

B**MCM/ICM****2528439****Summary Sheet**

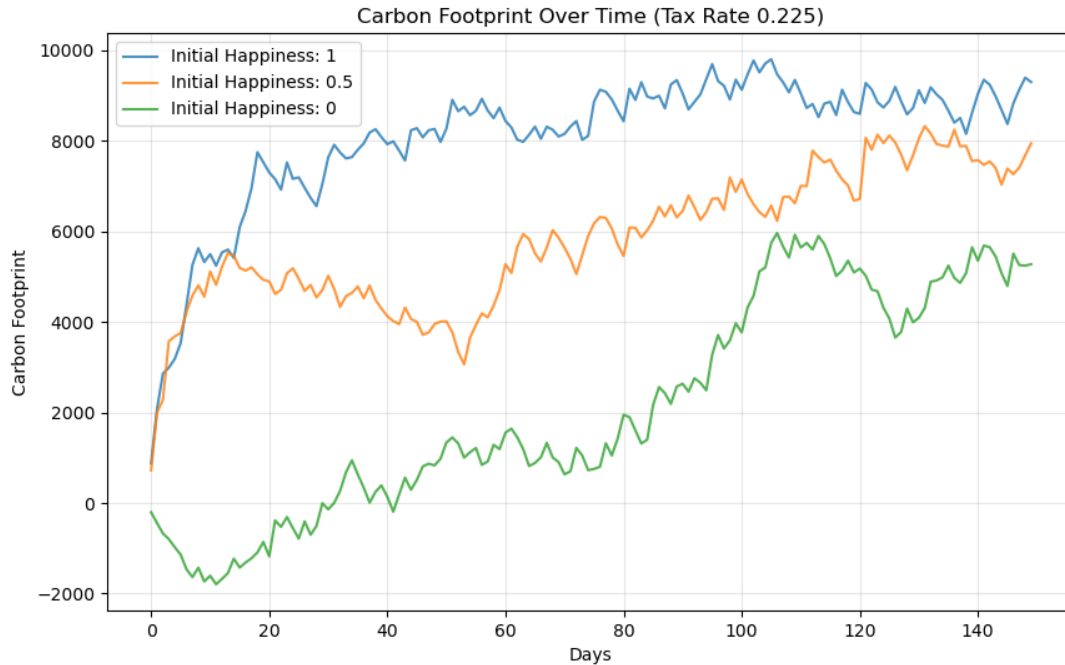


Figure 1: Stable Carbon-Footprint in Juneau, Alaska. Tourism taxation of 22.5%

In 2023, Juneau, Alaska had 1.6 million tourists over the summer season. With the maximum in one day being 20,000 visitors, two-thirds of the city's population. Environmental impacts of this amount of tourism have become untenable for the community. We propose a dynamic-discrete-stochastic model of tourist happiness to determine a more sustainable solution. By optimizing the value of Carbon-Footprint, which is proportional to the number of people and the tax imposed We determined that with an increase from 5% to 22.5% a stable Carbon-Footprint is reached. A 20% would still reduce the Carbon-Footprint by an order of magnitude with a less severe impact on the cities revenue from tourism.

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1 Introduction

Juneau, Alaska, USA, is the capital of Alaska, with a population of 30,000 residents. In 2023, the city set a new municipal record, for number of cruise ship passengers visiting the city, by having 1.6 million tourists over the summer season. With the maximum in one day being 20,000 visitors, two-thirds of the city's population. While the tourists brought in 375 million USD that year [4], issues related to overcrowding became very apparent. One of the main attractions of Juneau is the Mendenhall Glacier. However, concerns about the glacier are becoming more prominent. Since 2007, the glacier has receded eight football fields, or 2400 feet, primarily due to warming temperatures, which directly correlates to over-tourism. Because of this, locals worry about the sustainability of tourism in the city and the glaciers.

