



RESEARCH ARTICLE

Sustainable Tourism Development: Strategies, Challenges, and Emerging Opportunities — A System-Dynamics and Multi-Criteria Policy Assessment

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ABSTRACT

While tourism drives economic development, its uncontrolled growth degrades the environmental and social assets destinations depend on and accounts for a significant share of global greenhouse-gas emissions. Abstract—Tourism is a key enabler of economic development. Still, when poorly managed, it can degrade the environmental and social resources that underpin destination development and contribute a significant share of global greenhouse-gas emissions. Several approaches exist, such as limiting visitors, imposing tourism taxes, shifting to low-carbon transitions, and spatio-temporal diversification, but quantitative evidence on their long-run impacts in combination remains limited. A system-dynamics (SD) model is created that is reproducible and includes environmental, social, economic, and climate feedbacks in a mid-sized destination, and six policy scenarios are assessed for the next 25 years (2025-2050). The Sustainable Tourism Index (STI) is calculated through a composite process, followed by a Monte Carlo uncertainty analysis (400 runs), a one-at-a-time sensitivity analysis, a policy space sweep (1681 runs), and an entropy-weighted TOPSIS ranking. If the business-as-usual (BAU) scenario prevails, environmental quality will decrease from 0.79 to 0.54, crowding will peak above the social threshold, and the critical environmental-quality threshold has a 31.8% chance of being crossed by 2050. Modest gains (STI 3.5%-7.7%) can be achieved with single instruments, whereas an integrated policy mix results in an STI of 16.0% and ranks first under entropy and equal weighting. The optimum is revenue constrained, with a cap of close to 2.1 million arrivals per annum at an 8.5% levy, resulting in the highest STI (+27.6%) with a 14.8% reduction in cumulative emissions. The results indicate that sustainable tourism requires a package of complementary instruments and the shift from volume to value.

Keywords: Sustainable tourism, System dynamics, Overtourism, Carrying capacity, Tourism levy, Multi-criteria decision making, Monte Carlo simulation, SDGs, Decarbonization and TOPSIS.

INTRODUCTION

The tourism industry is one of the world's largest sectors and an important development avenue for many areas, providing jobs, foreign exchange, and preserving cultural and natural heritage [1] [2]. At the same time, this growth can destroy the destination: ecosystem degradation, congestion, rising housing prices, resident disenchantment, and greenhouse-gas (GHG) emissions. When considering the tourism supply chain, Lenzen et al. estimated tourism's contribution to global GHG emissions at around 8% [3]. These tensions have become very apparent in the phenomenon of overtourism in cities and natural sites [4] and [5].

The term sustainable tourism (ST), as defined by the UN World Tourism Organization as tourism that fully respects the current and future economic, social and environmental impacts [1], is now part of the 2030 Agenda and has been included in the Sustainable Development Goals (SDGs) 8, 12 and 14 [6]. Although there is a vast quantity of literature available on the fundamentals [7]– [9], there are still three gaps.

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First, most research focuses on individual instruments, while in reality, policy packages are being employed in real-life destinations, where their effects can be compounded. Second, destinations are systems with delayed and nonlinear feedbacks, as noted by Butler's life-cycle model [10] and Doxey's irritation index [11], but static indicator frameworks cannot capture these dynamics. Third, the robustness of policies under deep uncertainty of the tourism demand and ecological response has not been tested.

2. Research Gaps and Key Contributions of the Proposed Quantitative Assessment Framework

- An SD model developed to link visitor demand, environmental quality, resident satisfaction, local revenue, and emissions with a set of balancing feedback loops, based on the principles of tourism theory.
- A systematic comparison of five strategies (caps on visitors, green levies, low-carbon transition, diversification, integrated mix) to business-as-usual from 2025-2050.
- An analysis of policy design space that yields a policy space that maximizes revenue under certain constraints.
- Robustness analyzed using Monte Carlo simulation, sensitivity analysis, and entropy-weighted TOPSIS ranking, with open code and data.

2.1 Policy Strategies

Demand management instruments restrict the number of visitors or shift demand, such as by restricting entry, setting quotas, requiring reservations, and using dynamic pricing. They rely on carrying capacity considerations [12] and risk

revenue loss and displacement. Economic instruments like tourist taxes and levies internalize external costs, and their incidence and demand effects depend on price elasticity and destination substitutability [13]. The climate footprint is addressed with low-carbon transition measures, such as renewable energy in accommodation, local mobility (electrification) and access (modal shift) [14, 15]. Diversification spreads demand across seasons and sites by creating off-season products, additional attractions, and community-based tourism, counteracting the seasonality that concentrates impacts in a few months [16].

