather events on the insurance industry, Valverde and Convertino ^[2] applied Dynamic Regression Models to explore the relationships between hurricanes and return on equity for insurers and found that insurers have higher resilience to more significant impacts. Botzen et al. ^[3] predicted that floods and droughts will increase in the Netherlands by 2050. To close the insurance protection gap, they suggested that insurance companies should work with public institutions to reduce risks by reducing emissions. In another study, Sheehan et al. ^[4] also highlighted the cross-sectoral cooperation between the insurance and disaster risk management communities to reduce risk. As the insurance situation changes, some studies assessed the property value to identify protection measures. Tomić et al. ^[5] utilized the Land Administration Domain Model to assess Croatian property based on indicators of economy, society, and infrastructure. Yalpir et al. ^[6] employed Frequency Analysis, Principal Component Analysis, Factor Analysis, and Analytical Hierarchy Process approach to select legal, physical, local, and spatial indicators for property evaluation.

However, these studies do not propose sustainable measures of property insurance. Based on their work, we develop decision models for insurance companies, property developers, and communities.

1.4 Our Work

The modeling process is shown in **Figure 3**. First, we calculate the income of insurance companies by stocks, premiums, investments, and claims. Then we simulated the game process of property developers, insurance companies, and residents. Subsequently, we use economic, social, cultural, and climate indicators to assess communities and propose five strategies. Finally, we applied the models to the Mogao Caves and wrote a letter to the local community.

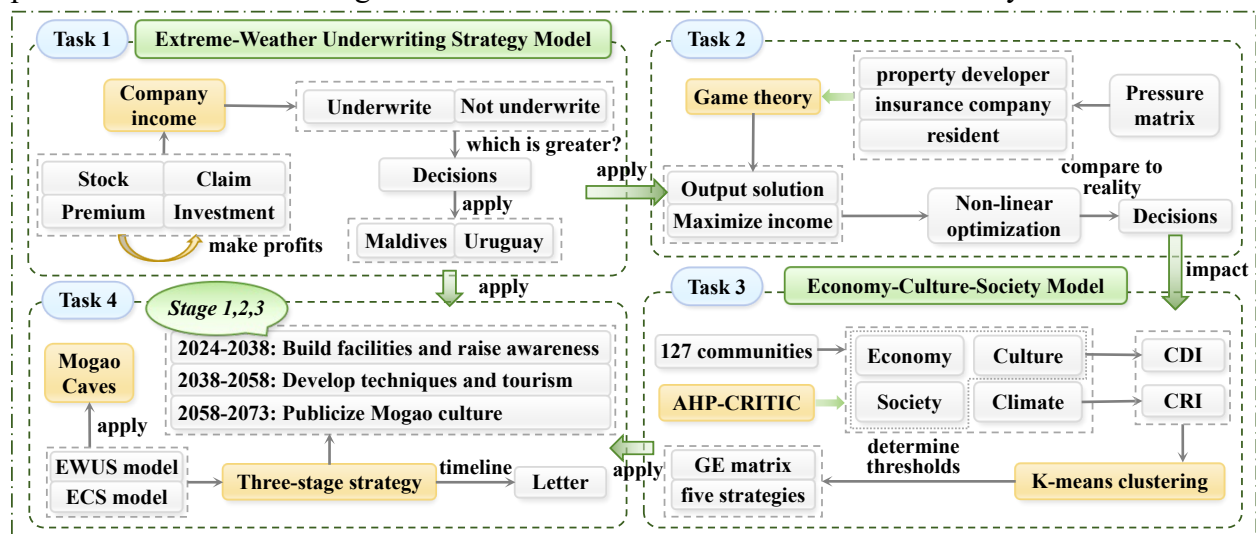


Figure 3: Flowchart of our study

2 Assumptions and Justifications

Extreme weather and the insurance industry are complex systems, and there are broad concepts that need to be clarified. To simplify the problem, we make the following main assumptions. Assumptions not listed here will be discussed during the modeling process.

Assumption 1: “Property” in the problem refers to real estate property (e.g., houses, land, and commercial property) and excludes personal items (e.g., cars, furniture, and jewelry).

Justification: The definition of property is so broad that we cannot take all factors into account. Personal items have very little value compared to buildings and can be ignored to simplify calculations.

Assumption 2: The data we collect from online databases and related websites are accurate, reliable, and consistent with each other.

Justification: Our data are obtained from official websites and organizations (e.g. World Bank and UNDRR). It is reasonable to assume the data are of high quality.

Assumption 3: The indicators we have not selected in the ECS model have little impact on the results.

Justification: We select several most representative indicators to build the ECS model. Some non-representative indicators that have slight impacts on the ECS model can be ignored.

Assumption 4: We assume that communities maintain their original trend and that there are no sudden events that would overturn their original pattern.

Justification: The likelihood of sudden events is low, and the historical trend is stable to assume that occasional events will not affect the overall trend of community development.

3 Notations

Some key mathematical notations used in this paper are listed in **Table 1**.

Table 1: Notations used in this paper

Symbol	Description	Unit
I	Total income of an insurance company	<i>dollar</i>
I_s	Stock income of an insurance company	<i>dollar</i>
$Ratio_{i,t}$	Cash holding rate of the company i at the time t	/
I_p	Premium income of an insurance company	<i>dollar</i>
I_i	Investment income of an insurance company	<i>dollar</i>
C	Claims paid to the damaged insured properties	<i>dollar</i>
P_r	Pressure matrix for players	/
ω_i	The weight of the i -th indicator	/
CDI	Community Development Index	/
CRI	Climate Risk Index	/
RL	Risk Level	/

*Some variables not listed here will be discussed in each section.

4 Extreme-Weather Underwriting Strategy Model

In this section, we establish the Extreme-Weather Underwriting Strategy (EWUS) Model. The EWUS model calculates the income of insurance companies underwriting and not underwriting policies under a certain number of extreme-weather events, therefore helping the company make decisions.

4.1 Income of Insurance Companies

As the income of insurance companies is complex and changes over time, we propose the following assumptions to simplify the model and explain the justifications:

- Insurance companies will set aside a statutory reserve for claims. These reserves are used to cover future property liabilities.
- **The total market value of insurance companies will remain stable for some time.** Companies have risk tolerance ability, and a stable stock market can facilitate regulation.
- **Residents are aware of hardship and all of them purchase property insurance.** If an area is being threatened, all residents feel at risk and will purchase insurance.
- There is only one type of insurance companies that sell property insurance within a particular region. It is too complex to calculate the combined effect of various companies.
- The total number of buildings in a region approximates the local population. Population growth requires more buildings to meet living and working needs.

By reviewing the literature, we believe that there are three main income sources for insurance companies: **stock**, **premium**, and **investment**. Among them, the market value of stocks grows over time to bring stock income, which is the most important income source for insurance companies. In addition, insurance companies charge residents for property insurance and provide services to earn premium income. Insurance companies then invest the premiums they receive to generate investment income. Meanwhile, if insured properties are damaged by extreme weather, insurance companies will pay claims. The formula for insurance company income is

$$I = I_s + I_p + I_i - C, \quad (1)$$

where I is the total income, I_s is the stock income, I_p is the premium income, I_i is the investment income, and C is the claims.

4.1.1 Stock Income

Stock income I_s for insurance companies depends on the total market capitalization of the stock price and the cash holding ratio. When an insurance company decides whether or not to underwrite policies based on the climate risk in a particular region, this in turn affects the stock price. The formula for stock income is

$$I_s = MV \cdot Ratio_{i,t} \cdot k_j, \quad (2)$$

where MV is the total stock market value of insurance companies, $Ratio_{i,t}$ is the cash holding rate of the company i at the time t , and k_j is the feedback coefficient the company receives after deciding whether to underwrite policies.

When calculating the cash holding rate $r_{i,t}$, we refer to and modify the study of Li ^[7]. The formula of the cash holding rate is

$$Ratio_{i,t} = \beta_0 + \beta_1 L_{i,t} + \gamma_t + \xi_i + \varepsilon_{i,t}, \quad (3)$$

where $L_{i,t}$ is stock liquidity of the company i at the time t , γ_t is a time-fixed effect, and ξ_i is an industry-fixed effect. Stock liquidity $L_{i,t}$ is the mean value of Amihud [8] and Roll [9] indexes, which are negative indicators, which indicates that when β is negative, the increase of stock liquidity $L_{i,t}$ will increase the cash holdings $Ratio_{i,t}$ of insurance companies.

