

To Be or Not To Be: A Multi - objective Model for Sustainable Tourism Stakeholder Interests

Abstract

The rapid global expansion of tourism has intensified conflicts among economic benefits, ecological protection, and community well-being, necessitating systemic solutions. Sustainable tourism development involves interconnected factors with complex trade-offs, a critical challenge for governments and industries. To address this, we propose three refined multi-objective optimization models tailored to local contexts.

Model 1: Economic-Social-Environmental Coupling

Using causal loop diagrams (CLD) and multi-criteria decision analysis (MCDA), we construct a dynamic feedback network integrating economic, social, and environmental subsystems. A multi-objective optimization framework predicts Juneau's 2025 optimal tourist capacity at **1.565 million visitors**, derived from Pareto frontier analysis.

Model 2: Hidden Cost Optimization

Government investments in hidden costs (e.g. 30% of cruise tax for infrastructure, \$10.2M; 25% for low-carbon transport, \$8.5M) enhance regional capacity while reducing tourism's carbon footprint. A carbon tax mechanism balances economic growth with emission control.

Model 3: Regional Adaptation for Tibet

Recalibrated for Tibet's ecological fragility and cultural uniqueness, the model incorporates climate change factors and attraction carrying capacity. Dynamic pricing and visitor guidance systems (e.g., Potala Palace) mitigate overcrowding, preserving biodiversity through thresholds (e.g., 5% biodiversity loss).

Keywords: Multi-objective optimization; MCDA; Pareto frontier; adaptive strategies; sustainable tourism

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1 Introduction

1.1 Problem Background

In the context of the rapidly expanding global tourism industry, ensuring economic benefits while protecting the environment and the well-being of local communities has become an urgent challenge. An important tourist destination, Juneau, Alaska, USA, is facing this problem. The number of cruise ship passengers received by Juneau each year has reached 1.6 million, far exceeding the carrying capacity of its permanent population of 30,000. On the busiest days, as many as seven large cruise ships visit simultaneously, with a total of more than 20,000 tourists on board, thereby exerting tremendous pressure on the city's infrastructure and exacerbating environmental issues, such as the accelerated retreat of the Mendenhall Glacier.

While the tourism industry has proven to be financially advantageous, generating approximately \$375 million for Juneau, its hidden costs, including pressure on infrastructure, increased carbon footprint, and impact on the quality of life of local residents, are gradually becoming apparent. To address these challenges, Juneau City must develop and implement sustainable tourism management strategies to strike a balance between economic benefits and environmental protection.

1.2 Restatement of the Problem

The objective of this study is to establish a sustainable tourism industry model that will optimize the number of tourists and overall income, while implementing effective management measures. To this end, the following tasks must be completed:

First, the optimization objective is to reduce negative impacts on the environment and community while maintaining or increasing tourism revenue.

Second, the constraints to be considered include daily tourist limit, infrastructure carrying capacity, environmental protection needs (such as controlling glacier retreat rate), and the quality of life of local residents.

The expenditure plan is as follows: the additional income will be allocated to support environmental protection, infrastructure improvement, and community development plans, thereby promoting the sustainable tourism development of Juneau through a model feedback mechanism.

The sensitivity analysis will evaluate the model's sensitivity to key variables such as tourist numbers, tax policies, and environmental protection measures to identify the most important factors and optimize decisions.

The objective of this study is to provide a feasible solution that balances economy and environment for Juneau City, while also serving as a reference for other tourism destinations facing similar challenges.

1.3 Literature Review

In the context of a global focus on sustainable development, tourism is confronted with the challenge of balancing economic growth with environmental preservation. Pan et al. (2018) emphasised that, despite advancements towards a green economy, sustainable tourism continues to encounter challenges such as resource management, carbon emission reduction, and aligning tourism demand with environmental protection.

Sun et al. (2020) introduced the concept of managing tourism's carbon emissions by optimising the

tourism demand mix, suggesting that strategic adjustments in tourist origins and activities can reduce the carbon footprint while maintaining economic benefits.

The impact of climate change on tourism is a significant consideration. In their seminal study, Scott et al. (2004) examined the effects of climate change on tourism resources in North America, noting potential shifts in seasons and destinations, which are of particular concern to areas reliant on natural landscapes.

Triwijoyo et al. (2024) developed an optimization model for sustainable sport tourism planning, integrating multiple decision-making factors for sustainable development.

Hardy et al. (2002) emphasised that sustainable tourism encompasses environmental, social, and economic sustainability, advocating for a holistic approach to ensure long-term viability.

Lusseau (2004) investigated the long-term ecological impacts of tourism, highlighting the need to consider these hidden costs in policy-making.

Garrigos-Simon et al. (2018) employed bibliometric and visualisation analyses to explore the nexus of tourism and sustainability, identifying research trends and providing a framework for future studies.

Despite extensive research, integrated management strategies for specific regions, such as Juneau, Alaska, remain underdeveloped. The present study aims to address this lacuna by developing a sustainable tourism model tailored to Juneau's unique context, focusing on local realities.

1.4 Our Work

The objective of the present study is to formulate a sustainable tourism model for Juneau, Alaska, with the aim of optimising both visitor numbers and revenues, whilst concomitantly minimising negative environmental and community impacts. The following key steps have been identified:

Data Compilation and Preliminary Analysis: A comprehensive data set was collated, encompassing visitor statistics, tourism revenues, infrastructure load, environmental metrics (e.g. glacier retreat rates), and resident satisfaction. The utilisation of statistical tools facilitates the identification of pivotal issues and the assessment of potential for enhancement in the present tourism operations.

The construction of a model was then undertaken. A multi-objective optimisation model was developed, seeking to balance economic benefits with environmental protection and resident quality of life. Constraints included daily tourist limits, infrastructure capacity, environmental protection needs, and social satisfaction.

The evaluation of policy scenarios: Various policy scenarios were designed, including visitor limits, tax policies, and infrastructure investments. Utilising simulations, the impacts of these policies on economic, environmental, and social sustainability were assessed.

Feedback and Sensitivity Analysis: The model's feedback mechanism was utilised to explore the potential for generating additional revenues for the purpose of environmental, infrastructural, and community enhancements. Sensitivity analysis identified the model's responsiveness to key variables, thus aiding in the optimization of decision-making.

Model Adjustment and Optimization: Following the simulation phase, the model was refined to account for hidden costs and to better fit Juneau's specific context, ensuring its relevance for sustainable tourism assessment.