2.2 Challenges

Persistent challenges include the governance gap between sustainability rhetoric and its application [17], stakeholder interests, leakage of economic benefits, the need for many destinations to rely heavily on long-haul aviation, and limited monitoring capacity [8, 18]. The COVID-19 pandemic has revealed the fragility of growth models based on volume and has called for a “build back better” [19].

2.3 Emerging Opportunities

Smart tourism technologies like real-time monitoring systems, big data analysis, and digital reservations enable dynamic demand management and create new opportunities [20]. Other models that can help achieve this include regenerative and community-based models, nature-positive finance, and decarbonizing transport and energy supply. Table 1 summarizes the strategies and how they relate to the model levers.

TABLE 1: Sustainable Tourism Strategies and Model Representation

Strategy	Mechanism	Model lever	Refs.
Visitor cap	Limit peak arrivals	L1: cap on monthly V	[5], [12]
Green levy	Price + conservation fund	L2: levy share of spend	[13]
Low-carbon	Cut emission intensity	L3: adoption stock I	[14], [15]
Diversification	Spread demand in time/space	L4: seasonal & spatial spread	[16]
Integrated mix	Bundle of L1–L4	L1 + L2 + L3 + L4	[17]

3. Methodology

3.1 Framework Overview

System dynamics is a suitable tool for tourism because destination outcomes can be derived from stocks, flows, delays, and feedbacks. The causal-loop structure is given in Fig. 1. Visitor arrivals V increase environmental pressure P, which in turn decreases environmental quality E, and

crowding C, which decreases resident satisfaction S, both of which feed back to the destination attractiveness, thus forming two balancing loops (B1 and B2) in line with Butler and Doxey. Four policy levers operate on the system. The model is a stylized medium-sized coastal or heritage tourist destination with 2.0 million tourists annually in 2025, simulated monthly from 2025 to 2050.

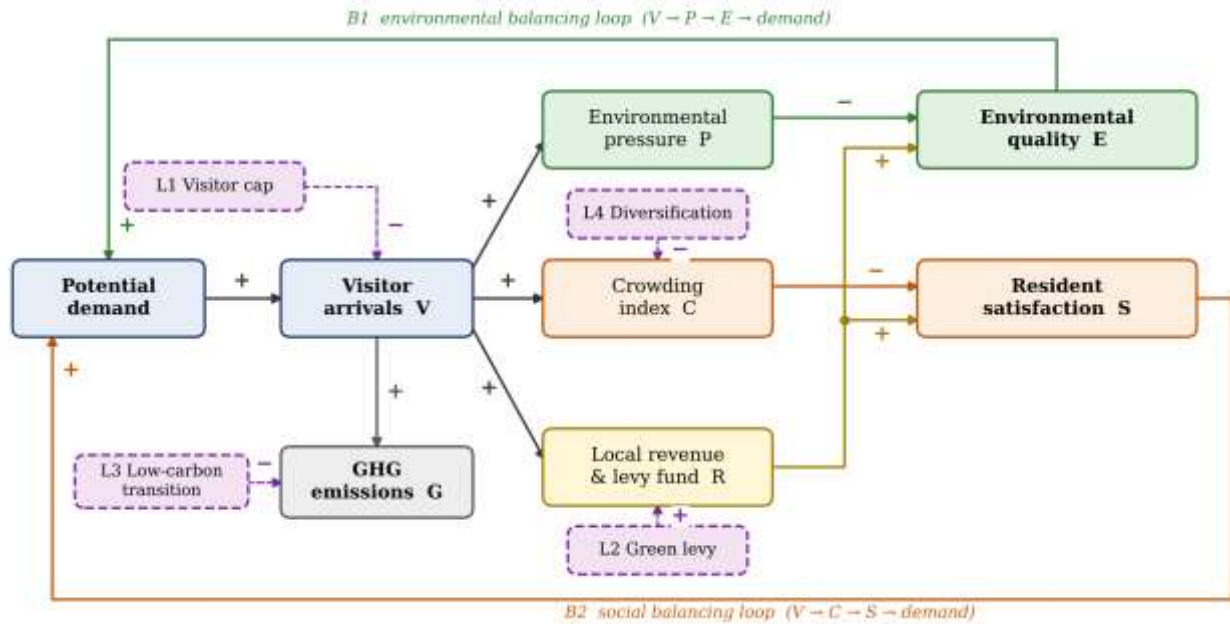


Fig. 1. Causal loop model of the destination model. Solid arrows represent causal relationships with polarity; B1 and B2 represent balancing loops; dashed purple boxes represent policy levers L1–L4.