The Roll index is calculated by

$$Roll = \begin{cases} 2\sqrt{-\text{cov}(\Delta P_t, \Delta P_{t-1})}, & \text{cov}(\Delta P_t, \Delta P_{t-1}) < 0, \\ 0, & \text{cov}(\Delta P_t, \Delta P_{t-1}) \geq 0, \end{cases} \quad (4)$$

where P_t is the daily stock return in the period t , and $\text{cov}(\Delta P_t, \Delta P_{t-1})$ is the first-order difference covariance of stock returns. The more volatile the stock price is, the higher the covariance, the higher the transaction costs, and the less liquid it is. The larger Roll index indicates the less liquid stock.

The Amihud index is calculated by

$$Amihud_{it} = 10^8 * 1/D_{it} \sum_{d=1}^{D_{it}} |R_{itd}|/VOLD_{itd}, \quad (5)$$

where D_{it} is the number of days that stock i is effectively traded in the period t , R_{itd} is the return on stock i on the day d in the period t , and $VOLD_{itd}$ is the daily turnover on the day d of stock i in the period t . The larger the Amihud index, the less liquid the stock is.

The formula for the feedback coefficient k_j is

$$k_j = \begin{cases} p_j^{++} \frac{\log(\sqrt{n} + 1)}{100}, & j = 1, \\ p_j^+ e^{-\frac{1}{n}}, & j = 2, \end{cases} \quad (6)$$

where p_j^{++} is the coefficient of not underwriting policies, p_j^+ is the coefficient of underwriting. n is the number of extreme-weather events, $j = 1$ represents insurance companies deciding to underwrite policies, and $j = 2$ represents insurance companies deciding not to underwrite.

When the number of disasters is within acceptable limits, the company underwrites policies to attract customers and increase premium income. This indicates that the company is under increased pressure to pay out claims and take on risk over the long term, hence the stock price will grow slowly.

As the number of disasters increases and the company no longer underwrites policies, the potential cost of future claims will decrease. As a result, the company's profitability rises and investors are optimistic about the company's future share price. The share price will then rise, but this positive effect is limited.

4.1.2 Premium Income

Premium income I_p is the sum of property premiums in the region. The risk of re-damaging a building that has already been damaged is high, and insurance companies will charge higher premiums. The formula for premium income is

$$I_p = B_d(1 + \alpha)P + (B - B_d)P, \quad (7)$$

where B_d is the number of damaged buildings, α is the risk addition, P is the premium, and B is the total number of insured buildings.

4.1.3 Investment Income

Between the time the premium is collected and the time the claim is paid, insurance companies use the premium income to make investment income I_i . The formula for investment income is

$$I_i = rI_p, \quad (8)$$

where r is the rate of return. We refer to the rate of return for insurance companies on the Statista database, which has been around 4.5% in recent years.

4.1.4 Claims

Insurance companies should pay claims C for damaged insured homes. This expense is related to the number of disasters, the size of the damaged property, and the amount of compensation. The formula is

$$C = nWB_d, \quad (9)$$

where W is the average claim promised in policies.

4.1.5 Model Overview

In summary, we obtain the EWUS Model as

$$\begin{cases} I = I_s + I_p + I_i - C, \\ I_s = MV \cdot Ratio_{i,t} \cdot k_j, \\ I_p = B_d(1 + \alpha)P + (B - B_d)P, \\ I_i = rI_p, \\ C = nWB_d. \end{cases} \quad (10)$$

When insurance companies choose not to underwrite policies, then I_p , I_i , and C is 0. In this case, the only source of income for insurance companies is the stock. We believe that insurance companies will compare the income from underwriting and not underwriting policies and then choose the one with **greater** return as the final decision.

According to the EWUS model, property owners can influence the decision outcome of insurers by **investing** in their stock and **paying** higher premiums. We will discuss the impacts on property owners below.

4.2 When to underwrite policies in Maldives and Uruguay?

We selected the Maldives, located in Asia, and Uruguay, located in South America, to apply the EWUS model. The Maldives attracts many tourists thanks to its natural environment, but it is threatened by floods and tsunamis caused by rising sea levels. Uruguay is rich in mining and forestry resources, but it is threatened by high temperatures and droughts. With both areas threatened by extreme weather, what decisions will insurance companies make?

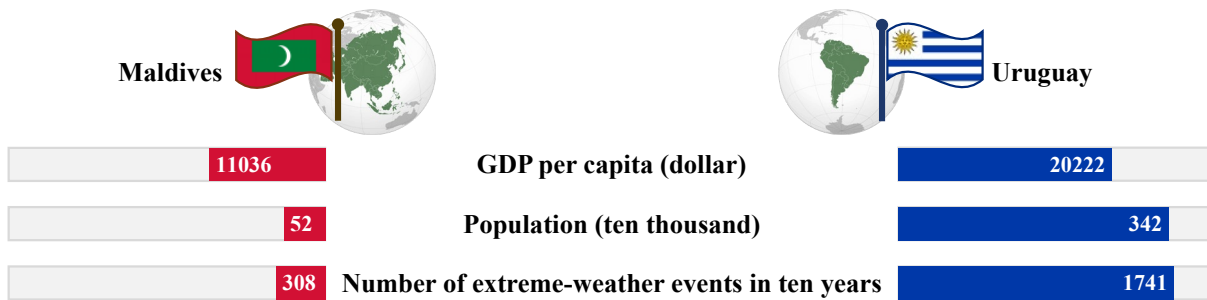


Figure 4: Comparison of Maldives and Uruguay

As shown in **Figure 4**, the GDP per capita of Uruguay is about twice that of the Maldives, which may be due to the diverse structure of the Uruguayan economy whereas the Maldives is dependent on tourism. Meanwhile, Uruguay has a larger territory and population, resulting in about six times as many extreme weather events as the Maldives.

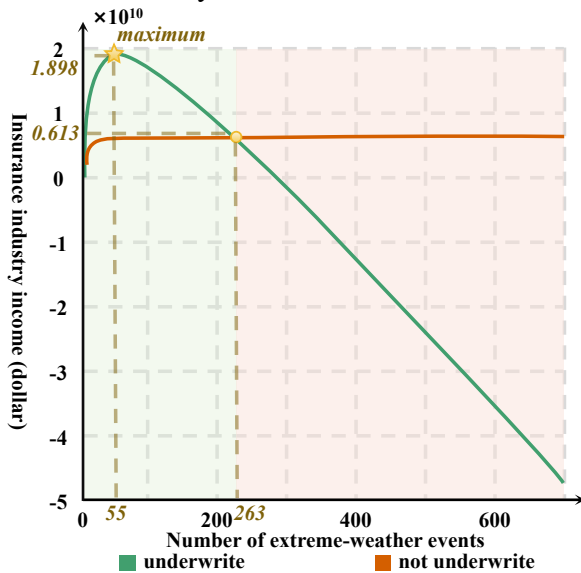


Figure 5: Insurance income in Maldives

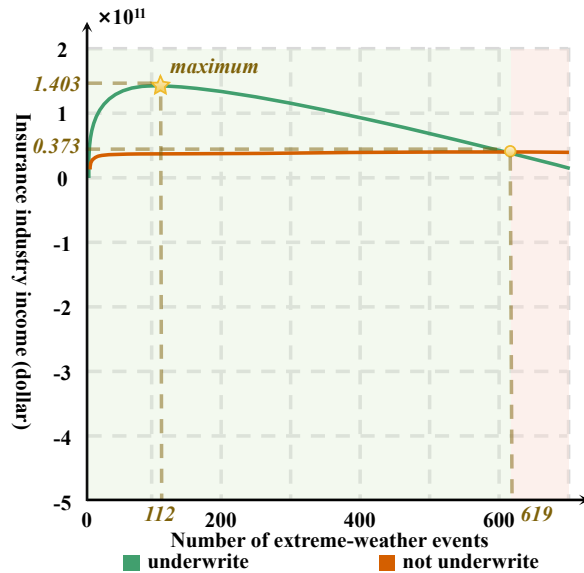


Figure 6: Insurance income in Uruguay

Figure 5 and **Figure 6** show the income of insurers from underwriting policies and not underwriting in the Maldives and Uruguay, respectively. We draw the following conclusions:

- The income of underwriting policies increases and then decreases with the number of extreme weather events, with a larger downward trend in the Maldives than in Uruguay. Maldivian insurers will have the highest benefits at **55** extreme-weather events per year, amounting to **18.98** billion dollars, while Uruguayan insurers will have the highest benefits at **112** extreme-weather events per year, amounting to **140.3** billion dollars.
- Based on the previous analysis, income from not underwriting will increase slightly as a result of higher stock prices. When the annual extreme-weather events reach a certain number, insurance companies will have less income from underwriting than from not underwriting, which is consistent with reality. This number is **263** for Maldives and **619** for Uruguay, implying that Uruguay has better resilience to extreme weather.
- The overall property insurance income in Uruguay is nearly ten times that of the Maldives, which may be attributed to a larger population and more extreme-weather events.