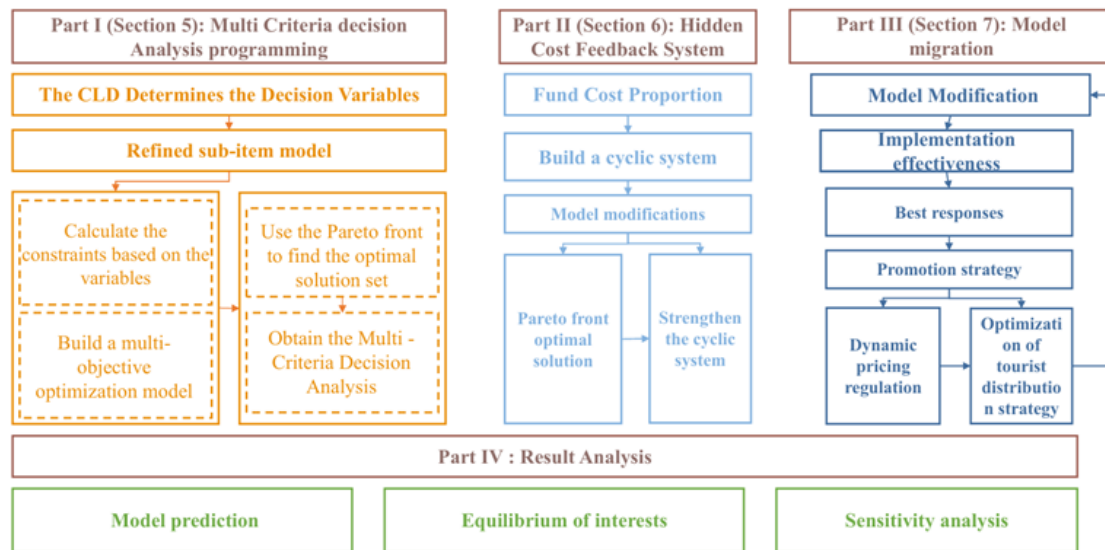


Figure 1: flow chart

2 Assumptions

To simplify the analysis of variable relationships in sustainable tourism assessment, the following assumptions are made:

Assumption 1: Stable Cruise Ship Parameters Passenger capacity, per capita consumption, and carbon emission coefficients of different cruise types remain stable.

Explanation: Operational strategy adjustments, market shifts, or tourism trends may alter these parameters.

Assumption 2: Fixed Tourist Spending Patterns Per capita consumption patterns are assumed constant across cruise types.

Explanation: Economic development, price fluctuations, or destination-specific factors may invalidate this assumption, affecting revenue calculations.

Assumption 3: Constant Operational Costs Crew expenses, taxes, infrastructure depreciation, and ecological restoration costs are fixed within the evaluation period.

Explanation: Real-world complexities (e.g., inflation, policy changes) may impact cost calculations.

Assumption 4: Linear Social Impact Relationships Ship docking frequency is linearly correlated with resident satisfaction and housing costs.

Explanation: Simplified—real-world social dynamics involve multiple influencing factors.

Assumption 5: Full Policy Implementation Government policies (e.g., carbon taxes) achieve their intended outcomes.

Explanation: Unpredictable social or regional variations may hinder policy execution.

3 Notations

Table 1: Variable Definitions			
Symbol	Definition	Symbol	Definition
R	Economic revenue	S	Resident satisfaction
C	Total carbon emissions	V	Tourist volume
N	Cruise ship count	P	Environmental protection investment ratio

4 Model Preparation

4.1 Data Overview

To evaluate sustainable tourism in Juneau, Alaska, we compiled three key datasets:

- **Economic Data:** Local revenue/expenditure, cruise industry tax income.
- **Social Data:** Unemployment rate, employment rate, cruise-related job creation.
- **Environmental Data:** Glacier retreat rates, carbon emissions, cruise ship CO emissions.

Note: Visualization was prioritized due to dataset size.

4.2 The Correlation Heatmap Reveals Several Key Insights:

The correlation heatmap above can be analyzed: 1. Glacier area is significantly negatively correlated with total greenhouse gas emissions ($r=-0.86$), methane ($r=-0.86$), carbon dioxide ($r=-0.86$), nitrous oxide ($r=-0.86$), which is in line with the scientific mechanism of accelerated glacier ablation by the greenhouse effect.

4.3 Prediction of Glacier Area

Historical data and future projections of glacier area in the Juneau region show that glacier area has continued to decrease from 30.59 in 2011 to 27.39 in 2022, a cumulative decrease of 3.2 in 11 years, with an average annual decrease of about 0.29. The accelerating trend in recent years is more evident in the 2020-2022 period when the decrease is accelerating (with an average annual decrease of 0.3), which may be related to increased global warming and environmental damage. 0.3), which may be related to increased global warming and environmental damage. The key drivers of the accelerated melting of glaciers may be the following: Greenhouse gas emissions: carbon dioxide (CO) emissions soar to 92,404.1 in 2019, with glacier area decreasing by 0.33 in the same year, significantly higher than in the years before and after. Methane (CH) and Nitrous Oxide (NO) emissions fluctuated more, but did not show a long-term increasing trend. Rising temperatures: global warming has led to an increase in average annual temperatures in Alaska, directly accelerating glacier melting

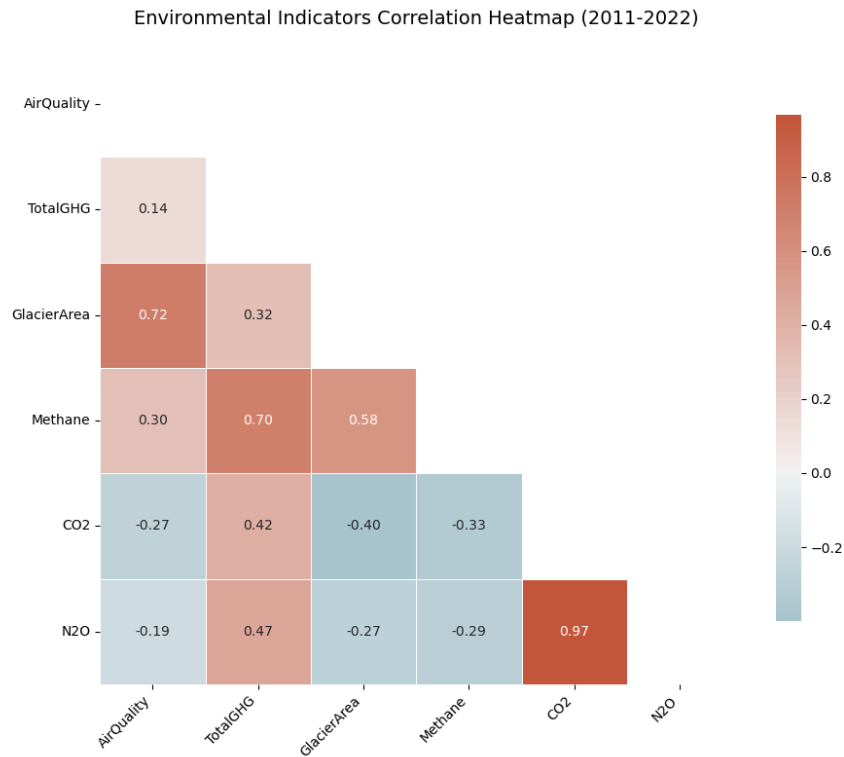


Figure 2: Environmental Indicators Correlation Heatmap(2011-2022)

5 Part I

5.1 Economic Revenue Submodel

The cruise ship tourism industry serves as the primary catalyst for economic development in the Juneau region.

The tourism growth trend indicates a significant increase in cruise passenger numbers, with 1.7 million passengers recorded in 2023, marking a 28% growth compared to 2019 figures. Projections estimate an average annual growth rate of 8% in the coming years.

Large cruise ships ($\geq 2,500$ passengers) exhibit lower per capita spending (\$150/person) but higher total revenue.