Tourism in Juneau is the largest private sector employer [6], and the loss of tourist attractions due to climate change is a considerable concern. With each tourist emitting 0.5 metric tons of CO_2 [18] residents are concerned about permanent damage and loss of the glaciers and other attractions if pollution, and therefore tourism, remains unchecked. The city has already put a season cap on the number of people visiting the glaciers at 517,650 people[12]. Juneau has experimented with raising taxes, fees, restrictions on alcohol sales and consumption, and setting daily and seasonal limits on attractions[16][11]. Our approach to the problem was to create a dynamic-discrete-stochastic model of tourist happiness. A visitor to Juneau will gain or lose happiness based on known factors in Juneau: optimal number of people visiting attractions, maximum number of people visiting attractions, total number allowed in Juneau. Happiness also changes based on how much people are taxed to participate in activities, this is the variable in the simulation. Happiness effects the number of people who come to Juneau in the following days. The optimized value of the simulation is Carbon-Footprint, which is proportional to the number of people and the tax imposed. By changing taxation we found that with an increase from 5% to 22.5% a stable Carbon-Footprint is reached.

2 Our Model

2.1 Motivation

Roller Coaster Tycoon was developed by Chris Sawyer and published by Hasbro Interactive in 1999. In this game, you have numerous scenarios where you have to balance two main things: Money and Park Rating. Your park rating will decrease or increase depending on: the rides in your park, the park entry fee, footpaths, bathrooms and food and drink stalls. Although Roller Coaster Tycoon is a video game, many of the core ideas can be abstracted and implemented into a mathematical model.



Figure 2: Roller Coaster Tycoon [7]

Our model is a dynamic-discrete-stochastic model that takes inspiration from Roller Coaster Tycoon. The model is a multi-agent environment, where the agent is the tourist, and the goal is to **maximize their “happiness-measure”** while maintaining a **stable Carbon-Footprint level**. To do this, we tune the taxes visitors pay during their visit. The model incorporates a self-correction loop, where if happiness increases to high a influx of people will come to Juneau. This leads to overcrowding and lower happiness, so less people will come to Juneau. As taxes are raised we see that fewer tourist come to Juneau, coupled with more money for carbon reduction measures leads to lower environmental impact.

2.2 Parameters and Functions

A tourist j is assigned the following variables:

- The number of the cruise ship n_j the passenger arrived on.
- Happiness measure $0 \leq h_j \leq 1$, with 1 being most happy and 0 being the least.
- Time t_j left for the current event the visitor is participating in, 0 if not active.
- Record of the places the tourist visited R_j ; we enforce that the tourist does not visit the same place twice.
- Current location L_j , the event the visitor is participating in.

Parameter	Definition	Value
h_j	Happiness of Visitors	$0 \leq h_j \leq 1$
t_j	Time Left of Visitors	$0 \leq t_j \leq 5$
R_j	Record Of Visitation	
n_j	Visitor Ship	$0 \leq n_j \leq 5$
L_j	Location of Visitor	

Table 1: List of Agent Variables

The global variables that monitor the ecosystem are:

- Global happiness $\mathcal{H}$, which reflects the historical satisfaction level of previous tourists.
- Time $0 < \tau < 12$, represents the hours 8:00 am to 8:00 pm. Ships can arrive between the hours of 8:00 am and 12:00 pm, and depart after an 8 hour layover [14].
- Number of ships $1 \leq n \leq 5$ [10], set at the beginning of each day. Every ship is set to arrive between $\tau = 0$ (8:00 am) and $\tau = 4$ (12:00 pm) with a number of passengers between 2000 and 4000. Both arrival time and number of passengers are sampled uniformly.

- Number of visitors at a given event $\mathcal{N}_{E_j}$, where E_j is event j . The sum over E_j is capped at 16000, however total number of visitors can be larger than 16000. There are four events: Glaciers, Whale, City and Tram.
- Carbon-Footprint $\mathcal{F}$ in metric tons.

Parameter	Definition	Value
$\mathcal{H}$	Global Happiness	$0 \leq \mathcal{H} \leq 1$
τ	Times	$0 \leq \tau \leq 12$
n	Number of ships	$0 \leq n \leq 5$
$\mathcal{N}_{E_j}$	Visitors at Event j $j \in \{\mathcal{G}, W, T, C\}$	
$\mathcal{N}$	Visitors	$\in \mathbb{N}$
$\mathcal{F}$	Carbon-Footprint	$\in \mathbb{R}$

Table 2: List of Global Variables

Constant values of the model

- Cost C_{E_j} of event j .
- Maximum people at any given event M_{E_j} . No more than this number of people can be at an event during one hour.
- Optimal number of people at an event O_{E_j} . Number of people yield the largest increase in happiness from an event.
- Base attractiveness of event β_{E_j} . This is the base happiness gained from an event and the probability of going to an event.
- Time for each event τ_{E_j} . How long an event takes in hours.