3.2 Profitability and value of visits

Monthly demand is exogenous growth, attractiveness feedback, response to the price of the levy and seasonality:

$$D(t) = (V_0/12)(1+g)^t A(E,S) \Phi(\lambda) \sigma(t) \quad (1)$$

$$A(E,S) = (E/E_0)^{\beta_E} (S/S_0)^{\beta_S} \quad (2)$$

$$\Phi(\lambda) = (1+\lambda)^{-\varepsilon} \exp(-\kappa\lambda^2) \quad (3)$$

$$\sigma(t) = 1 + a \cos[2\pi(m-6)/12] \quad (4)$$

where A is the destination attractiveness (with elasticities β_E and β_S), m the calendar month, λ the levy share of visitor spending, ε the price elasticity, κ a competitiveness penalty due to substitution to other destinations at high levies, and a the amplitude of the seasonality. In the presence of a cap, arrivals will be $V = \min(D, 1.15 V_{cap}/12)$, which provides for a small peak-month tolerance of 1.15 times.

3.3 Health and Social Services

The environmental quality is logistic regeneration, pressure-driven degradation, and the conservation investment funded by levies U :

$$dE/dt = rE E(1-E) - dE P E + cI U(1-E) \quad (5)$$

$$P = (\delta V/K_{env})^{\alpha}, \quad C = \max(0, \delta V/K_{soc} - 0.5) \quad (6)$$

where $\delta \leq 1$ is the spatial-dispersion factor under diversification, and K_{env} and K_{soc} are the environmental and social carrying capacities. The convex pressure term ($\alpha > 1$) reflects increasing damage when approaching capacity. Resident satisfaction changes, with a time lag τ_S , with a target that decreases with crowding and increases with

locally shared benefits B :

$$dS/dt = [S^*(C, B) - S] / \tau_S(7)$$

4 Economy and Emissions

Local revenue is $R = V w \rho$, with w , the spending per visit, and ρ , the local retention rate (one minus leakage). 70% of levy revenues go toward conservation and 30% for community uses. Emissions are modeled as $G = V e_0(1 - \gamma)t(1 - 0.45I)$, with $I \in [0,1]$ being a logistic green-transition stock, which only increases when lever $L3$ is in use.

4.1 Sustainable Tourism Index

A strong sustainability composite index is based on the geometric mean of the four pillars' performance. It thus cannot be fully compensated for a poor performance in any pillar.

$$STI = (E_{2050} \cdot S_{2050} \cdot \Pi_{eco} \cdot \Pi_{clim})^{1/4} \quad (8)$$

Both of them would be clipped to the interval $[0, 1]$ with $\Pi_{eco} = 0.5 R_{cum}/R_{cumBAU}$ and $\Pi_{clim} = 1 - 0.5 G_{cum}/G_{cumBAU}$ so that they would score 0.5 on the two relative pillars.

F. Scenarios

The parameters are given in Table 2 and the six scenarios in Table 3. Model parameters are made-up but reasonable values for a generic destination, rather than being "tuned" to a particular site.

TABLE 2: The base case parameters for the model are listed.

Symbol	Description	Value
V_0	Arrivals in 2025	2 M yr ⁻¹
g	Potential demand growth	4.0% yr ⁻¹
β_E, β_S	Attractiveness elasticities	1.2, 0.6
ε, κ	Price elasticity, levy penalty	0.4, 30
a	Seasonal amplitude (BAU)	0.55
$K_{\text{env}}, K_{\text{soc}}$	Carrying capacities	0.45, 0.25 M month ⁻¹
α	Pressure exponent	2
r_E, d_E	Regeneration, degradation	0.3, 0.45 yr ⁻¹
c_I	Conservation efficacy	0.04 yr ⁻¹
τ_S	Attitude adjustment time	2 yr
w, ρ	Spend per visit, retention	900 USD, 0.6
e_0, γ	Emission intensity, decline	0.6 tCO ₂ e, 1% yr ⁻¹

Table 3: Policy Scenarios

Scenario	Cap (M yr ⁻¹)	Levy	Divers.	Low-carbon
S0 BAU	—	—	—	—
S1 Visitor cap	3.0	—	—	—
S2 Green levy	—	8%	—	—
S3 Low-carbon	—	—	—	✓
S4 Diversification	—	—	✓	—
S5 Integrated mix	3.4	6%	✓	✓