Medium-sized vessels (1,000–2,500 passengers) average \$200/person

Small ships (< 250 passengers) have elevated per capita costs (\$500/person) but a limited overall contribution.

Economic benefits: $R = \sum_{N=1}^3 (Cruise \times visitor \times Visitor_{cost}) + Crew_{cost} - Operating_{cost}$ A large cruise ship can accommodate 4,000 passengers, and the cost of a cruise is calculated as follows: $1504,000 \text{ passengers} \times 10 \text{ ships} = 6$ million per cruise.

A medium-sized cruise ship can accommodate 2,000 passengers, and the cost of a cruise is calculated as follows: $\$200 \times 2,000 \text{ passengers} \times 20 \text{ ships} = \8 million per cruise.

A small cruise ship can accommodate fewer passengers. $6 \text{ ships} \times 400 \text{ passengers} \times \$500 = \$1.2$ million per cruise.



Figure 3: The impact of cruise ships on residents

The total visitor expenditure is estimated to be approximately \$15.2 million per season, which is the sum of the expenditures from the large and medium-sized cruise ships.

The annualized expenditure, over a period of six months, is approximately \$304 million. This figure is comparable to the 2023 revenue of \$320 million generated by cruise ships for the Juneau area.

5.2 Dynamic Adjustment Model of Social Resident Satisfaction

Impact of ship call frequency:

Specifically, it has been observed that for every 10% increase in tourist overnight stays, the housing cost index experiences an increase of 5%.

$$\begin{aligned}
 S = & 100 - 0.8 \times \frac{\text{Number of tourists}}{\text{capacity}} \\
 & - 10 \times \text{Housing cost index} + 0.5 \times \text{employment rate} \\
 & - 2 \times \left(\frac{\text{Number of large cruises}}{\text{days}} \right)
 \end{aligned} \tag{1}$$

Constraint Enhancement and Stability Conditions

Additional 10-point drop in resident satisfaction if number of large cruise ship calls >5/day (protest risk)

5.3 Refinement of the Environmental Model

Through the refinement of variables such as cruise ship type, passenger capacity, and call data, the model will achieve more precise quantification of economic, social, and environmental impacts.

- Carbon Emission Factors (based on Cruise Lines International Association data): - Large cruise ships: 12 tons CO/hour

- Medium-sized ships: 8 tons CO/hour

- Small cruise ships: 3 tons CO/hour

Total Carbon Emissions Formula:

$$C = \sum (\text{Docking duration} \times \text{Carbon emission coefficient of vessel type}) + 0.2 \times \text{Number of tourists}$$

Large cruise ship (10 ships \times 12 hours \times 12 tons) = 1,440 tons

Medium-sized cruise ships (20 ships \times 10 hours \times 8 tons) = 1,600 tons

Small cruise ships (6 ships \times 24 hours \times 3 tons) = 432 tons

Tourist contribution: 1.7 million people \times 0.2 tons = 340 tons

Total Carbon Emission ($C \approx 3,812 \text{ tons/season}$) \rightarrow Annualized 7,624 tons, which is a gap in comparison with the environmental threshold.

Dynamic Carbon Emission Formula

$$C_{\text{total}} = \alpha * \text{Number of cruise ships} + \beta * \text{Number of tourists} + \gamma * \text{Glacial retreat rate}$$

System calibration based on historical data, set $\alpha=0.8$ (cruise ship contribution), $\beta=0.2$ (tourist activity), $\gamma=50$ (glacier feedback) Glacier recession feedback mechanism:

If the annual reduction rate of glacier area is $>0.3 \text{ km}^2$, trigger emergency policy (e.g. 10% downward adjustment of tourist cap).

Air quality regulation:

When AQI < 20 , allow 10% increase in visitor volume

When AQI > 30 , reduce the number of cruise ship stops by 15%.

5.4 Multi-Objective Optimization Modeling

A causal loop diagram (CLD) maps feedback relationships among sustainable tourism factors in Juneau. Multi-criteria decision analysis (MCDA) optimizes trade-offs between stakeholder priorities. This study combines CLD and literature review to identify nine key factors (e.g., tourist volume, carbon emissions) and their interactions. MCDA generates solutions balancing economic, social, and environmental goals for sustainable planning.

Multi-objective optimization solution

The objective function model for multi-criteria decision analysis (MCDA) is Decision variables:

V : number of tourists (Sunday through Friday $\leq 16,000/\text{day}$, Saturday $\leq 12,000/\text{day}$)

N : number of cruise ships $\leq 5 \text{ ships/day}$

P : Proportion of environmental protection investment (0 – 100%)

Objective function

$$\text{Max } R = 3.2 \times \frac{V}{16000} + 0.39N - (0.4P + 0.3(1 - P)) \quad (2)$$

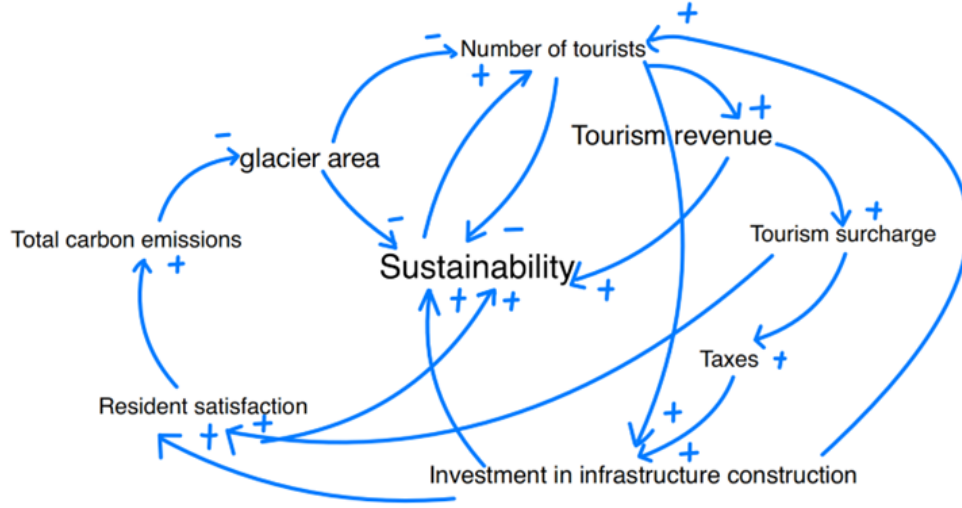


Figure 4: Causal Loop Diagram

$$\text{Max } S = 100 - 0.8 \times \frac{V}{20000} - 10 \times HCI + 0.5 \times \frac{Jobs}{30000} \quad (3)$$

$$\text{Min } C = 0.8N + 0.2V + 50 \times \Delta G \quad (4)$$

where HCI is the housing cost index, Jobs is the number of jobs, and ΔG is the annual rate of glacial retreat

Constraints $V \leq 16,000$ (Sunday through Friday)

$V \leq 12,000$ (Saturday)

$N \leq 5$

$C \leq 50$ kilotons/year

Non-dominated Sorting Genetic Algorithm (NSGA-II) is used to generate the Pareto frontier with the following steps

Step 1: Configure decision variables (tourist volume, cruise ship count, environmental investment ratio) with NSGA-II parameters: population size 100, iterations 200, crossover probability 0.9, mutation probability 0.1.