5 Game for Property Development

Once property developers decide to build specific sites in the future, they want insurance companies to reduce property risks by providing insurance for the growing population. Meanwhile, insurance companies want property developers to make their properties as disaster-proof as possible as a way to reduce expected claims and company risk.

Property developers and insurance companies are subject to pressure and influence from each other when making future decisions. Besides, we assume that residents will not be pressured or influenced by property developers and insurance companies. However, their desire to obtain more shelters and services will put pressure on property developers and insurance companies. Can property developers, insurance companies, and residents reach a consensus and build properties in particular sites? We will model and solve this task through **game theory**.

5.1.1 Game Players

There are three players in our game, 1 is the property developers, 2 is the insurance companies and 3 is the residents. To assess the risk of an area being subjected to extreme-weather events in the future, we introduce the risk level. It considers the mean and variance of the number of extreme-weather events in the region over the last decade, indicating the magnitude of the future risk. The formula for risk level (**RL**) is

$$\begin{cases} RL_i = \left\lceil \frac{RL'_i}{RL_{\max}} \times 5 \right\rceil, \\ RL'_i = \frac{\sum_{t=1}^{10} n_{it}}{10} + \delta(n_{it}), \end{cases} \quad (11)$$

where RL_i is the risk level of the region i , n_{it} is the number of extreme-weather events in the year t , and $\delta(n_{it})$ is the variance of the events in the last ten years.

During the game, the property developer needs to deliberately enhance the resilience of the buildings, and insurance companies increase the premium to reduce losses, so the decision domain includes eight solutions:

$$x_k = (x_{k1}, x_{k2}) \in \{(0, 0), (0, 1), (1, 0), (1, 1), (2, 0), (2, 1), (3, 0), (3, 1), (4, 0), (4, 1), (5, 0), (5, 1)\}. \quad (12)$$

In **Equation (12)**, x_k represents the decision vector of a round k of the game, x_{k1} is the RL the property developers will make the buildings resistant to, and x_{k2} represents whether insurance companies will raise premiums. Then we can derive the priority of x_{k1} and x_{k2} , respectively:

$$\begin{cases} x_{k1} = 0 \rightarrow x_{k1} = 1 \rightarrow x_{k1} = 2 \rightarrow x_{k1} = 3 \rightarrow x_{k1} = 4 \rightarrow x_{k1} = 5, \\ x_{k2} = 0 \rightarrow x_{k2} = 1. \end{cases} \quad (13)$$

This priority indicates that both real estate developers and insurance companies will defend their interests. Specifically, property developers tend to reduce costs by avoiding raising the risk resistance of their buildings as much as possible. Insurance companies will avoid raising premiums as much as possible to avoid underwriting more policies that increase expected claims.

Property developers and insurers will be pressured by three players. Developers and

companies also put pressure on themselves when the difference between actual and expected is too large. We define a matrix P_r to show the pressure on players:

$$P_r = [p_{ij}]_{3 \times 2}, \quad (14)$$

where p_{ij} is the pressure the player i gives to the player j . As we previously assumed, residents (player 3) will not be pressured. Then we obtain the pressure on the player j is

$$p_j = \sum_{i=1}^3 p_{ij}. \quad (15)$$

Similarly, the pressure given by the player i is $p_i = p_{i1} + p_{i2}$.

5.1.2 Game Rules

- **Players with higher status can put more pressure on other players.** Property developers dominate in developing buildings. In addition, the willingness of residents to purchase insurance also influences insurance companies. We have

$$p_{11} + p_{12} \geq p_{31} + p_{32} \geq p_{21} + p_{22}, \quad (16)$$

- **The pressure exerted by players has an upper limit of 3.** While real estate developers, insurance companies, and residents can be pressured by making demands and public opinion, this impact is limited. We have

$$p_{11} + p_{12} \leq 3, \quad (17)$$

- **The degree of pressure depends on the difference between expectation and reality.** Each player has an expected solution for property construction. We define the expected matrix as

$$XE_i = (xe_1, xe_2)_i = \begin{bmatrix} xe_{11} & xe_{21} \\ xe_{12} & xe_{22} \end{bmatrix}_i, i = 1, 2, 3. \quad (18)$$

In **Equation (18)**, XE_i is the solution player i expected, xe_1 is the expectation for property developers, and xe_2 is the expectation for insurance companies. The difference between the expected and actual values is

$$XP_i = (xp_1, xp_2)_i = \begin{bmatrix} ((xe_{11})_i - x_{11})^2 & ((xe_{21})_i - x_{21})^2 \\ ((xe_{12})_i - x_{12})^2 & ((xe_{22})_i - x_{22})^2 \end{bmatrix}, i = 1, 2, 3, \quad (19)$$

where XP_i is the difference between reality and the expectation of the player i , xp_1 is the difference of property developers, xp_2 is the difference of insurance companies. This difference cannot directly reflect pressure. Because $(xp_j)_i$ is not linearly related to p_{ij} ; the larger the difference, the higher the pressure, which can be expressed by a cubic function. Second, in each round of the game, players focus on other players differently, thus the coefficients of the difference function will change. The pressure exerted by a player i on player j is

$$p_{ij} = fh_{ij}(xp_j)_i^3, \quad (20)$$

where fh_{ij} is the pressure coefficient, $(xp_j)_i$ is the difference of player j expected by player i .

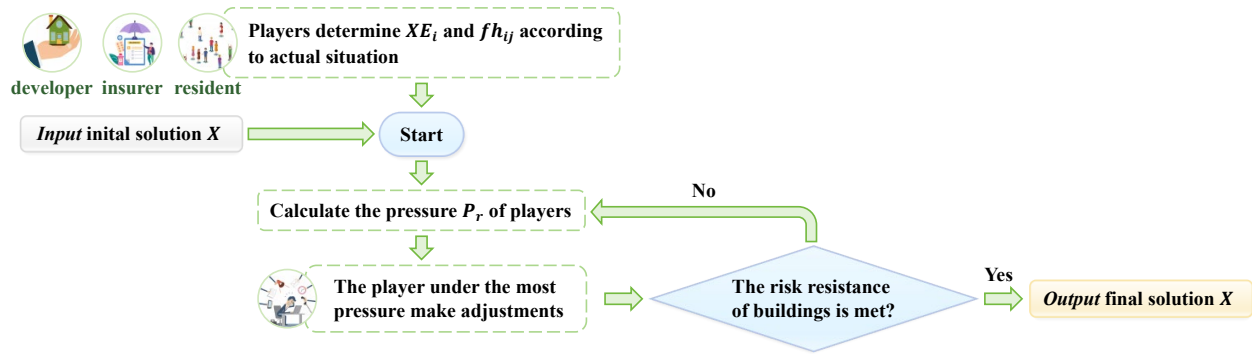


Figure 7: Game process

As shown in **Figure 7**, the player under the most pressure will adjust their decision at each round of the game. When buildings can withstand the RL in this region, insurance companies will underwrite policies that can be more profitable, the safety of the residents will be assured, and the game is over.

After the game is over, we establish a **non-linear optimization** model based on the EWUS model to determine the maximum benefits for the property developers. Because many regions have not yet developed property insurance claims policies, we use the data on the California Department of Insurance ^[10] as the benchmark.

In the optimization model, the objective function is to maximize the difference between the selling price of the building and the purchasing level of residents. The decision variables are the average price of construction and GDP per capita. The constraints are: the building price is greater than the insurance claims; insurance companies receive a larger income from underwriting policies than from not underwriting them; the building price and GDP per capita are positive. The equations are as follows:

$$\text{Maximize } (1 + \mu)x_1 - \eta x_2, \quad (21)$$

$$s.t. \begin{cases} x_1 - \frac{H(1 + \theta)x_2}{G} \geq 0, \\ I_u - I_n - \frac{H(1 + \theta)x_2}{G} \geq 0, \\ x_1 \geq 0, \\ x_2 \geq 0. \end{cases} \quad (22)$$

In **Equation (21)**, μ is the increase in building price ratio by upgrading the level of risk resistance, x_1 is the average price for a building, η is the purchase coefficient, and x_2 is the expected GDP per capita.