Tax, $0 \leq T \leq 1$, is the percentage taxes on events. This is the parameter of our model and is used to find Carbon-Footprint stable solutions.

Parameter	Definition	Value
C_{E_G}	Cost of Event G	\$65
C_{E_W}	Cost of Event W	\$200
C_{E_T}	Cost of Event T	\$80
C_{E_C}	Cost of Event C	\$100
M_{E_G}	Max Attendance of Event G	3500
M_{E_W}	Max Attendance of Event W	4500
M_{E_T}	Max Attendance of Event T	3500
M_{E_C}	Max Attendance of Event C	4500
O_{E_G}	Optimal Attendance of Event G	1500
O_{E_W}	Optimal Attendance of Event W	2000
O_{E_T}	Optimal Attendance of Event T	1500
O_{E_C}	Optimal Attendance of Event C	2000
β_{E_G}	Base Happiness of Event G	0.35
β_{E_W}	Base Attractiveness of Event W	0.3
β_{E_T}	Base Attractiveness of Event T	0.25
β_{E_C}	Base Attractiveness of Event C	0.1
τ_{E_G}	Time of Event in hours G	5
τ_{E_W}	Time of Event in hours W	4
τ_{E_T}	Time of Event in hours T	1
τ_{E_C}	Time of Event in hours C	2

Table 3: List of Constants

2.3 Mass Flow Diagram

A number, n , of cruise ships planned to come through the day, not necessarily the same time for all ships. Each ship carries some tourists, and will stay in port for 8 hours. Each tourist starts with an initialized value of happiness h_j uniformly distributed around the current global happiness $\mathcal{H}$ between -0.05 and $+0.05$ and clipped between 0 and 1. At the beginning of the simulation $\mathcal{H}$ will be initialized to 0, 0.5 or 1 for stability testing. Passengers on the ships currently in harbor will be randomly selected to go ashore, up to 16000. They will then select an event they can visit, if a suitable event exists. Event eligibility is based on time until the tourists ship leave and repeated visits. No repeated visits are allowed and a tourist will not go to an event if their ship leaves before the event concludes.

Each time a tourist visits an event E_j in the city, they will spend some time τ_{E_j} at the event alongside some money cost to attend the event, which is directly affected by the tax T . Their

happiness level will either increase or decrease after they go to the events; **event cost** and **crowd-
edness** of each event plays the most significant role in changing the happiness level for each visitor. Every hour, tourists leave a carbon footprint. Tourist who cannot attend an event due to time or overcrowding loose 0.2 happiness.

A set of events have been chosen to serve as **umbrella events**, whale watching for instance, represents all the nature watching events. Once the ship runs out of time, the ship will leave with the same passengers it came with. When a ship leaves, the happiness value of all tourists on that ship is used to update value of global happiness. Global happiness $\mathcal{H}$ representing the worldwide view of what experience tourists expect from their visit. Global happiness is calculated at the end of the day and is used initialize the happiness of people coming on ships the next day and to determine number of ships. Below is a mass flow diagram describing the ecosystem Fig: 3.