Uncertainty, Sensitivity, and Ranking

Ten parameters are sampled from uniform distributions, covering values of $\pm 20\%$ of their base values, and a total of 400 runs are performed per scenario (Monte Carlo analysis). Sensitivity analysis: All parameters are varied individually around 20%. The STI is mapped by policy sweep, which is a 41×41 grid of caps (2–6 M yr⁻¹) and levies (0–20%) with diversification and low carbon active. Ranking: entropy-weighted TOPSIS [23, 24] ranks scenarios according to their values of 5 criteria: cumulative revenue (benefit), E2050 (benefit), S2050 (benefit), cumulative emissions (cost), and mean peak crowding (cost). The weights for the entropies are $w_j = (1 - H_j)/\Sigma(1 - H_j)$, and the weights for the closeness coefficient are $C_i = d_i^-/(d_i^+ + d_i^-)$.

H. Implementation

The model is implemented in Python 3 (NumPy, pandas, Matplotlib) with explicit Euler integration ($\Delta t = 1$ month).

One script restores all the figures and tables and writes the data underlying the figures and tables as csv files (supplementary material with this paper).

4. Results

4.1 Business-as-Usual Dynamics

BAU is a projection scenario in which numbers increase from 2.0 to 2.96 million per year by 2050, with the growth rate slowing down as both balancing loops come into play (as illustrated in Fig. 2). The environmental quality drops from 0.79 to 0.535, approaching the critical zone ($E < 0.5$), and resident satisfaction decreases from 0.74 to 0.586. Crowding peaks from June to August (see Fig. 3(a)), with the highest index at 1.03, exceeding the irritation threshold ($C = 1$) during 4 late-horizon peak months. This is closely related to the stagnation stage of the tourism area life cycle [10].

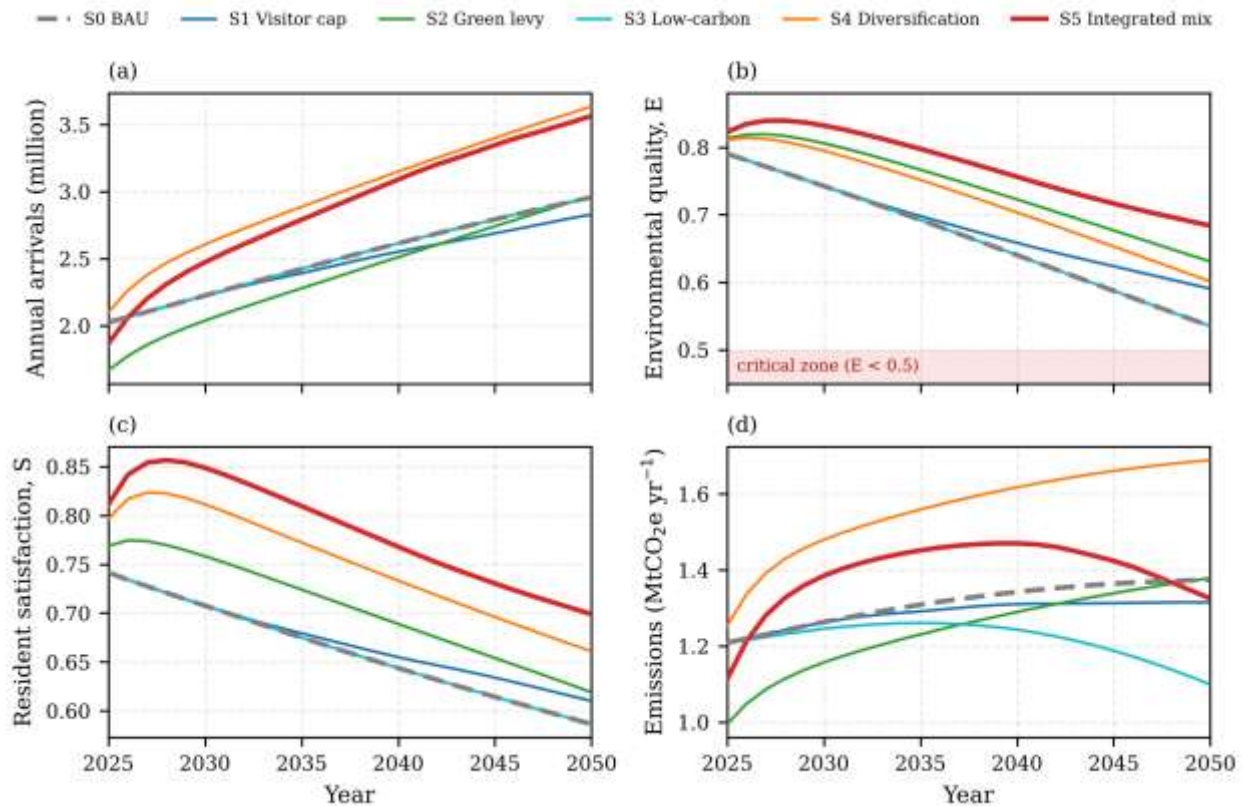


Fig. 2. The scenarios of the projections for 2025-2050: (a) annual arrivals, (b) environmental quality, (c) resident satisfaction, and (d) annual emissions. In (a)–(c), the BAU curve (dashed grey) is the same as S3 since the low-carbon lever only impacts emissions.