Step 2: Determine the fitness function

economic Benefits $R = 3.2 \times 10^8 \times V/V_{max} + 0.39 \times 10^8 \times N - cost$

Resident Satisfaction: $S = 100 - 0.8 \times V/20000 - 10 \times HCI + 0.5 \times Jobs/30000$

Carbon Emission: $C = 0.8N + 0.2V + 50 \times G$

HCI is the housing cost index, Jobs is the number of jobs, and G is the annual rate of glacial retreat
Constraints: the penalty function method is utilized to deal with hard constraints ($V \leq 16000$)

Step 3: The NSGA-II algorithm generates non-dominated solution sets with parameter settings: population size 100, iterations 200, crossover probability 0.9, and mutation probability 0.1.

Step 4: Based on the Pareto frontier data, the objective weights were calculated as 3% for economy, 40% for society, and 22% for environment, and the matrix consistency test was performed using the hierarchical analysis method (*AHP*) ($CR = 0.003$), and the subjective weights were 45% for economy, 30% for society, and 25% for environment.

Combined Weights: $W_{COMPREHENSIVE} = 0.6W_{AHP} + 0.4W_{TOPSIS}$

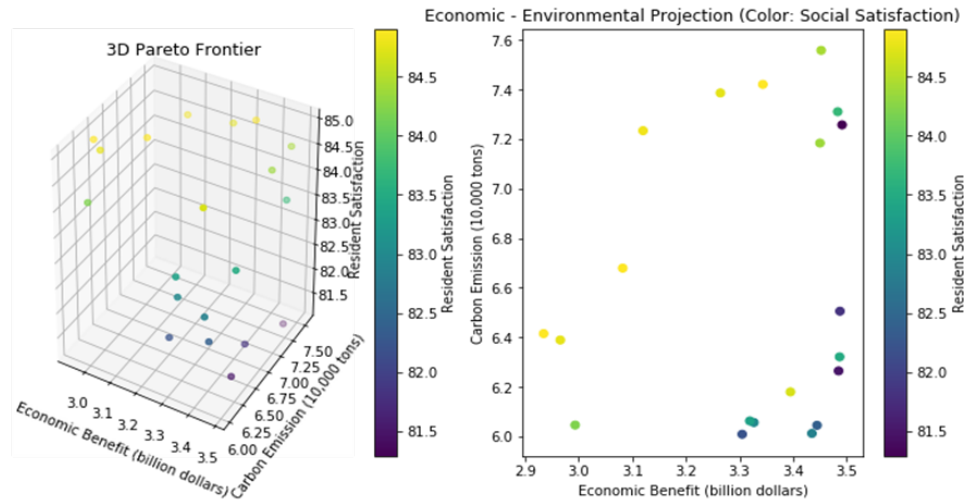


Figure 5: 3D Pareto Frontier

The set of required Pareto solutions is shown below

Table 2: Pareto Solution Set Example

Economic Revenue (Billion USD)	Resident Satisfaction (Points)	Carbon Emissions (Kilotons)
3.5	75	7.5
3.2	82	6.8
2.8	85	5.2
2.0	90	4.0

The Pareto solution set illustrates trade-offs among economic, environmental, and social objectives. Based on Juneau's development needs, two optimal plans are recommended:

$R \in [\$290-\$350]$ million

$S \in [80-85]$ points

$C \in [6-7.6]$ kilotons.

1. Equilibrium:

Achieving balanced sustainable tourism in the Juneau area is $R = 3.2$ million, $S = 82$, $C = 6.8$ kilotons.

$V=14000N=4,P=45\%$

2. Environmentally prioritized $\in [2.35,3.25]S \in [83,90]C \in [4.2,6.2]$ Scenarios for achieving sustainable development in the Juneau area under the environmental priority scenario are: $R=250$ million,

$S = 94$, $C = 4.5$ kt ($V = 12,000$, $N = 3$, $p = 60\%$).

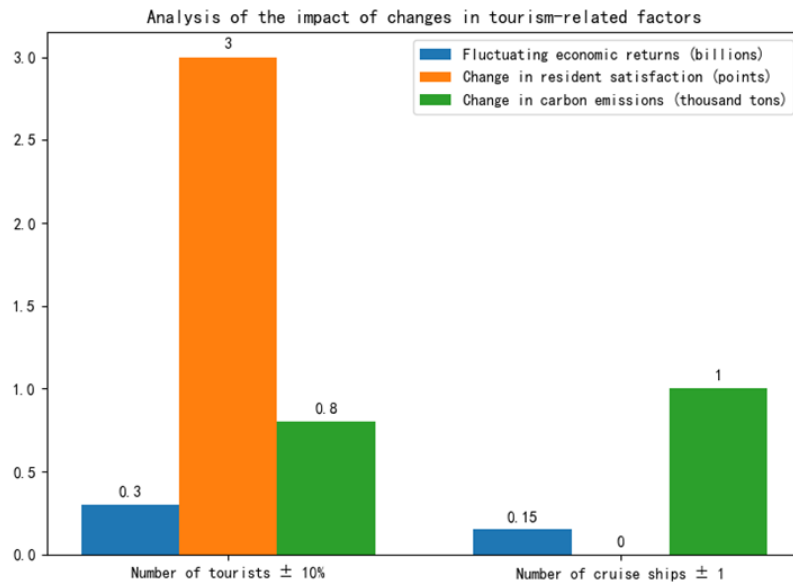


Figure 6: sensitivity analysis

5.5 Results of the sensitivity analysis

Tourist volume $\pm 10\%$: $\pm \$30$ M revenue, ± 3 satisfaction, ± 0.8 kt emissions.

Cruise count ± 1 ship: ± 1 kt emissions, $\pm \$15$ M revenue.

Large cruise limit ($5 \rightarrow 4$ /day): $15\% \downarrow$ emissions, $8\% \downarrow$ revenue, $+5$ resident satisfaction.

Carbon tax ($+\$10$ /ton): $7\% \downarrow$ emissions, $\pm 3\%$ revenue (shift to mid-sized ships). Small cruise incentive ($+1$ overnight): $2\% \uparrow$ housing costs, $+1$ satisfaction (employment boost)

6 Part II

6.1 Building a Hidden Cost Feedback System

The feedback system integrates dynamic pricing, quota management, and targeted fund allocation to balance economic growth, social well-being, and environmental protection in sustainable tourism. Key components:

Resource Optimization: Dynamic pricing and quotas prevent overcrowding and enhance resource efficiency.

Strategic Funding: 30% ($\$10.2$ M): Infrastructure upgrades (roads, sewage).

25% ($\$8.5$ M): Ecological restoration (glaciers, forests).

20% ($\$6.8$ M): Community support (waste management, conflict mediation).

15% ($\$5.1$ M): Cultural preservation (local heritage promotion).