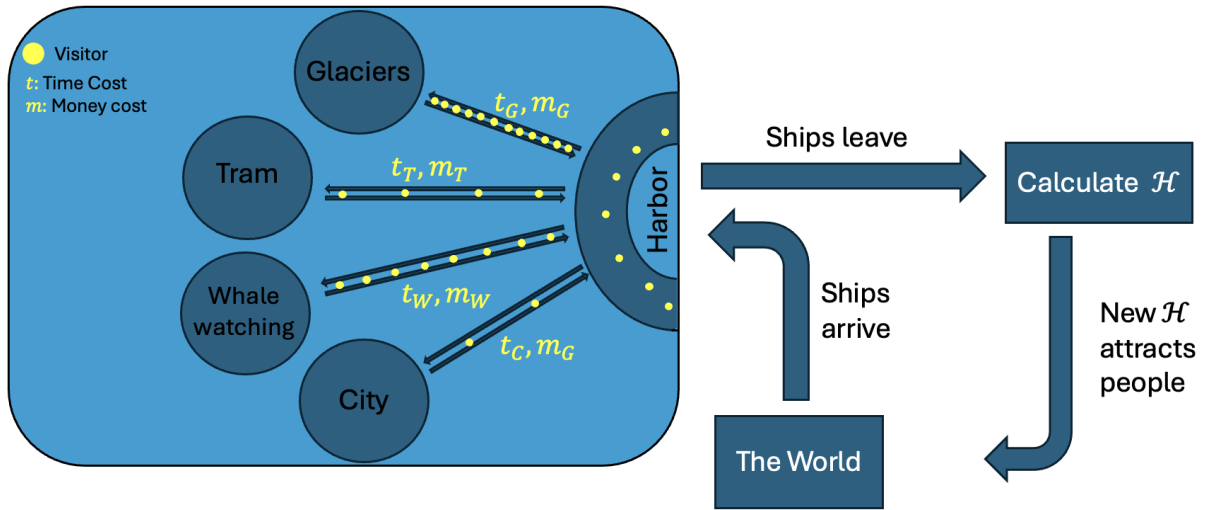


Figure 3: Mass-Flow Diagram of Tourists

3 Assumptions

Our model aims to find a value of the tax parameter to maximize the global happiness $\mathcal{H}$ while still having a balanced or stable carbon footprint value $\mathcal{F}$. Many assumptions were made to accomplish this.

- The global happiness level $\mathcal{H}$ is updated at the end of each day according to the following equation:

$$\mathcal{H}_{i+1} = \frac{7\mathcal{H}_i + \langle \hat{h} \rangle}{8}, \quad \langle \hat{h} \rangle = \frac{\sum_{i=0}^n \langle h \rangle_i}{n} \quad (1)$$

Where $\langle h \rangle_i$ is the average happiness of the people on the ship i , and n is the number of ships on that day. The motivation for putting more weight on $\mathcal{H}$ is to imply that the satisfaction level from the last 7 days Has a larger impact.

- Each day has at least one ship, more ships will arrive based on the value of the global happiness $\mathcal{H}$. A uniform random number between 0 and 1 is selected, if it is less than $\mathcal{H}$, we add a ship. This process is preformed four times. Each ship holds between 2000 and 4000 people randomly sampled within that range[3].
- The values of $\mathcal{H}_0 = 1$, $\mathcal{H}_0 = 0.5$, and $\mathcal{H}_0 = 0$ were used as initial global happiness to ensure a stable model.
- Happiness of tourist is updated in two parts:
 - For visitors who did not make it to an event due to overcrowding, their happiness is reduced by 0.2; this represents the disappointment in not being allowed to enter the city.
 - The happiness for visitors who found an attraction is computed based on several factors: the **tax** T , **base happiness** of the event β_{E_j} , the number of people at the event $\mathcal{N}_{E_j}$, the optimal number of people at the event O_{E_j} that ensures best experience, and maximum number of people that can attend the event M_{E_j} . The new happiness of the visitor at an event E_j is computed every hour with the formula:

$$h_{t+1} = h_t \cdot \Psi(\mathcal{N}_{E_j}, O_{E_j}, M_{E_j}) \cdot (1 - T) + \beta_{E_j} \quad (2)$$

$$\Psi(N_{E_j}, O_{E_j}, M_{E_j}) = \begin{cases} 1 - \left(\frac{N_{E_j} - O_{E_j}}{M_{E_j} - O_{E_j} + 1000} \right)^2, & 0 < 1 - \left(\frac{N_{E_j} - O_{E_j}}{M_{E_j} - O_{E_j} + 1000} \right)^2 \\ 0, & 0 \geq 1 - \left(\frac{N_{E_j} - O_{E_j}}{M_{E_j} - O_{E_j} + 1000} \right)^2 \end{cases} \quad (3)$$

A happiness scaling function was used based on number of people at the event. If an event is empty, tourists don't enjoy the experience, but if the event were full and overcrowded, then tourists would also not enjoy their experience. To compensate for this we used a quadratic function to scale the happiness. If the event had 0.4 – 0.6 its maximum capacity, then tourists would have the best experience they could [17]. Consider our glacier: the maximum number of people it can hold is set to 4500, but the number of people to get the best satisfaction level is 1500. Plotting the Ψ function for E_G is Fig: 4.