4.2 Single-Instrument Strategies

An individual instrument positively affects only a limited number of outcomes, but at the expense of the rest (Table IV). The visitor cap (S1) raises E2050 by 10.3% but lowers revenue by 2.1%. The green levy delivers the largest single-lever environmental gain ($S2 = 0.631$) because it funds conservation, but it also lowers revenue by 5.1% due to its demand effect. Emissions from the low-carbon transition

(S3) are curtailed to a small extent, with a cumulative emissions reduction of 7.3% by 2050 and a corresponding downward bend in the emissions curve starting after 2035 (Fig. 2(d)). Diversification (S4) is the most successful social instrument, reducing mean peak crowding from 0.80 to 0.50, decreasing seasonality (Fig. 3(b)), and increasing revenue by 31.0%. However, the extra visitors it brings in increase emissions by 18.8%, a typical rebound effect.

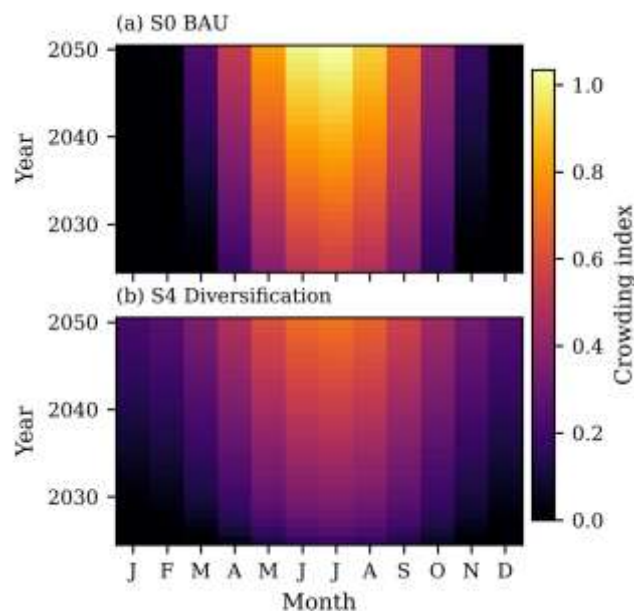


Fig. 3. Monthly crowding index heat maps for (a) BAU and (b) diversification. Diversification flattens the summer peak and distributes visitation across shoulder seasons.

Table 4: Scenario Outcomes (2025–2050)

Scenario	V_{2050} (M)	E_{2050}	S_{2050}	Rev. (B USD)	GHG (Mt)	Peak C	STI
S0 BAU	2.96	0.535	0.586	35.2	34.2	0.80	0.529
S1 Visitor cap	2.83	0.590	0.610	34.5	33.5	0.64	0.548
S2 Green levy	2.97	0.631	0.619	33.4	32.3	0.73	0.559
S3 Low-carbon	2.96	0.535	0.586	35.2	31.7	0.80	0.539
S4 Diversification	3.64	0.601	0.661	46.1	40.6	0.50	0.570
S5 Integrated mix	3.56	0.684	0.699	44.6	36.2	0.43	0.614

The 2025-2050 values have been revised (Rev.) and recalculated (GHG); Peak C is the average of the annual peak crowding indices. Bold row: best STI of the predefined scenarios.

4.3 Integrated Policy Mix

The integrated mix (S5) counterbalances the weaknesses of the individual levers and leverages their strengths. It achieves the highest E_{2050} (0.684) and S_{2050} (0.699) among the predefined scenarios and increases revenue by 26.7% relative to BAU, giving an STI of 0.614 (+16.0%). The 4.06 B USD in tax revenue funds conservation, and diversity offsets the demand the cap would lose. Cumulative emissions are 6.1% higher than BAU because more visitors come to the destination, while emissions per visitor decrease by 7.9% (0.482 versus 0.524 tCO₂e per visit). Across all growth scenarios, climate is the least resilient pillar, as

shown in Fig. 9.