In **Equation (22)**, H is the average property claims in America, G is the GDP per capita in California, θ is the claim coefficient, I_u is the income of insurance companies when underwriting policies, and I_n is the income not underwriting policies.

We use LINGO to solve the optimization model. If the x_1 is consistent with common sense and x_2 is close to the actual GDP per capita, property developers can establish buildings on the current site. If the difference between x_2 and the actual GDP is more than 15%, the current economic situation of this region is not resilient to extreme-weather events, therefore developers

should build on another site.

5.1.3 Game Result

We follow the two areas of the EWUS model and simulate the gaming process of property developers trying to establish new buildings in the Maldives and Uruguay.

Table 2: Game results of Maldives

Round	1	2	3	4	5
PD	D	D	N	N	D
IC	N	N	D	D	N

Table 3: Game results of Uruguay

Round	1	2	3	4	5
PD	D	N	N	N	D
IC	N	D	D	D	N

*PD is the property developer, IC is the insurance company, D represents adjusting decisions, and N represents doing nothing.

The results are shown in **Table 2** and **Table 3**. After five rounds of gaming, property developers in the Maldives and Uruguay will deliberately reinforce the structure of the buildings to make them resilient to local climate risks. In addition, insurance companies will agree to underwrite the houses after raising a certain premium to provide basic protection to the residents.

The results of the non-linear optimization model indicate then that the selling price of a building in the Maldives should be **91,941** dollars, while the expected GDP per capita is **12,471** dollars. Buildings in Uruguay should sell for **401,461** dollars with an expected GDP per capita of **20,148** dollars. The gap in real GDP per capita for Maldives and Uruguay is **12.5 %** and **0.3%**, respectively. Therefore, the selling prices of buildings that satisfy the conditions of the game are realistic, and property developers can build in these two areas.

6 Preservation Model for Community

Given the changing insurance landscape, we develop the Economy-Culture-Society (ECS) model to assess community values and help community leaders make decisions in response. In addition, we suggest five preservation strategies for community leaders based on the **GE matrix**.

6.1 Indicators Selection

6.1.1 Economy

- **Property output.** It refers to the sum of secondary and tertiary output, which is dominated by industry and services, respectively. Increased property output indicates that the community is in good economic health, leading to more demand for properties.
- **Property enterprises.** More property enterprises mean more jobs and economic investment, which drives the regional economy.
- **Real estate investment.** Real estate investment shows the confidence residents have in the future of their community and brings in funds for facility construction.
- **Tourism revenue.** High tourism revenues are accompanied by high real estate demand and prices, which contribute to the economic prosperity of the community.

6.1.2 Culture

- **Museum.** The number of museums reflects the cultural wealth of the community and the importance it places on heritage. Communities rich in history have a higher cultural value.

- **Cultural center.** The number of cultural centers reflects the richness and importance of cultural activities in the community.
- **Radio station.** Radio stations can spread cultural awareness, arts programs, and community activities, which have a positive impact on the level of cultural development.

6.1.3 Society

- **Population.** The resident population in a community reflects the scale of the community. An increase in population means more economic activity and demand for consumption.
- **School.** The number of schools represents the importance the community places on education. Educational resources reflect the social value of the community.
- **Hospital.** The number of hospitals reflects the level of medical care in the community and the health status of the population.

6.1.4 Climate

- **Risk Ratio.** A larger ratio of property insurance claims to premiums indicates that the properties in the community are damaged by more extreme-weather events.
- **Storm.** This indicator refers to the area affected by hurricanes, rainstorms, etc. A larger area affected by storms indicates a greater risk of extreme weather.
- **Flood.** The area affected by floods reflects the flood risk of the community.
- **Drought.** This indicator indicates the area of the community affected by drought and wild-fire. The more droughty the land, the worse the extreme weather.

6.1.5 Indicators Overview

In summary, the description of indicators for evaluating community and climate risks is shown in **Table 4**.

Table 4: Indicators description

Level I	Level II	Description	Unit
Economy	Property output	The sum of the secondary and tertiary output	<i>dollar</i>
	Property enterprises	Number of property enterprises	/
	Real estate investment	Investment in real estate development	<i>dollar</i>
	Tourism revenue	Community tourism revenue	<i>dollar</i>
Culture	Museum	Number of museums	/
	Cultural center	Number of cultural centers	/
	Radio station	Number of radio stations	/
Society	Population	Resident population	/
	School	Number of schools	/
	Hospital	Number of hospitals	/
	Risk ratio	The ratio of property insurance claims to property insurance premium	/
Climate	Storm	The area affected by storms	<i>hm²</i>
	Flood	The area affected by floods	<i>hm²</i>
	Drought	The area affected by droughts and wildfires	<i>hm²</i>

6.2 Data Collection and Pre-processing

6.2.1 Data Collection

We obtain the data from the official databases in **Table 5** to ensure the accuracy and reliability of the following analysis. The data are from 135 communities around the world, and we remove communities with more than 50% missing values, leaving 127 communities. These communities include famous historic landmarks as well as some obscure ones.

Table 5: Database used in the Preservation Model

Name	Website
Statista	https://www.statista.com/
The World Bank	https://data.worldbank.org/
Our World in Data	https://ourworldindata.org/
Easy Professional Superior	http://olap.epsnet.com.cn/
National Bureau of Statistics	https://data.stats.gov.cn/
United Nations Office for Disaster Risk Reduction	https://www.undrr.org/

6.2.2 Data Filling

The data we obtain from the website has some missing values that need to be interpolated. Proper interpolation methods close the inserted data to the actual value and help ensure the reliability of our analysis.

- If the variance of an indicator is slight, we use mean interpolation, filling in the missing values with the mean value of the indicator.
- If the variance of an indicator is significant, we use **KNN interpolation**. The steps are as follows:

Step 1: Determine the value of K. We use four nearest neighbors to fill in the missing values.

Step 2: Calculate distances. For each community containing missing values, calculate their Euclidean distance to communities without missing values. We have

$$d(P, Q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \dots + (p_n - q_n)^2} \quad (23)$$

where $P = (p_1, p_2, \dots, p_n)$ and $Q = (q_1, q_2, \dots, q_n)$ are data points of two communities.

Step 3: Select nearest neighbors. For each missing value, select the four communities closest to it.

Step 4: Fill in the missing values. We use the average value of the four nearest communities to calculate the missing value.

$$X_{ij} = \frac{X_{i1j} + X_{i2j} + X_{i3j} + X_{i4j}}{4} \quad (24)$$

where X_{i1} , X_{i2} , X_{i3} and X_{i4} are the four sample points closest to the missing value X_{ij} .

6.2.3 Data Normalization

Because data normalization is very sensitive to outliers, we replaced outliers with upper and lower boundaries using the **quartile intercept** method before normalization. The fourteen indicators collected are all benefit-type indicators. The larger the community indicator, the better the

community is doing. The larger the climate indicator, the greater the risk of extreme weather. To transfer data in each indicator to a standard scale from 0 to 1, each value x_i subtracts the minimum value:

$$\hat{x}_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}, \quad (25)$$

where \hat{x}_i is the normalized value of the data point x_i , x_{\min} is the minimum value in the i -th indicator, and x_{\max} is the maximum value in the i -th indicator.

6.3 AHP-CRITIC for Community Evaluation

We combine AHP and CRITIC to calculate the weights of community indicators and climate indicators. In this case, AHP compares the relative importance of each criterion, and CRITIC considers the correlation between the criteria. Combining subjective factors and data characterization can better evaluate complex issues.

6.3.1 AHP

The Analytic Hierarchy Process (AHP) is a decision-making method that measures various criteria. We need to compare the relative importance of each indicator.

Step 1: Establish the decision hierarchy. The first step is determining how much the criteria impact each indicator.

Step 2: Pairwise comparisons. Compare each indicator with every other indicator in terms of their relative importance.

Step 3: Create the pairwise comparison matrix. Construct a matrix representing the pairwise comparisons. The matrix is usually square and symmetric.

Step 4: Calculate the priority weights. Determine the priority weights of indicators by computing the geometric mean or eigenvector method based on the pairwise comparison matrix. The weight of the i -th indicator is

$$\omega_i = \frac{\prod_{j=1}^n a_{ij}^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n a_{ij}^{1/n} \right)}, \quad (26)$$

where ω_i is the priority weight of the indicator i , and a_{ij} is the pairwise comparison value between elements. From this, we obtain weights ω_{AHP} .

Step 5: Check consistency. The consistency ratio (CR) is calculated by comparing the consistency index (CI) with a random index (RI) for the given matrix size. The formula for CR is

$$CR = \frac{CI}{RI}. \quad (27)$$

When CR is less than 0.1, it passes the consistency test.