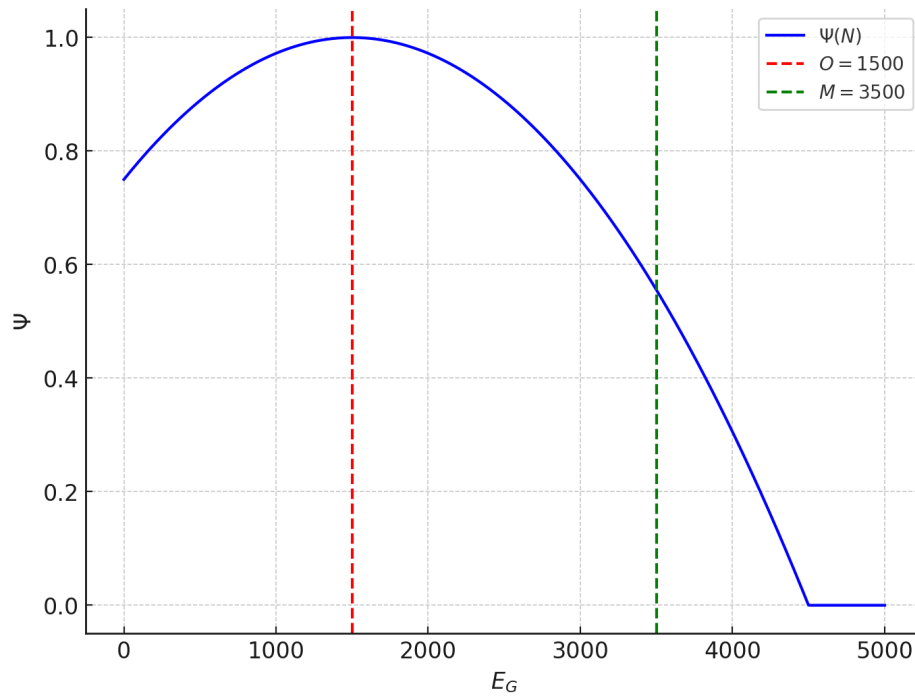


Figure 4: $\Psi(N_{E_G}, O_{E_G}, M_{E_G})$

- Tax reduces the carbon footprint, more taxation corresponds to more revenue for the city to enhance infrastructure for carbon reduction and reduce the number of tourists away by making their visit more expensive. The coefficient $\gamma = 0.2/500$ was determined by 0.2 for the percentage of tax put towards carbon [11], and a minimum of 500 dollars needed to remove

one ton of carbon [15]. The first sum in equation 4 is the reduction term. The second term represents the amount of Carbon-Footprint produced by the tourist at each event at a given hour. Lambda was fitted at 3.75 from tax at 0.05, the currently imposed tax in Juneau and ensuring the model obtained 140000 tons of carbon in one season of 150 days[8].

The change in Carbon-Footprint is determined by:

$$\mathcal{F}_{t+1} = \mathcal{F}_t - \sum_{E_j} \gamma T_{E_j} \cdot C_{E_j} \cdot N_{E_j} + \sum_{E_j} e^{\lambda \frac{N_{E_j} - O_{E_j}}{O_{E_j}}} \quad (4)$$

- There are only four attractions, each event was categorized under the umbrella terms of “**Glaciers**”, “**Tram**”, “**City**” and “**Whale Watching**”. Any attractions that dealt with outdoor excursions, i.e. hiking, were put in the “Tram” event. Attractions that were wildlife-based were under the “Whale Watching” event. The “Glaciers” attraction encompasses all glacier and glacier-based attractions in Juneau. All attractions, such as museums, art galleries and restaurants, are part of the “City” event. This was done to simplify the model into only four events.[1]
- The probability that people want to go to each event $P(E_j)$ is was based on historical data on how often people visit that event when they visit the city[12][4] [2][13].
- The amount of money it costs each visitor to go to an event m_{E_j} was obtained from last season’s prices and tourist spending [5][2][9].

3.1 Results

First we looked at a baseline tax of 0.05, this currently the tax rate in Juneau, and was used to fit the model. We then increased it by 0.10 until the carbon footprint levels decreased. This decrease occurred when the tax rate was 0.25. We incorporated a binary search to find that a tax of 0.225. When this tax rate was incorporated, carbon footprint levels and happiness levels over time converged nicely.

The Tram and City events were the most popular, with a population per hour of 1000 ± 100 participants. The population of each of the events are well below the maximum number of people allowed at each event, with an average population of 812.4 visitors. Setting the tax to 0.225, the daily revenue is the second lowest at 1.4 ± 0.3 million dollars per day. This results in revenue in a season being ~ 210 million dollars, a 165 million dollar decrease from the 2023 season revenue [4]. The average happiness levels were lowest when the tax rate was 0.25, being 0.35 ± 0.05 . When the tax was 0, happiness levels were 0.55 ± 0.05 . These were the highest recorded happiness levels. At the ideal tax rate of 0.225, the average happiness was 0.40 ± 0.05 .