4.4 Policy Design Space

Fig. 4 shows the STI as a function of the cap–levy plane diversification and low-carbon activity. As STI approaches the limits and moderate levies, levies above approximately 13% or very tight caps force cumulative revenue into the low BAU (hatched region), which is politically and economically unviable. Imposing $R_{cum} \geq R_{cumBAU}$ yields an interior constrained optimum at a cap of 2.1 M yr⁻¹ and a levy of 8.5%, with STI = 0.675 (+27.6% over BAU), E_{2050} = 0.841, and S_{2050} = 0.859. This configuration ensures a positive revenue (+0.4%) and a negative cumulative emissions (-14.8%). It moves the focus from volume to value: fewer visitors, more evenly distributed throughout the year, with the same amount of income but much less impact

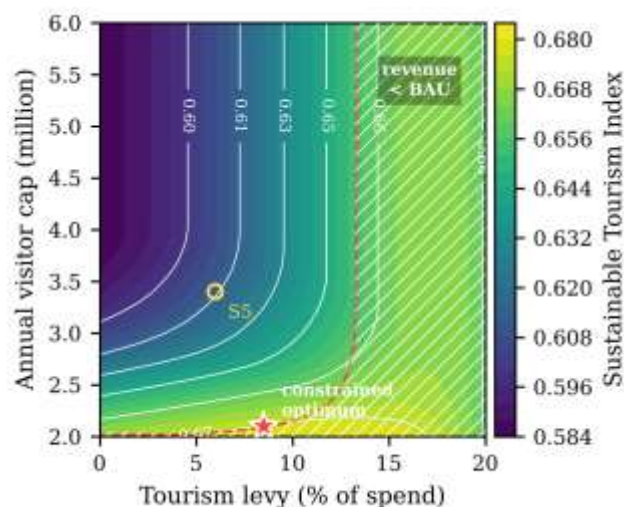


Fig. 4. Sustainable Tourism Index over the visitor-cap and levy design space (diversification and low-carbon active). Hatched region: cumulative revenue below BAU. Star: revenue-constrained optimum; circle: predefined scenario S5.

Fig. 5 presents the trade-off between economic and environmental outcomes. The Pareto front exhibits a clear knee: beyond about 35 B USD, each additional unit of

revenue costs a disproportionate loss in environmental quality. The constrained optimum lies at this knee, and S5 also lies on the front, whereas all single-instrument

scenarios are dominated.

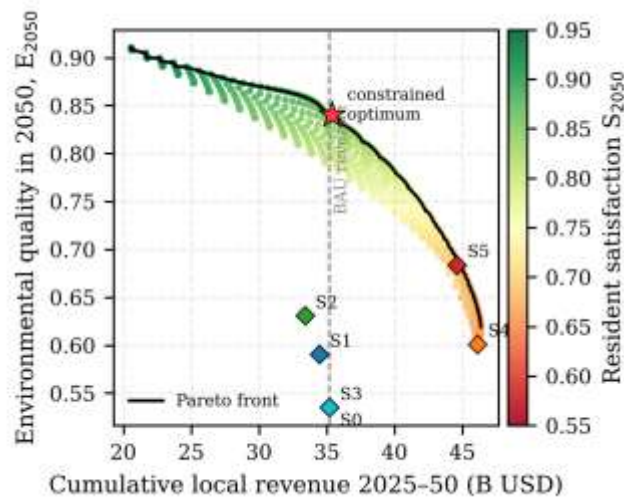


Fig. 5. Revenue–environment trade-off across the 1681 policy combinations, coloured by resident satisfaction. Black line: Pareto front; diamonds: predefined scenarios; star: constrained optimum.

4.5 Robustness under Uncertainty

Fig. 6 shows Monte Carlo fan charts for E. The 90% interval for BAU in 2050 spans 0.42–0.65, and in 31.8% of runs the destination crosses the critical threshold. Under S5, the

interval shifts to 0.56–0.79 and the threshold is crossed in 0.0% of runs. S5 outperforms BAU on the STI in 100% of the paired runs, so its advantage is robust to parameter uncertainty (Table V).