6.3.2 CRITIC

The CRITIC (CRiteria Importance Through Intercriteria Correlation) method is used for

multi-criteria decision-making. It considers the inter-criteria correlations rather than relying solely on the subjective judgments of the decision-maker. The CRITIC weight is calculated by

$$\omega_i = \frac{1}{n} \sum_{j=1}^n \frac{r_{ij}}{\sum_{i=1}^n r_{ij}}, \quad (28)$$

where ω_i is the weight of the i -th indicator and r_{ij} represents the elements of the normalized correlation matrix. From this, we obtain weights ω_{CRITIC} .

6.3.3 Weight Combination

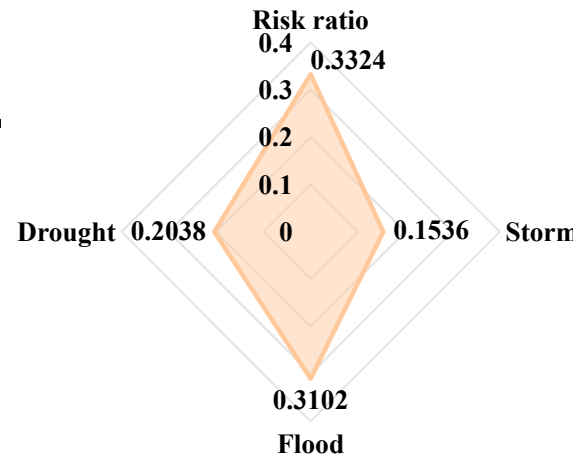
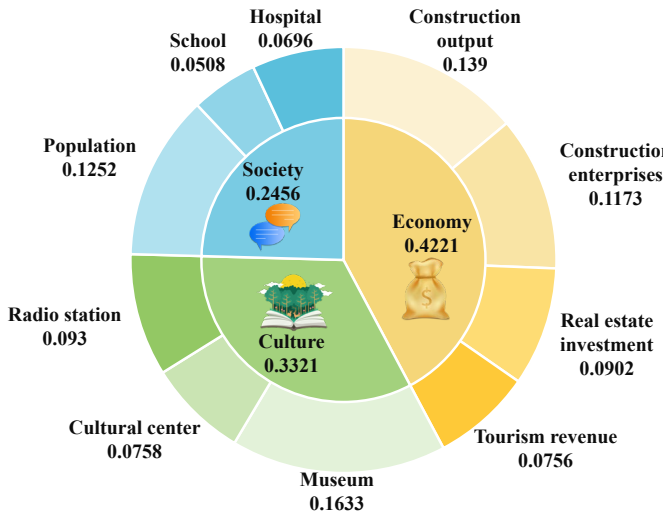


Figure 8: Weights of community indicators

Figure 9: Weights of climate indicators

We combine two weights that consider expert knowledge and actual indicators. The final weights will be more reflective of the real situation. Based on Minimum Relative Information Entropy, the objective is minimizing the relative deviation of results under two decision methods ω_{AHP} and ω_{CRITIC} :

$$\text{Minimize } \sum_{i=1}^n \omega_i (\ln \omega_i - \ln \omega_{AHP}) + \sum_{i=1}^n \omega_i (\ln \omega_i - \ln \omega_{CRITIC}), \quad (29)$$

$$s.t. \begin{cases} \sum_{i=1}^n \omega_i = 1, \\ \omega_i > 0, \\ i = 1, 2, \dots, n. \end{cases} \quad (30)$$

To solve this optimization problem, we construct the **Lagrangian function**:

$$L(\omega, \gamma) = \sum_{i=1}^n \omega_i (\ln \omega_i - \ln \omega_{AHP}) + \sum_{i=1}^n \omega_i (\ln \omega_i - \ln \omega_{CRITIC}) + \gamma \left(1 - \sum_{i=1}^n \omega_j \right), \quad (31)$$

where γ represents the Lagrange multiplier. Then, we can obtain the final weight by

$$\omega_i = \frac{(\gamma_i \alpha_i)^{0.5}}{\sum_{i=1}^n (\gamma_i \alpha_i)^{0.5}}. \quad (32)$$

The weights of community and climate indicators are shown in **Figure 8** and **Figure 9**, respectively.

6.3.4 CDI and CRI

Based on the previous evaluation model, we introduce the Community Development Index (CDI), which is an overall measure of the economic, cultural, and social significance of a community. The CDI is a score from 0 to 1, with a higher score indicating a higher value of the community. The formula for CDI is

$$CDI = \sum_{i=1}^{10} \omega_{1i} \hat{x}_{1i}, \quad (33)$$

where ω_{1i} is the weight of the i -th community indicator, and \hat{x}_{1i} is the normalized i -th community indicator. Similarly, the Climate Risk Index (CRI) is calculated by

$$CRI = \sum_{j=1}^4 \omega_{2j} \hat{x}_{2j} \quad (34)$$

where ω_{2j} is the weight of the j -th climate indicator, and \hat{x}_{2j} is the normalized j -th climate indicator. The CRI is a score from 0 to 1, with a higher score indicating a higher risk of the climate. The CDI and CRI allow community leaders to measure community value and its risks so that they can take protective measures.

6.4 Preservation Measures Based on GE Matrix

6.4.1 K-means Clustering

To distinguish between extreme-weather risk and community value in 127 communities, we use the elbow method to categorize their CDIs and CRIs into three levels: low, medium, and high, respectively. Then we obtain the three clustering centers by the k-means algorithm^[11]. The pseudocode of k-means clustering is in **Algorithm 1**.

Algorithm 1: k-means clustering

Input: The number of clusters k , set of data points X , number of data points n

Output: k cluster centers $\{c_1, c_2, \dots, c_k\}$

- 1: Randomly assign initial values for cluster centers $\{c_1, c_2, \dots, c_k\}$
 - 2: **Repeat**
 - 3: Assign each data point to its closest cluster center
 - 4: Compute the new center of each cluster
 - 5: **Until** the cluster centers do not change
-

Then, we use the mean values between two of the three centers to calculate the thresholds. The threshold between low level and medium level is $\theta_1 = (c_1 + c_2)/2$, and the threshold between medium level and high level is $\theta_2 = (c_2 + c_3)/2$.

6.4.2 GE Matirx and Preservation Measures

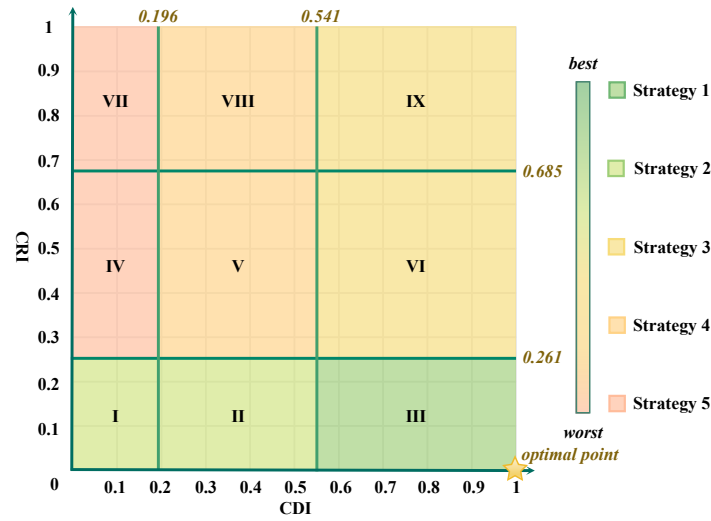


Figure 10: GE matrix and five preservation strategies

The GE matrix ^[12] in **Figure 10** shows the thresholds for CDI and CRI, which divide the GE matrix into nine regions. For different regions, we propose five preservation strategies for community leaders as follows:

Strategy 1: Emphasize building maintenance and raise community preservation awareness. Region III is the best region with high CDI and low CRI. This indicates a high building value and a low climate risk, which only needs moderate intervention. Community leaders should emphasize routine maintenance, implement monitoring systems, and raise community awareness of building protection.

Strategy 2: Invest according to resources and upgrade buildings. Regions I and II have low or medium EDI but low CRI. The value of the community is medium or low, but the climate risk is low, so community leaders need to improve the economic and cultural level of the community. They should make investments based on available resources and upgrade some of the buildings based on long-term plans and community development direction.

Strategy 3: Reinforce buildings, reserve supplies, and relocate buildings. Regions VI and IX have high CDI while medium or high CRI. This indicates that the buildings have high community value but are exposed to large climate risks. Therefore, community leaders need to take various protective measures. They should reinforce the building structure, design a plan, and stock materials to cope with extreme weather. Also, they can relocate or rebuild buildings in safer areas, especially high-value ones.