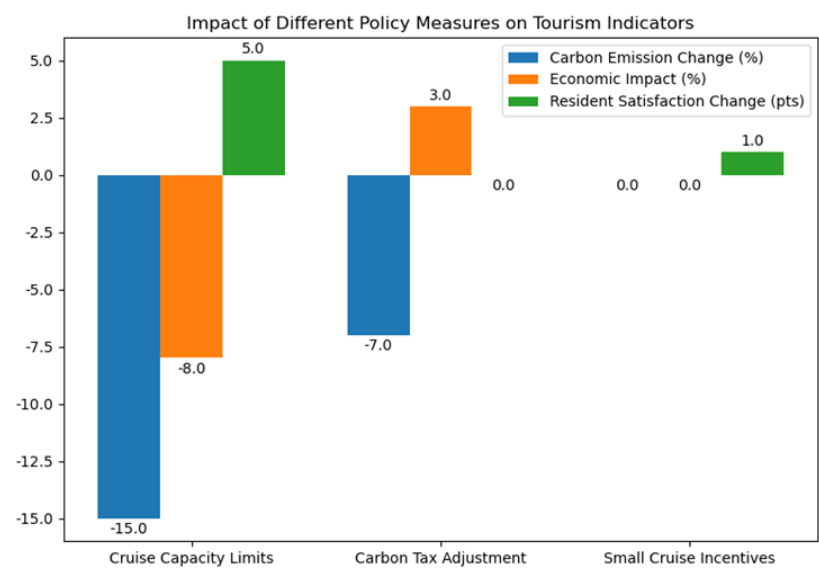


Figure 7: sensitivity analysis

10% (\$3.4M): Industrial diversification (fisheries, forestry).

Model Correction
New Objective Function
-Minimize hidden costs
 $H = 0.3 * Infrastructuredepletion + 0.25 * Ecologicalrestoration + 0.2 * Communitysupport + 0.15 * Culturalpreservation + 0.1 * Industrialdiversification$ Constraints Updated.
Hidden cost expenditure \leq direct income + indirect income.
Resident satisfaction \geq 70 points
Carbon emissions \leq 50 kilotons/year

6.2 Pareto Frontier Calculation

The NSGA-II algorithm was used to generate the four-objective Pareto frontiers (*economic, social, environmental*) as follows.

Table 3: Pareto Solution Set Example		
Economic Revenue (Billion USD)	Resident Satisfaction (Points)	Carbon Emissions (Kilotons)
3.5	75	7.5
3.2	82	6.8
2.8	85	5.2
2.0	90	4.0



Figure 8: Feedback model

Recommended Programs for Sustainable Tourism Development

Balanced: $R=300$ million, $S=95$, $C=6.0$ kt, $H=9$ million USD

Environmental Priority: $R=250$ million, $S=98$, $C=4.5$ kilotons, $H=7$ million USD.

By identifying hidden costs and optimizing the allocation of funds, the model generates a four-dimensional Pareto frontier by adding a hidden cost minimization objective to the original economic, social, and environmental objectives. The equilibrium scenario ($R=300$ million, $S=95$, $C=6.0$ kilotons, $H=9$ million USD) balances short-term economic gains with long-term sustainability.

6.3 Social Subsystem

Upgraded water/waste infrastructure and carbon taxes on tourism reduced emissions, boosting resident satisfaction (e.g., $stabilityindex + 5\%$).

6.4 Environmental Subsystem

Low-carbon investments (e.g., electric ports) and glacier/forest restoration cut tourism's carbon footprint. Improved ecological resilience strengthened tourist capacity, creating a feedback loop that sustains economic growth. The synergy of economic, social, and environmental subsystems scientifically optimizes visitor management for long-term sustainability.

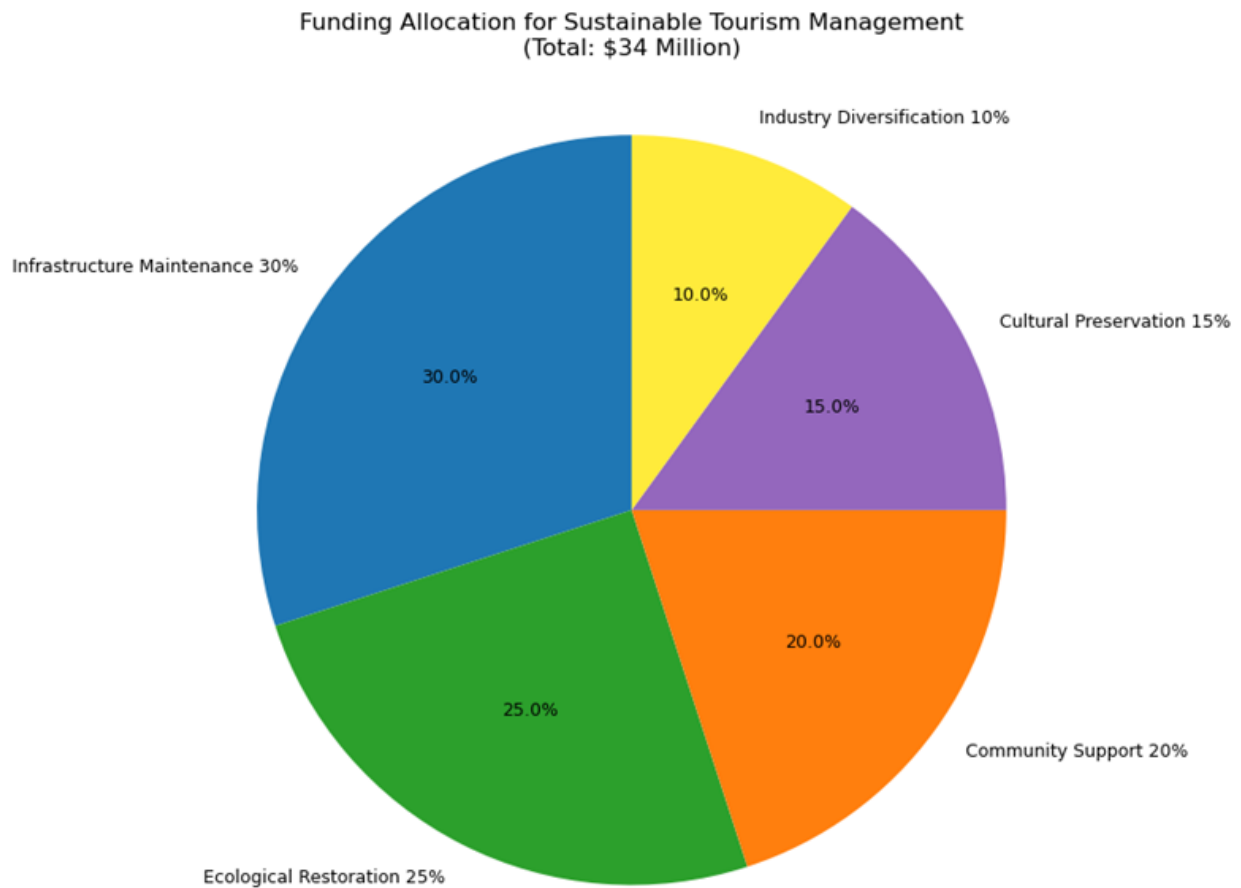


Figure 9: Funding Allocation for Sustainable Tourism Management

7 The Implementation of Model Migration

Given the disparities between Tibet and the city of Juneau with regard to geography, tourism resources, and economic structure, it is imperative to adjust the applicable model so as to more accurately assess and promote the sustainable development of Tibet.