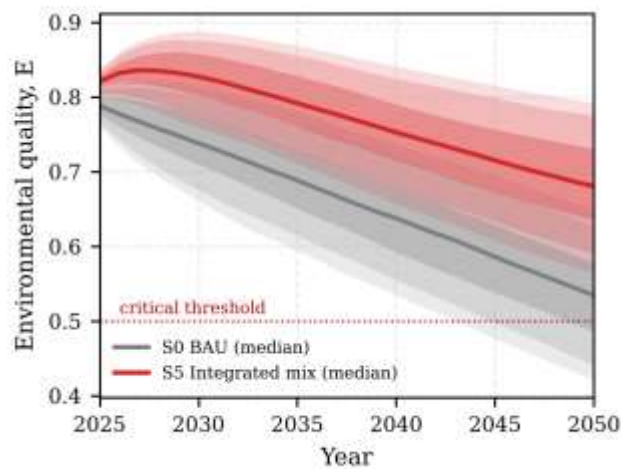


Fig. 6. Monte Carlo fan chart of environmental quality (400 runs)—shaded bands: 50%, 80%, and 90% intervals; solid lines: medians.

Table 5: Monte Carlo Statistics For 2050 (400 Runs)

Metric	S0 BAU	S5 Integrated mix
E_{2050} mean [5–95%]	0.534 [0.42–0.65]	0.681 [0.56–0.79]
S_{2050} mean [5–95%]	0.585 [0.46–0.69]	0.700 [0.59–0.79]
STI mean [5–95%]	0.526 [0.50–0.55]	0.612 [0.59–0.64]
$P(E_{2050} < 0.5)$	31.8%	0.0%
$P(STI_{S5} > STI_{BAU})$	—	100%

The tornado diagram (Fig. 7) shows that the STI of S5 is

most sensitive to baseline emission intensity, spending per

visit, and local retention. This indicates that the largest remaining leverage lies in decarbonizing access transport and in reducing economic leakage, for example through

local sourcing and ownership, rather than in further visitor control. Ecological parameters have smaller effects within $\pm 20\%$.

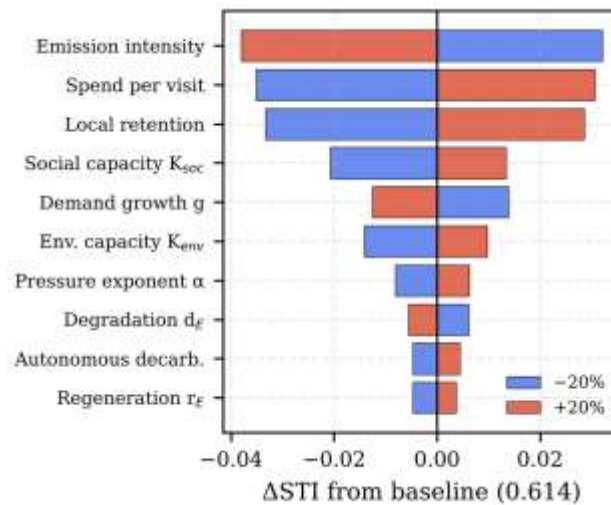


Fig. 7. Tornado diagram: change in the STI of scenario S5 when each parameter is varied by $\pm 20\%$ (ten most influential parameters).

4.7 Multi-Criteria Ranking

Entropy weighting assigns the largest weight to peak crowding (0.580), followed by revenue (0.202), E2050 (0.087), emissions (0.083), and S2050 (0.048), reflecting where the scenarios differ most. TOPSIS ranks S5 first ($C_i =$

0.960) and S4 second (Fig. 8, Table VI). With equal weights, the ranking order remains unchanged ($S5 = 0.838$, $S4 = 0.653$, $BAU = 0.215$), confirming that the conclusion does not depend on the weighting scheme.

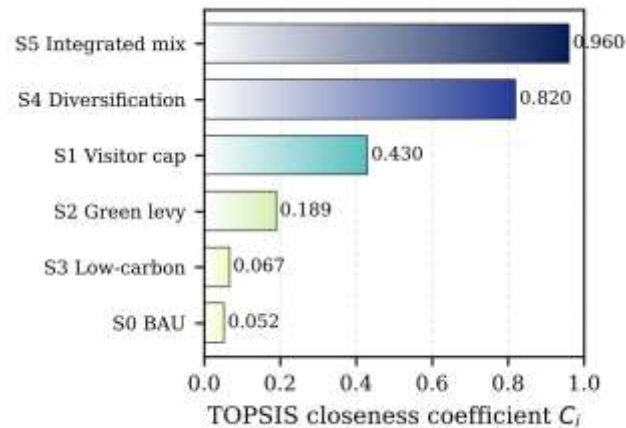


Fig. 8. Entropy-weighted TOPSIS closeness coefficients of the six scenarios (higher is better).