Strategy 4: Design emergency plans and improve building value. Regions V and VII have a medium CDI, but a medium or high CRI. Although the community has a high climate risk, it has some value and potential for future growth. Community leaders should design emergency plans for climate hazards and strengthen structures. At the same time, they can publicize local buildings and enhance their value.

Strategy 5: Give up buildings and relocate residents. Regions IV and V have low CDI and medium or high CRI. This indicates low community values but high climate risk. It is not cost-effective to invest a lot of money in preservation. Community leaders should abandon some of their buildings, help residents move to safer places, and build new buildings of high value.

7 Case Study of the Mogao Caves

The **Mogao Caves**, located in Dunhuang City, Gansu Province, China, boast numerous cave paintings and statues and are a witness to the Silk Road. However, affected by extreme-weather events, this landmark becomes hotter, more humid, and prone to heavy rainfall. This not only causes valuable paintings to fall off but also threatens the safety of residents.

7.1 Models Application

We apply the EWUS model and the ECS evaluation model to Mogao Cave.

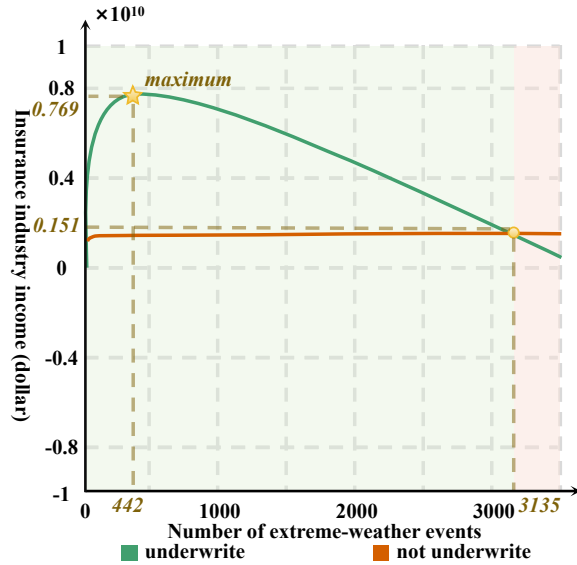


Figure 11: EWUS model result

Figure 11 shows that insurance companies earn a maximum profit of 7.69 billion dollars when the number of annual extreme-weather events is 442. However, this number is much larger than the actual average number of disasters per year in Dunhuang. Therefore, we recommend that community leaders expand property insurance coverage to secure the properties of residents and reduce the risk of extreme-weather events.

As shown in **Figure 12**, the historical data of CDI and CRI from 2000-2023 indicate a steady rise in CDI, except for a sudden drop in 2019, which we suppose was a blow to COVID-19. Meanwhile, the CRI fluctuates and rises, suggesting the high uncertainty of extreme weather.

We used **GM(1,1)** to predict trends in secondary indicators over the next fifty years and then calculate the corresponding CRIs and CDIs. According to **Figure 12**, if the community does not take protective measures for the Mogao Caves, its CRI will reach 0.51 by 2073. This suggests that the climate threat to the Mogao Caves will intensify over time and hinder community development.

According to Dunhuang Academy ^[13], the funds for the conservation and management of Mogao Caves in 2021 amounted to 145,605,300 yuan. Within this, most funds were spent on protection facilities and emergency plans, accounting for more than 20%. However, less funds were spent on cultural propaganda, heritage monitoring, and public education. We therefore propose a three-stage strategy based on the current status and future trends of Mogao Caves. Each stage contains measures that contribute to the sustainable development of the Mogao community.

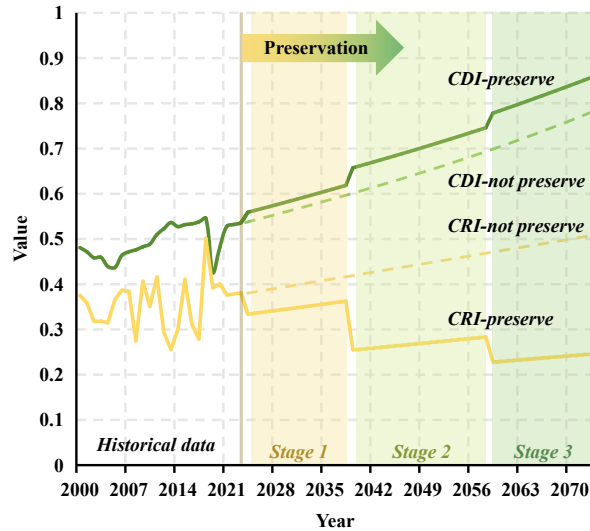


Figure 12: CDI and CRI from 2000 to 2073

7.2 The three-stage strategy for Mogao Caves

7.2.1 Stage 1: Build infrastructure and raise community awareness (2024-2038)

From 2024 to 2038, community leaders should expand their applications for conservation funds at an annual rate of **10%**, with **60%** for preservation facilities and emergency plans and the rest for preservation technology development and tourism management.

7.2.2 Stage 2: Develop preservation techniques and tourism (2039-2058)

From 2039 to 2058, community leaders could spend **60%** of funds on tourism management, academic research, public education, and preservation technology development, and reduce investment in preservation facilities.

7.2.3 Stage 3: Publicize Mogao culture to enhance international impact (2059-2073)

From 2059 to 2073, community values and climate risk prevention will be stable. Community leaders could reduce funds applications by **20%**. Together with revenues from tourism and other industries, they could spend 60% of the funds on cultural propagation, heritage monitoring, and public education to increase the international impact of the Mogao Caves.

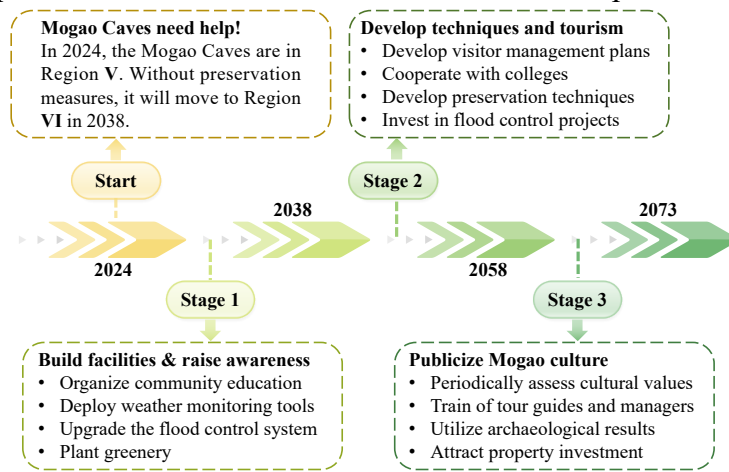


Figure 13: Timeline for preservation

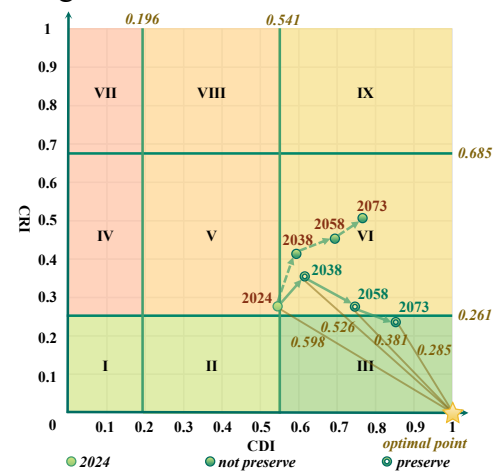


Figure 14: Strategy impacts

The specific measures for the three stages are shown in **Figure 13**. Compared to not implementing preservation measures, our preservation measures can further increase the CDI and decrease the CRI in each stage, see **Figure 14**. This indicates that our measures and investments can effectively boost the economic and cultural value of the Mogao Caves as well as diminish the threat of extreme-weather events.

We make reasonable assumptions about the impact of preservation measures on the indicators and recalculate the CDI and CRI for Mogao Caves in the next fifty years. **Figure 14** illustrates the change in its position in the GE matrix over time. If community leaders do not take any measures, it will move from Region V to Region VI in fifteen years. The climate risk will intensify over time. However, our three-stage strategy can enhance the value of the community and reduce climate risks, with a CRI increasing from **0.383** to **0.509**. The distances from the Mogao Caves to the optimal point after each stage will be **0.526**, **0.381**, and **0.285**, respectively, and this number is expected to decrease further in the future.