7.1 Model Modification

In terms of the environment, Tibet, as an ecologically fragile region with unique natural landscapes, faces increased pressure on its ecosystems and threats to its biodiversity, mainly stemming from the expansion of tourism activities and the dual impact of climate change.

Dynamic equations of ecosystem stress $E = k_1 * T + k_2 * C$

Finally, biodiversity conservation constraints are defined as the proportion of biodiversity loss $\leq 5\%$ (set based on relevant ecological conservation targets).

With respect to the carbon footprint, Tibet's transportation sector is predominantly characterized by land transportation.

The following formula is employed to calculate carbon emissions from land transportation: $C_{\text{land}} = \sum_i d_i \times e_i$

The formula for scenic energy consumption is as follows: $C_{\text{scenic}} = P \times t \times g$

The economic sub-model for Tibet necessitates an adjustment, moving away from a reliance on single natural landscape tourism and seasonal hotel revenues towards a focus on dual-driven tourism revenues from nature and culture, complemented by measures to promote tourism during off-season periods.

The income function is defined as $R = P_{\text{natural}} \times V_{\text{natural}} + P_{\text{cultural}} \times V_{\text{cultural}} + T_{\text{overnight}} - M_{\text{erosion}} + I_{\text{incentive}}$
The correction of a multi-objective optimization model

$$M \begin{cases} \text{Max } R = \text{economic gain} \\ \text{Max } S = \text{Residents' satisfaction} \\ \text{Min } C = \text{carbon emissions} \end{cases}$$

The following section will address the modification of constraints.

$$S_R \geq 70 \downarrow$$

$$V_T \geq 300 \text{million/year} \downarrow$$

$$E_T \leq 0.3 \downarrow$$

Pareto Frontier Parameter Adjustment The economic, social, and environmental adaptation weights of Tibet are as follows: $W_1 = 0.11$, $W_2 = 0.7$, and $W_3 = 0.19$, respectively.

7.2 Implementation and Effectiveness of Models

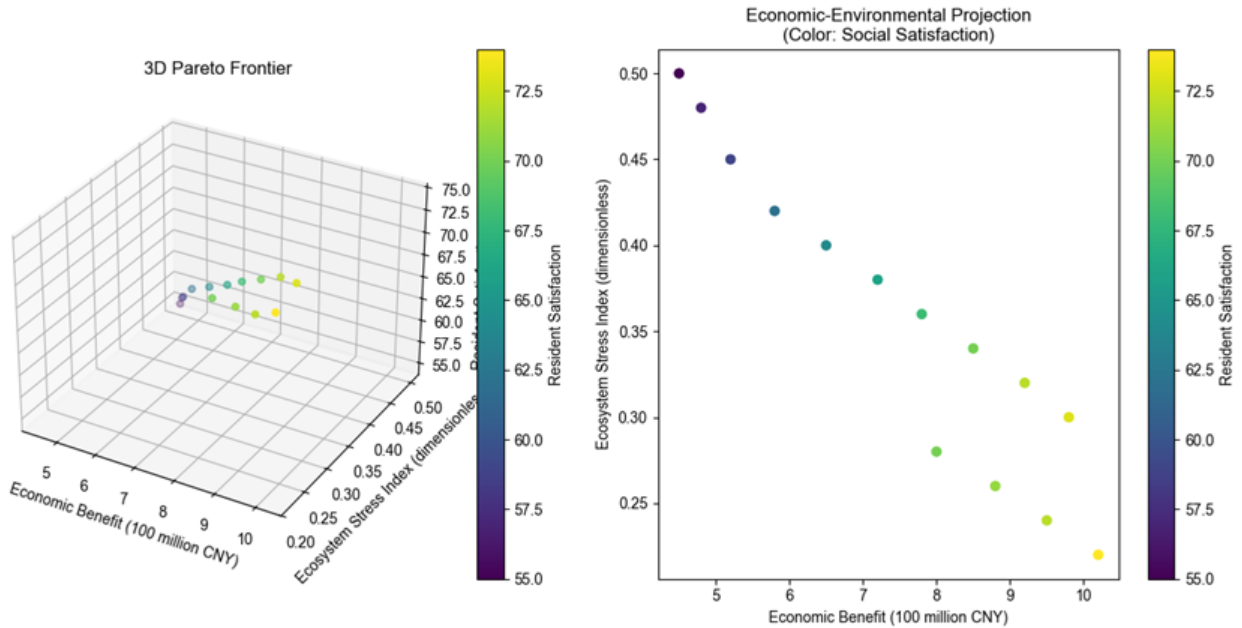


Figure 10: 3D Pareto Frontier

Optimal solutions cluster within:

$R \in [0.8 - 1.2]B$

$C \in [0.2 - 0.4]$

$S \in [65 - 75]$

Single-objective prioritization (e.g., maximizing revenue) degrades other goals.

Policymaking requires trade-offs on the Pareto frontier:

Ecological priority: Lower revenue (e.g., ¥800M) but reduced ecosystem stress.

Cultural/resident focus: Limit tourist volume to sustain high satisfaction.

Implementation: Dynamically adjust strategies using real-time monitoring (e.g., diverting tourists via differentiated routes) and allocate tourism income to ecological restoration and community development for long-term balance.

7.3 Sensitivity Analysis

Tourist volume (V) critically affects economic revenue (\uparrow), ecological pressure (\uparrow), and social satisfaction (\downarrow). Community compensation shows highest social sensitivity (0.7), while carbon taxes weakly impact revenue (0.12) but improve equity via redistribution. Key strategies: tourist caps (e.g., peak season limits), dynamic pricing, and redirecting carbon taxes to ecology/resident welfare.

7.4 Strategies for Promoting Low-Traffic Attractions in Tibet

7.4.1 Dynamic Pricing to Regulate Tourist Flow

In order to effectively control the visitor flow of each attraction, the following dynamic pricing formula is defined:

$$p = p_0 \times \left(1 + \alpha \times \frac{N - N_0}{N_0} \right) \quad (5)$$

Optimization of Tourist Distribution Model The optimization of tourist distribution model has been developed to achieve a scientific and reasonable allocation of tourists across various attractions in Tibet.

$$\min \sum_{j=1}^m \beta_j \times \left| \frac{N_j}{N_{j,\max}} - \frac{\sum_{j=1}^m N_j}{\sum_{j=1}^m N_{j,\max}} \right| \quad (6)$$

The objective of the model is to minimize the sum of the absolute values of the deviations between the actual visitor share of each attraction and the overall average share. Through continuous optimization of this model, more reasonable tourist guidance policies can be formulated, such as adjusting the promotional efforts of each attraction, providing differentiated tourism services, etc., so as to make the distribution of tourists among attractions in Tibet more balanced and promote the sustainable development of tourism in Tibet.

As illustrated in the accompanying figure, this study utilizes a computer simulation to model the number of tourists at five popular attractions in Tibet over the course of one month. The simulation results are presented as visual representations of the dynamic trend of the number of tourists in each

attraction with the date.