Table 6: Entropy-Weighted Topsis Results

Rank	Scenario	d^+	d^-	C_i (entropy)	C_i (equal)
1	S5 Integrated mix	0.0055	0.1332	0.960	0.838
2	S4 Diversification	0.0245	0.1117	0.820	0.653
3	S1 Visitor cap	0.0773	0.0583	0.430	0.409
4	S2 Green levy	0.1103	0.0257	0.189	0.346
5	S3 Low-carbon	0.1330	0.0095	0.067	0.273
6	S0 BAU	0.1330	0.0073	0.052	0.215

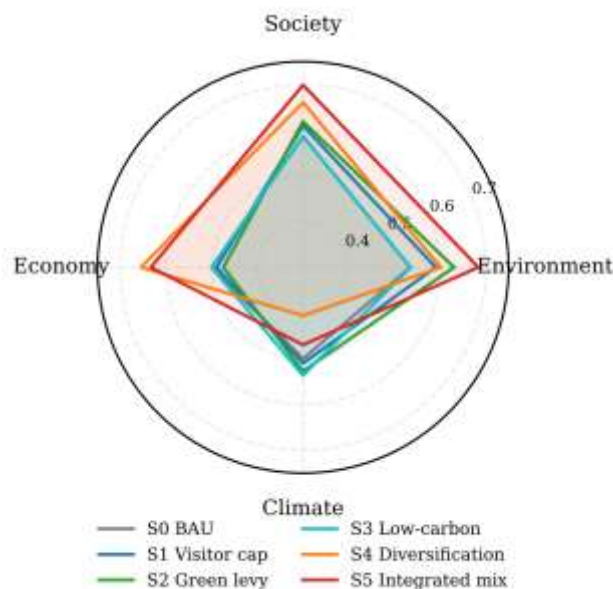


Fig. 9. The sustainability pillar scores of the six scenarios (environment = E2050; society = S2050; economy + climate relative to BAU (BAU = 0.5)).

5. Discussion

5.1 Strategic Implications

Four policy lessons come to the fore. First, bundle instruments are better than single instruments: any single instrument is associated with a trade-off, e.g., loss of revenues under caps and levies and rebound of emissions under diversification, which is compensated for by complementary instruments. This reinforces the need to change tourism governance at a third-order level [17]. Second, don't focus on volume: constrained optimum means keeping the number of arrivals close to today's level, with a strong focus on maintaining revenue, and in line with the concepts that have been followed after the pandemic (emphasis on yield, length of stay and spending by visitors to a territory) [19]. Third, it's about the visibility of the earmark; levies have a greater impact on outcomes when it is clear that the revenue is targeted to conservation and community benefits, thereby maintaining resident support. Fourth, for destination-level measures to offset emissions from growth, access transport must be decarbonized, as the low-carbon imperative in Gössling and Higham [15].

5.2 Implementation Challenges and Barriers

The political acceptance and reliable enforcement of caps and levies, as well as competition from other destinations (marked as κ), cap the potential rise of levies, and diversification necessitates infrastructure investments and product innovations. Slow resident attitude change (τ_S) and ecological recovery delay benefits relative to the electoral cycles of costs.

5.3 Emerging Opportunities

Static caps can be converted into adaptive, real-time demand management using a smart tourism data platform [20]. To

facilitate the leveraging of green finance for renewable energy and nature restoration, green taxes can be collected. The sensitivity analysis shows that the key parameter for increasing tourism retention in the community is ρ , which gains importance when it is present in the tourism offer.

5.4 Limitations

The model is stylized and not calibrated to any specific destination; the parameters are educated guesses within plausible ranges, and the results should be taken as indications of the structure, not predictions. The model combines diverse visitor sub-groups and stakeholder groups, excludes interactions between the housing and labor markets, externalizes the impact of climate on the destination, and assumes uniform parameter distributions across groups. In the future, the model will be calibrated using destination time series, integrate additional agent-based stakeholder behavior, and be coupled with climate-risk scenarios.

6. Conclusion

This paper introduced an integrated system-dynamics and multi-criteria assessment system for sustainable tourism strategies. If past trends continue over the next 40 years, the environment at a stylized destination will be 0.54 by 2050, with a 31.8% chance it will be worse. The combination of the four elements of sustainable tourism—visitor management, earmarked levies, diversification, and low-carbon transition—increases the index of Sustainable Tourism by 16.0%, brings an additional local revenue of 26.7%, eliminates all threshold crossings over 400 Monte Carlo runs, and is the first system according to both entropy and equal weights. A revenue-constrained optimum of approximately 2.1 M arrivals per year and an 8.5% levy

provides the best overall balance with a 14.8% reduction in emissions. These findings justify a paradigm shift from volume-driven to value-driven tourism development through

policy bundling. An open model enables DMs to replace local data and test strategies before implementing them.

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