8 Sensitivity Analysis

Because extreme-weather events are uncertain, their damage to properties is sometimes difficult to predict. The EWUS model should have the ability to withstand uncertainty. At the same time, the AHP-CRITIC method used in the ECS model is subject to expert subjectivity in assessing community values, so we need to test the sensitivity of CDI to changed weights.

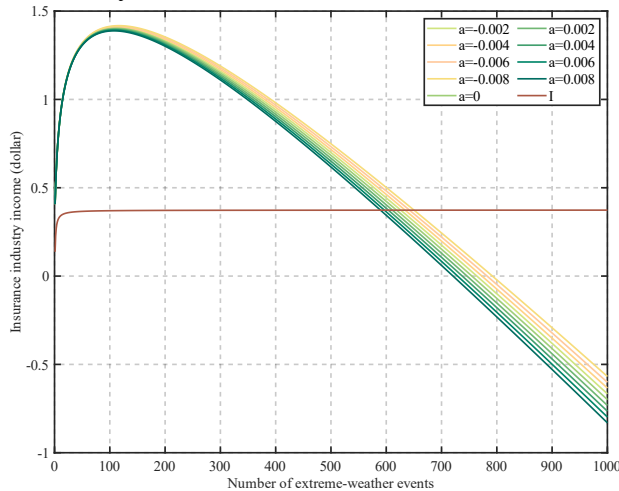


Figure 15: Change damaged buildings

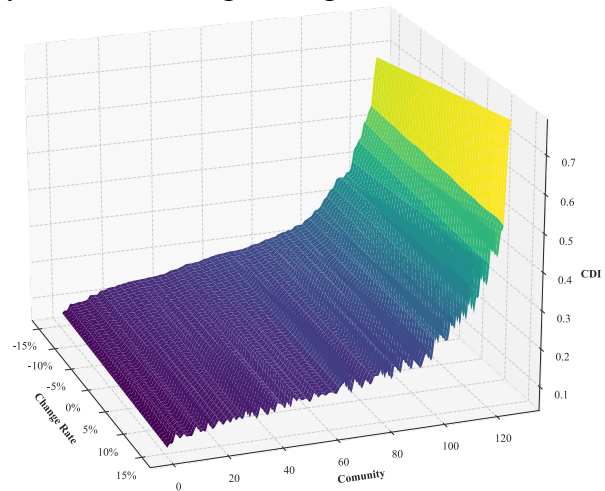


Figure 16: Change construction output

For the EWUS model, we vary the area of damaged buildings in Uruguay from -8% to 8% and observe the change in the income of insurance companies when they underwrite policies. Insurance companies make a profit through stock when not underwriting, so this is not affected by the area of damaged buildings. As shown in **Figure 15**, the model results are stable. The number of annual extreme-weather events that insurance companies can withstand decreases slightly as the area of damaged buildings increases.

For the ECS evaluation model, we previously concluded that the secondary indicator with the highest weight is Museums, followed by Construction output. However, the number of museums does not change much over time due to resource constraints and government regulation. Construction output, on the other hand, reflects the real estate and service development of the community and is more susceptible to extreme weather. Therefore, we vary the weight of Construction output from -15% to 15% and observe the changes in CDIs of 127 communities.

Figure 16 shows that the CDIs remain stable as we change the weights of Construction output. This indicates that the weights determined by the evaluation model are consistent with common sense. As the weight of Construction output increases, the rankings of the 127 community CDIs change slightly. This suggests that the communities with better real estate and service industries receive higher EDIs due to their larger weights.

In summary, our insurance model and evaluation model are **stable** when changing inputs. These two models help insurance companies and community leaders make decisions under some uncertainty.

9 Model Evaluation and Further Discussion

9.1 Strengths

- The EWUS model accounts for stock income, premiums income, investment income, and claims of insurance companies, which is consistent with reality.
- We employ game theory to simulate the negotiation between property developers, insurance companies, and residents, which well explains the decision-making process with multiple participants.
- The selection of indicators in the ECS model is multi-facilitated. We consider not only community development indicators such as property output and tourism revenue but also climate risk indicators such as risk ratio and storm.
- We combine AHP and CRITIC methods using information entropy minimization and solve it by Lagrange multiplier to obtain the final weights. The AHP-CRITIC method combines objective and subjective and can better reflect the actual situation.

9.2 Weaknesses

- The ECS model contains many indicators, and the accuracy depends on the dataset, which may lead to some bias.
- Extreme weather has uncertainty and the GM(1,1) model can only predict its overall trend, but not the specific fluctuations.

9.3 Further Discussion

- In the ECS model, we can incorporate regional effects, such as the degree of public support, to provide a more comprehensive evaluation.
- We can apply our models to business management problems such as company site selection and intangible cultural heritage conservation after making some modifications.

10 Conclusion

First, this paper proposed the EWUS model, which calculated the income of insurance companies in terms of not underwriting and underwriting. This allowed them to obtain more benefits based on the number of extreme-weather events in different regions. Second, we simulated the negotiation process among property developers, insurance companies, and residents through game theory and maximized the benefits of developers using non-linear optimization equations based on the EWUS model. If the result was consistent with the actual situation, it was suitable to develop the property in this location. Then, we developed the ECS model that used the AHP-CRTIC to obtain the weights of indicators from four aspects: economy, culture, social, and climate. We derived the GE matrix based on the calculated CDI and CRI and proposed five preservation measures. Subsequently, we applied the EWUS model and the ECS model to the Mogao Caves and proposed a three-step strategy, summarizing the timeline and cost proposal into a recommendation letter. Finally, the sensitivity analysis showed that the EWUS model and ECS model are stable when changing input variables.

References

- [1] *Our world in data*. (n.d.). Our World in Data. <https://ourworldindata.org/>
- [2] Valverde Jr, L. J., & Convertino, M. (2019). Insurer resilience in an era of climate change and extreme weather: an econometric analysis. *Climate*, 7(4), 55.
- [3] Botzen, W. J. W., Van den Bergh, J. C. J. M., & Bouwer, L. M. (2010). Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands. *Natural hazards*, 52, 577-598.
- [4] Sheehan, B., Mullins, M., Shannon, D., & McCullagh, O. (2023). On the benefits of insurance and disaster risk management integration for improved climate-related natural catastrophe resilience. *Environment Systems and Decisions*, 43(4), 639-648.
- [5] Tomić, H., Ivić, S. M., Roić, M., & Šiško, J. (2021). Developing an efficient property valuation system using the LADM valuation information model: A Croatian case study. *Land Use Policy*, 104, 105368.
- [6] Yalpir, S., Sisman, S., Akar, A. U., & Unel, F. B. (2021). Feature selection applications and model validation for mass real estate valuation systems. *Land use policy*, 108, 105539.
- [7] Weiqi, L. (2023). *The impact of stock liquidity on corporate cash holdings*.
- [8] Amihud, Y., & Mendelson, H. (1986). Liquidity and stock returns. *Financial Analysts Journal*, 42(3), 43-48.
- [9] Chordia, T., Roll, R., & Subrahmanyam, A. (2000). Commonality in liquidity. *Journal of financial economics*, 56(1), 3-28.
- [10] California, S. O. (n.d.). *California Insurance market share reports*. <https://www.insurance.ca.gov/01-consumers/120-company/04-mrktshare/>
- [11] Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A k-means clustering algorithm. *Journal of the royal statistical society. series c (applied statistics)*, 28(1), 100-108.
- [12] Shen, L., Zhou, J., Skitmore, M., & Xia, B. (2015). Application of a hybrid Entropy–McKinsey Matrix method in evaluating sustainable urbanization: A China case study. *Cities*, 42, 186-194.
- [13] Dunhuang Academy. (n.d.). <https://www.dha.ac.cn/>

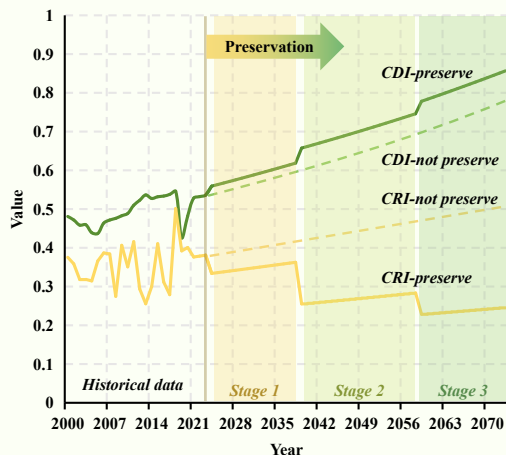
Letter to Mogao Caves Community



February 05, 2024

Dear Mogao Caves Community Members:

Given the intensified climate risks and the significant potential of the Mogao Caves, we propose a three-stage strategy in the main body of this letter. As shown in the line chart left below, this strategy can effectively enhance combined community value (CDI) and reduce climate risk (CRI). In addition, we provide a specific timeline and corresponding cost proposal in this letter to help you build your home.