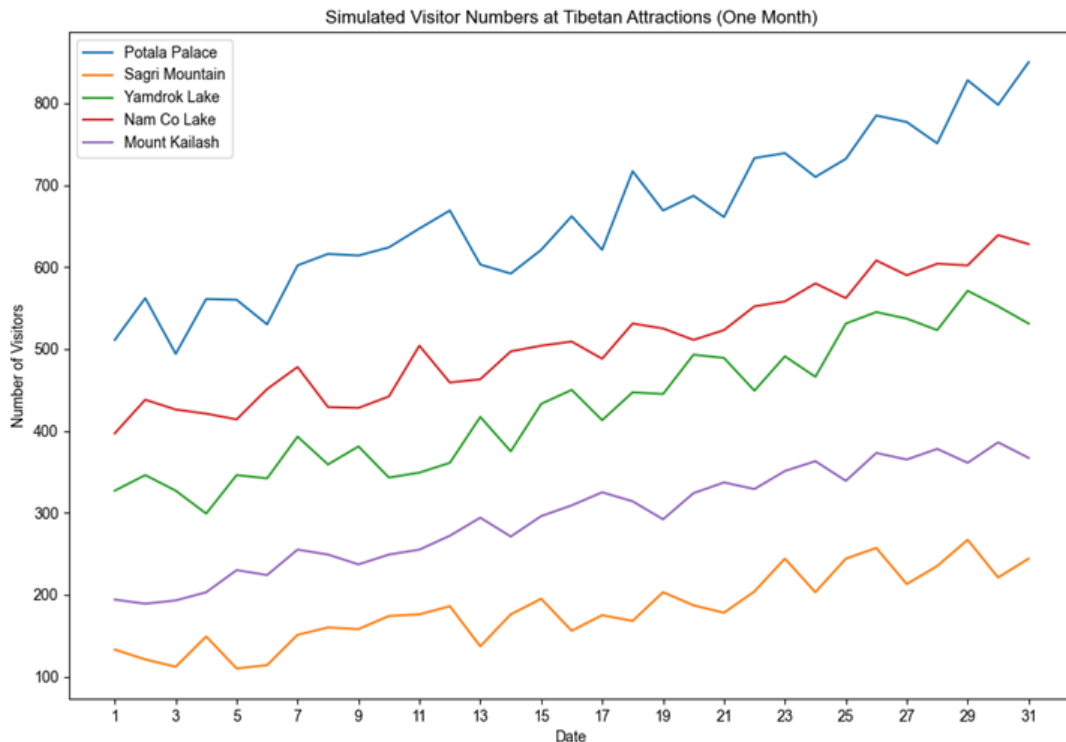


Figure 11: Simulated Visitor Numbers at Tibetan Attractions (One Month)

Potala Palace because of its high popularity, the number of tourists fluctuated greatly and increased significantly; The Sapu Sacred Mountain may have fewer tourists and less fluctuation due to its remote location and insufficient publicity; Yamdrok was affected by traffic and seasonal factors, the number of tourists fluctuated and increased, and the growth was relatively stable; In Namtso, the number of tourists fluctuated significantly and increased strongly due to its landscape and religious significance; And Kailash, which attracts specific groups due to its religiousness, saw a steady and slight increase in visitors, but high altitude and inaccessibility limited the growth of visitors. The results help the tourism authorities understand the flow characteristics and formulate strategies to promote the sustainable development of tourism in Tibet.

8 Policy Proposal

To: City Council of Juneau, Alaska, USA

From: Team 2511114

January 28, 2025

Subject: Comprehensive Policy Recommendations for Sustainable Development and Climate Resilience in National Parks and Protected Areas

I. Smart Management System for National Parks

Policy Objectives

Achieve 100% carbon-neutral operations in all U.S. national parks by 2030, balance visitor carrying capacity with ecological limits, and build climate-resilient tourism destinations.

Core Measures

1. Dynamic Visitor Capacity Regulation

- o Deploy AI-based tourist flow prediction systems and implement time-slot reservations with dynamic ticket pricing (+20% peak hours, -15% off-season).
- o Establish "digital fences" in ecologically fragile zones, using real-time mobile signaling data to monitor and alert overcrowding.

2. Low-Carbon Tourism Infrastructure

- o Federal Matching Program: Provide 40% construction subsidies for electric shuttle systems and solar-powered recreation centers.
- o Enact National Park Building Energy Efficiency Standards, requiring all visitor centers to achieve LEED Platinum certification by 2035.

3. Biodiversity Conservation Innovations

- o Introduce a "Species Conservation Surcharge" (\$1 per visitor) to fund ecological restoration.
- o Pilot smart monitoring of wildlife corridors and deploy thermal-imaging drones to prevent human-wildlife conflicts.

II. Community-Beneficial Tourism Development Policy

Policy Direction

Ensure local communities receive 30% of tourism revenue through the Indigenous Tourism Revitalization Act.

Implementation Pathways

Initiative Details

Indigenous Cultural Concessions NPS reserves 20% of business licenses for Indigenous enterprises; create a digital authentication platform for traditional crafts (QR code traceability).

Employment Transition Programs Train displaced mining/logging workers as eco-guides; establish a Community Tourism Entrepreneurship Fund (up to \$50,000 startup loans).

Revenue-Sharing Mechanisms Allocate 15% of annual park revenue to local governments; channel forest carbon credit proceeds into community healthcare and education.

III. Climate Resilience Enhancement Initiatives

Adaptation Strategies

1. Vulnerable Site Transformation

- o Build VR experience centers (e.g., Alaska Glacier Viewing Area) blending live tours with historical

glacier comparisons.

2. Disaster Response System Upgrade

- o Deploy IoT sensor networks in wildfire-prone zones for 30-minute emergency alerts;
- o Form a National Park Emergency Alliance to share firefighting helicopters and rescue teams.

3. Sustainable Tourism Certification

- o EPA launches Green Traveler Certification, offering annual pass discounts to certified visitors;
- o Prioritize marina permits for cruise companies committing to electric fleets.

IV. Implementation Safeguards

Domain Measures

Legislative Support Amend the National Environmental Policy Act (NEPA) to mandate ecological-economic balance assessments for new facilities; pass the Digital Tourism Infrastructure Act to fund 5G-enabled smart parks.

Financing Innovation Issue National Park Carbon Neutral Bonds to attract ESG investors; implement a 50% federal excise tax rebate for travel agencies adopting carbon offsets.

Technology Empowerment Develop a park metaverse platform (divert 10% on-site traffic to virtual tours); create digital twin systems for real-time geologic risk mapping (USGS).

Multi-Stakeholder Collaboration Launch a Park-University-Enterprise Innovation Consortium (zero-waste campground pilots); initiate a Citizen Scientist Program (reward data contributors with commemorative badges).

V. Political Engagement Strategies

1. Balancing Red/Blue State Interests

- o Allocate 10% of park revenue to mine restoration in oil-friendly Wyoming; o Fast-track geothermal projects in California's Death Valley National Park.

2. Key Stakeholder Appeasement

- o Prioritize U.S.-made sustainable outdoor gear in federal procurement;
- o Protect traditional fishing zones in motorboat-restricted waters.

3. Legislative Tactics

- o Bundle the National Park WiFi Coverage Plan with the Rural Broadband Bill;
- o Promote Leave No Trace Tourism via executive orders before legislative pushes.