Strategy Overview:

Foundation Building (2024-2038):

- Organize community education and annual Dunhuang Art Festivals to enhance cultural heritage awareness and boost tourism.
- Implement advanced weather monitoring and improve infrastructure, including flood defenses, to protect the caves.
- Initiate eco-projects to fight against sand erosion and encourage green development around the caves.
- Increase preservation funding by 10% yearly, dedicating 60% to infrastructure and emergency plans for the preservation of Mogao Caves.

Advancement and Sustainability (2039-2058):

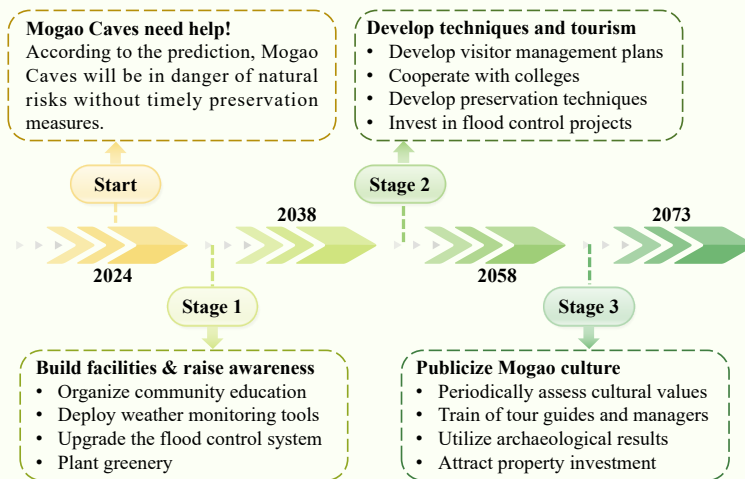
- Develop a strict reservation system and limit the number of visitors per day, which minimizes damage to the caves.
- Collaborate with colleges to develop advanced restoration and preservation techniques. Upgrading flood control dams to curb the threat of flooding to the caves.
- Shift your focus to sustainable tourism and advanced preservation techniques, investing 60% of funds in these areas to sustainably increase the value of the Mogao Caves.

Ongoing Stewardship (2059-2073):

- Conduct regular assessments of the environment and professional training programs which will ensure adaptation to emerging challenges and improve visitor experiences.
- Train tour guides and managers to maintain the exemplary image of the local tourism industry.
- Introduce advanced archaeological techniques to promote the number of archaeological discoveries.
- Reduce the need for preservation funds by capitalizing on economic benefits from tourism and industry growth, directing 60% of funds towards environmental management and education to boost the international impact of the caves.

Finally, insurance companies could continuously underwrite property insurance for the residents according to our insurance model. Thus, we recommend that community leaders should constantly improve the resilience of the community by promoting the coverage rate of property insurance.

The above is the three-step strategy that we derived from the model results and related background, from which we can see the great potential of Mogao Caves to enhance its value in the future. In addition, the three-step strategy will contribute to the sustainable development of the Mogao Caves. Therefore, we believe that through continuous efforts, Mogao Caves will benefit the community and move towards a bright future.



Sincerely,
Team # 2422579

Report on Use of AI

OpenAI *ChatGPT* (Nov 5, 2023 version, ChatGPT-4)

Query1:

I want to search for a dataset containing data related to extreme weather, climate change, and natural disasters where should I search?

Output:

To find datasets related to extreme weather, climate change, and natural disasters, you can explore several reputable sources. Here are some recommendations on where to start your search:

1. National Centers for Environmental Information (NCEI): Part of the National Oceanic and Atmospheric Administration (NOAA), NCEI offers a wide range of climate and weather datasets, including data on extreme weather events.
2. Global Historical Climatology Network (GHCN): This network provides long-term historical data on temperature, precipitation, and pressure. It's a useful resource for studying climate change.
3. NASA's Earth Observing System Data and Information System (EOSDIS): NASA provides access to a wealth of data from its Earth observation satellites, including data on climate variables, natural disasters, and environmental changes.
4. The European Centre for Medium-Range Weather Forecasts (ECMWF): Offers access to a variety of datasets, including reanalysis datasets that are useful for climate research and understanding extreme weather patterns.
5. The World Bank Climate Change Knowledge Portal: Provides access to global, regional, and country data related to climate change and its impacts.
6. The International Disaster Database (EM-DAT): Curated by the Centre for Research on the Epidemiology of Disasters (CRED), this database provides data on the human impact of natural disasters.
7. Google Dataset Search: A tool that enables the search for datasets stored across the web. You can use keywords related to your interest in extreme weather, climate change, and natural disasters.
8. Kaggle: An online community of data scientists and machine learners that provides access to datasets uploaded by users. You can find datasets related to climate change and natural disasters by searching the platform.

Each of these sources may require different levels of familiarity with data analysis and manipulation tools. Be sure to review the access and use policies for any dataset you plan to use to ensure compliance with licensing and attribution requirements.

Validation:

After searching some of the databases through the website, we found that extreme climate data for some countries can be found in The World Bank Climate Change Knowledge Portal. Some losses caused by disasters can also be found in the EM-DAT database. However, as we searched for useful data on websites such as UNDRR and the World Bank, the remaining datasets were not utilized.

Query2:

If an insurance company doesn't cover property insurance because of the frequency of natural disasters, will that insurance company's stock price fall?

Output:

An insurance company's decision not to underwrite property insurance due to the frequency of natural disasters may affect its share price in a number of ways, depending on a number of factors:

Market Expectations: If investors expect natural disasters to result in a large number of claims, which could harm the insurer's financial position, the insurer's decision may be viewed as a positive step to minimize potential losses, which could have a positive impact on the share price. However, if the market perceives the decision as highlighting a failure in the company's risk management or heralding a limitation on business growth, then the share price may fall.

Business Diversification: For those insurers with diversified businesses, property insurance may be just one of their many insurance products. If the company is able to compensate for or exceed the revenue lost by not writing property-casualty insurance through other lines of business (e.g., life insurance, health insurance, etc.), then the impact of this decision on the stock price may be moderated.

Long-term strategy: Investors are usually concerned about long-term returns. If an insurer demonstrates a sound set of strategic plans that show that not writing property insurance is part of its long-term sustainability plan and helps mitigate the risk of potentially large claims in the future, this may be viewed as a positive.

Communication and transparency: How an insurer explains its decisions to the market is also important. Effective communication can help alleviate investor concerns, while poor communication can lead to negative market perceptions of a company's prospects.

External environment: The wider market environment and economic conditions can also affect share prices. In times of economic prosperity, an insurer's share price may remain stable or rise even if it decides not to underwrite certain risks, as investors may be more focused on other positive factors.

In summary, the impact of an insurer's decision not to write property insurance due to the frequency of natural disasters on its stock price depends on how investors assess the impact of this decision on the company's long-term profitability. The decision may be viewed as a prudent measure to reduce risk, or it may be seen as an indicator of the challenges the company

faces. Investors typically make investment decisions based on a combination of factors, including the company's overall financial health, the degree of business diversification, and the market and economic environment.

Validation:

According to the study conducted by Woolridge and Snow^[1], they suggest that the stock market tends to react positively when companies make smart strategic investment decisions. Hereby, we verify that the results of the large language model answers are reasonable. We conclude that the cautious approach of insurance companies in refraining from underwriting property insurance to mitigate further losses does not significantly affect their stock market performance.

Query3:

Which normalization is susceptible to outlier interference?

Output:

In data preprocessing, normalization is a method of adjusting the scale of the data so that it falls within a small specific range, such as between 0 and 1 or -1 and 1. Different normalization methods have different sensitivities to outliers. One of the normalization methods that is most susceptible to interference from outliers is Min-Max Normalization (Min-Max Normalization).

Validation:

After normalizing the collected indicator data, we found that most of the data in some columns was very small. We speculate that it is the reason for the outliers in the data. By questioning the large language model and searching on the website, we found that this data normalization method is more sensitive to outliers in the data, thus verifying the rationality of the response to a certain extent.

References

- [1] Woolridge, J. R., & Snow, C. C. (1990). Stock market reaction to strategic investment decisions. *Strategic Management Journal*, 11(5), 353–363. <https://doi.org/10.1002/smj.4250110503>