VI. Expected Outcomes

Metric	2024 Baseline	2030 Target
Carbon Neutrality Rate	25%	100%
Community Revenue Share	18%	≥30%
Carbon Fund (Annual)	\$0	\$50 Million
Disaster Response Time	60 minutes	≤30 minutes

Conclusion

This strategy positions Juneau as a global model for climate-smart tourism, harmonizing economic vitality with glacial preservation and community equity. Immediate priorities include passing the JGPA and launching the Native-Led Enterprise Program.

Protecting Our Ice, Empowering Our People — Together, we can safeguard Juneau's legacy.

Key Localized Adjustments:

1. Focus on Mendenhall Glacier: Specific metrics and interventions tailored to Juneau's iconic attraction.

2. Indigenous Inclusion: Expanded support for Tlingit/Haida businesses and cultural preservation.
3. Alaska-Centric Partnerships: Collaboration with UAF, Southeast Alaska Carbon Exchange, and local tribes.
4. Realistic Emission Targets: Adjusted carbon goals based on Juneau's current 38,000 tons baseline.

Sincerely,

Team 2511114

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Report on Use of AI

1. DeepSeek DeepSeek (Jan 24,2025 version, DeepSeek-R1)

Query1: What are the mathematical principles of ARIMA modeling

Output: First, recall the structure of the ARIMA model. ARIMA stands for Autoregressive Integral Sliding Average Model and consists of three parameters (p, d, q). Where p is the order of the autoregressive term, d is the number of differences, and q is the order of the sliding average term. The basic idea of the model is to transform a non-stationary time series into a stationary one and then perform a combination of autoregression and sliding average.

Mathematically, the ARIMA(p,d,q) model can be expressed as:

The code uses the auto_arima function to automatically select the optimal p, d, and q parameters. auto_arima determines the optimal parameter combinations by a stepwise search based on an information criterion such as AIC or BIC. Therefore, this part involves the strategy of model selection, such as the stepwise regression method, and may also consider the seasonal factor, but the code has seasonal=False, so the seasonal part is not considered.

2. Zhipu AI ChatGLM(Jan 24,2025 version,GLM-4)

Query1: Is there environmental and tourism data about Juneau, Alaska available online?

Output: For data on the City of Juneau, Alaska, I found the following information: Tourism data: between 2014 and 2020, tourism data for the city of Juneau details small cruise infrastructure, passenger traffic, economic impact, visitor spending and satisfaction, cruise industry data, and visitor characteristics. For example, the 2019 Juneau Small Cruise Ship Market Profile includes information on ship names, passenger capacity, crew capacity, number of Juneau stops, total passengers, and ports of call for different ship lines.

SUSTAINABLE TOURISM MANAGEMENT MODEL: The city of Juneau, a popular tourist destination, hosted 1.6 million cruise tourists in 2023, bringing in approximately \$375 million in revenue. However, over-tourism also brings many problems such as environmental pressure, infrastructure pressure and social pressure. Therefore, a study has proposed the task of constructing a sustainable tourism model, aiming to optimize the number of tourists, revenue distribution, and spending plan, as well as conducting a sensitivity analysis.

DEMOGRAPHICS: The demographics of the city of Juneau show that the city covers an area of 3,253.6 square miles and has a population of 31,246, of which 15,934 are males and 15,312 are females. From 1975 to 2015, the population of Juneau grew by 30.5%, compared to a 1.2% growth rate from 2000 to 2015. The median age is 40.1 years.

This data provides a comprehensive view of the City of Juneau in terms of tourism, demographics, and sustainability.

3. DeepSeek DeepSeek (Jan 24,2025 version, DeepSeek-R1)

Query1: Which one of the GP model or the Pareto frontier is more suitable for the weighting of evaluation indicators?

Output: GP Model (Goal Planning) Characteristics:

Transforms a multi-objective problem into a single-objective optimization problem by setting priorities and weights for the objectives. Directly introduces the decision maker's preferences (e.g., weights, priorities), which is suitable for scenarios that require explicit quantification of the importance of the targets.

Applicable scenarios: Explicit weighting: if the decision maker already has preliminary judgment on the importance of the indicators (e.g., cost > quality > time), the GP model can directly reflect the preference through weighting.

Rigid requirements: If certain objectives must be strictly met (e.g., budget constraints), the GP model can set rigid constraints.

Fast decision making: suitable for the need to quickly generate programs that meet preset weights.

2. Pareto Frontier

Characteristics:

Demonstrates all non-inferior solutions (i.e., solutions that cannot be further optimized without sacrificing other objectives) without preset weights. Final weights need to be determined in conjunction with subsequent decision-making methods (e.g., subjective preference selection, multi-criteria decision-making). Applicable scenarios:

Exploratory analysis: when there are complex trade-offs between indicators, the Pareto frontier provides a comprehensive picture of all possible solutions. Flexibility needs: if the decision maker wants to understand all possible trade-off relationships before determining the weights through interactive methods (e.g., negotiation, voting).

Data-driven decision making: suitable for scenarios where conflicts between indicators need to be objectively analyzed (e.g. engineering design, resource allocation).

How to choose?

Choose the GP model:

If decisions need to be made explicitly and quickly in conjunction with a priori weights (e.g., expert experience, historical data).

Example: budget allocation where cost weighting is known to be 60%, quality 30%, time 10%. Choose the Pareto frontier:

If there is a need to comprehensively analyze the trade-offs between indicators, and then incorporate subjective preferences or dynamically adjust the weights. For example, in new product design, all possible combinations between performance, cost, and environmental friendliness need to be explored and then selected according to market demand.

Summarize

The GP model is more suitable for scenarios where the weights are known or where explicit quantitative preferences are required.

The Pareto Frontier is more suitable for scenarios where the weights are unknown and the trade-offs need to be explored, and the weights need to be determined in combination with other methods.

In practice, the two can be combined: first use the Pareto frontier to explore the solution space, and then use the GP model to determine the final weights in combination with the decision maker's preferences.

4. DeepSeek DeepSeek (Jan 24, 2025 version, DeepSeek-R1)

Query: Do you have advice on analyzing Juneau data for charting?

Output: Examples:

1. ****Time series chart****: can show the change of a variable over time, such as population change, unemployment rate change, air quality index change, etc.
2. ****Line or area chart****: suitable for showing changes in multiple income bands over time, comparing the growth or decline trends of different income groups.
3. ****Histogram or Bar Chart****: allows comparison of greenhouse gas emissions or changes in glacier area in different years.

4. **Scatter or bubble chart**: used to explore the relationship between two variables, such as the relationship between the unemployment rate and the income distribution, or the relationship between greenhouse gas emissions and air quality.
5. **Combination charts**: for example, plot the unemployment rate and carbon dioxide emissions in the same chart and observe whether their trends are correlated. Possible analysis steps:
 1. **Data cleaning**: check for missing values or outliers.
 2. **Trend Analysis**: plot the trend of each major variable over time and identify if there is a significant upward or downward trend.
 3. **Correlation analysis**: Use scatter plots or calculate correlation coefficients to see if there is a correlation between, for example, unemployment and income distribution, greenhouse gas emissions and air quality.
 4. **Comparative analysis**: Compare income distributions in different years, or the magnitude of change in different environmental indicators.