The model shows us that a tax rate of 0.25 gives us an average carbon footprint of ~ -5833 tons per season. This was the lowest carbon footprint level. The highest average carbon footprint level per season was ~ 180000 when the tax rate was 0. At 0.225, the average carbon footprint levels were ~ 10000 .

With the tax rate at 0.225, the carbon footprint levels converge to above 4500 and below 10000 for initial happiness levels 0 to 1, respectively. The happiness levels over time converged between 0.3 and 0.45 for all initial happiness levels. Population over time ranged from 16000 to 2500 for initial happiness. Compared to other tax rates, the population over time, carbon footprint over time, and happiness over time are very stable. There are very few major fluctuations.

The tax rates that are most sustainable for the city would be from 0.15 to 0.20. Happiness over time converges nicely with few fluctuations, with carbon footprint levels ranging from 25000 to 65000, respectively and daily revenue ranging from 1.4 million to 1.55 million dollars.

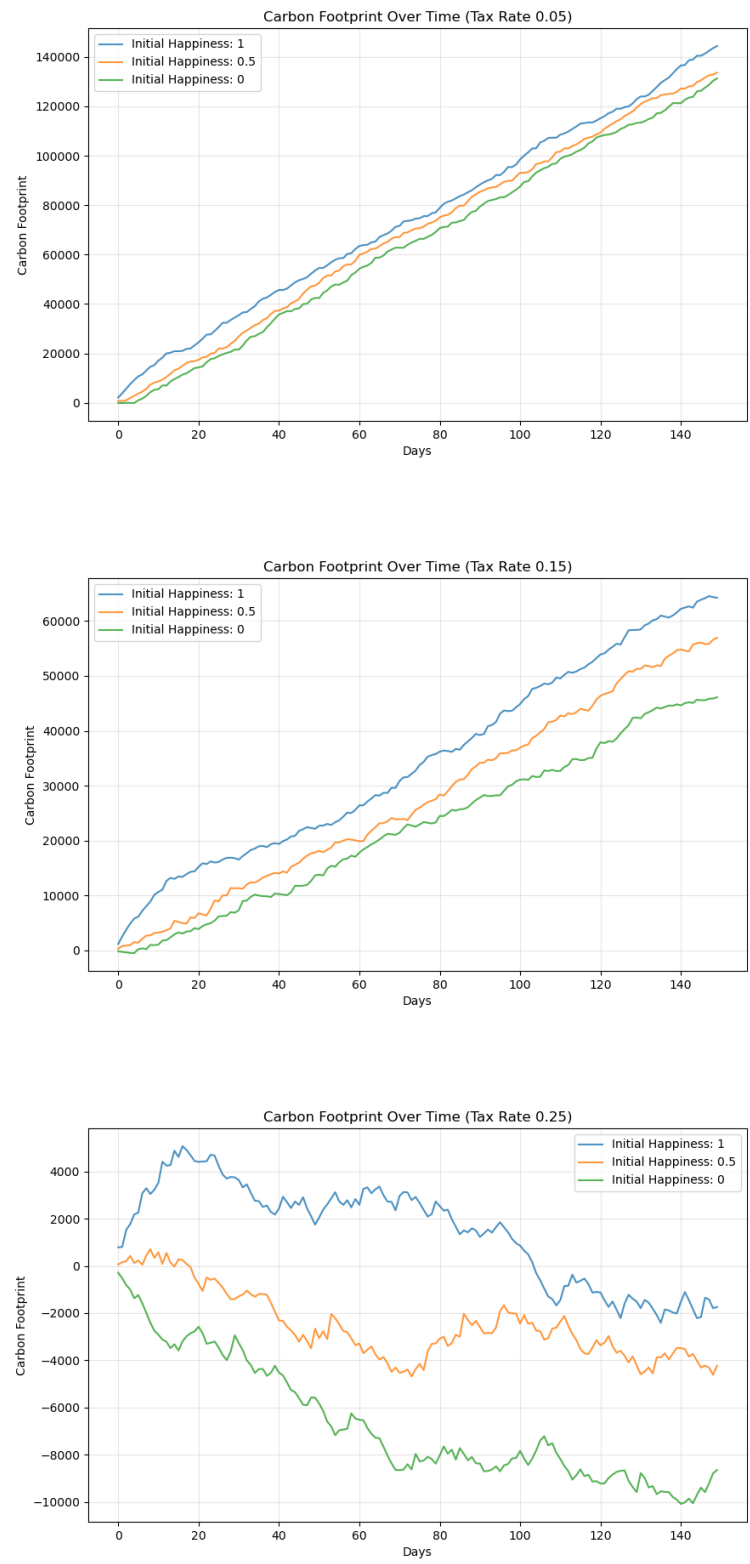


Figure 5: Carbon Footprint Comparison

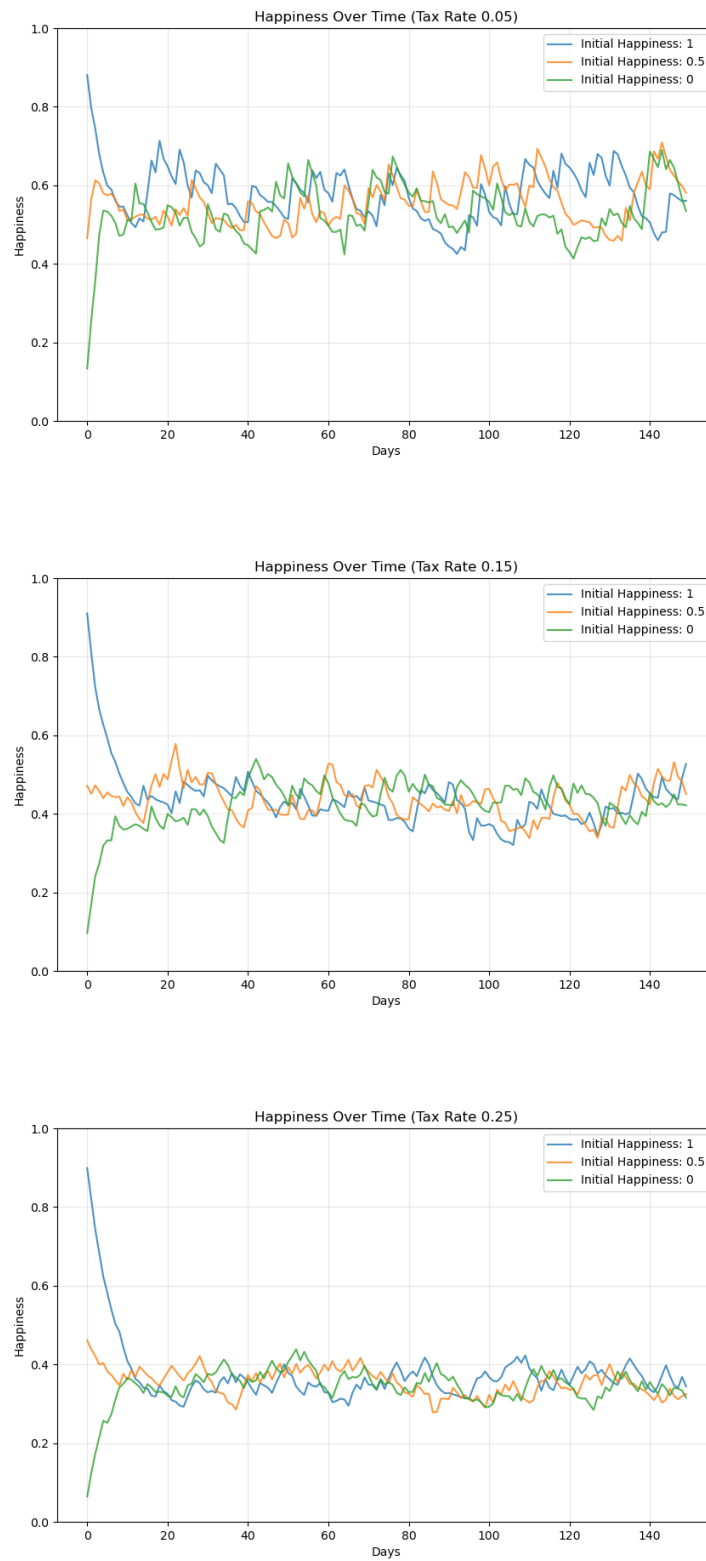


Figure 6: Happiness Comparison

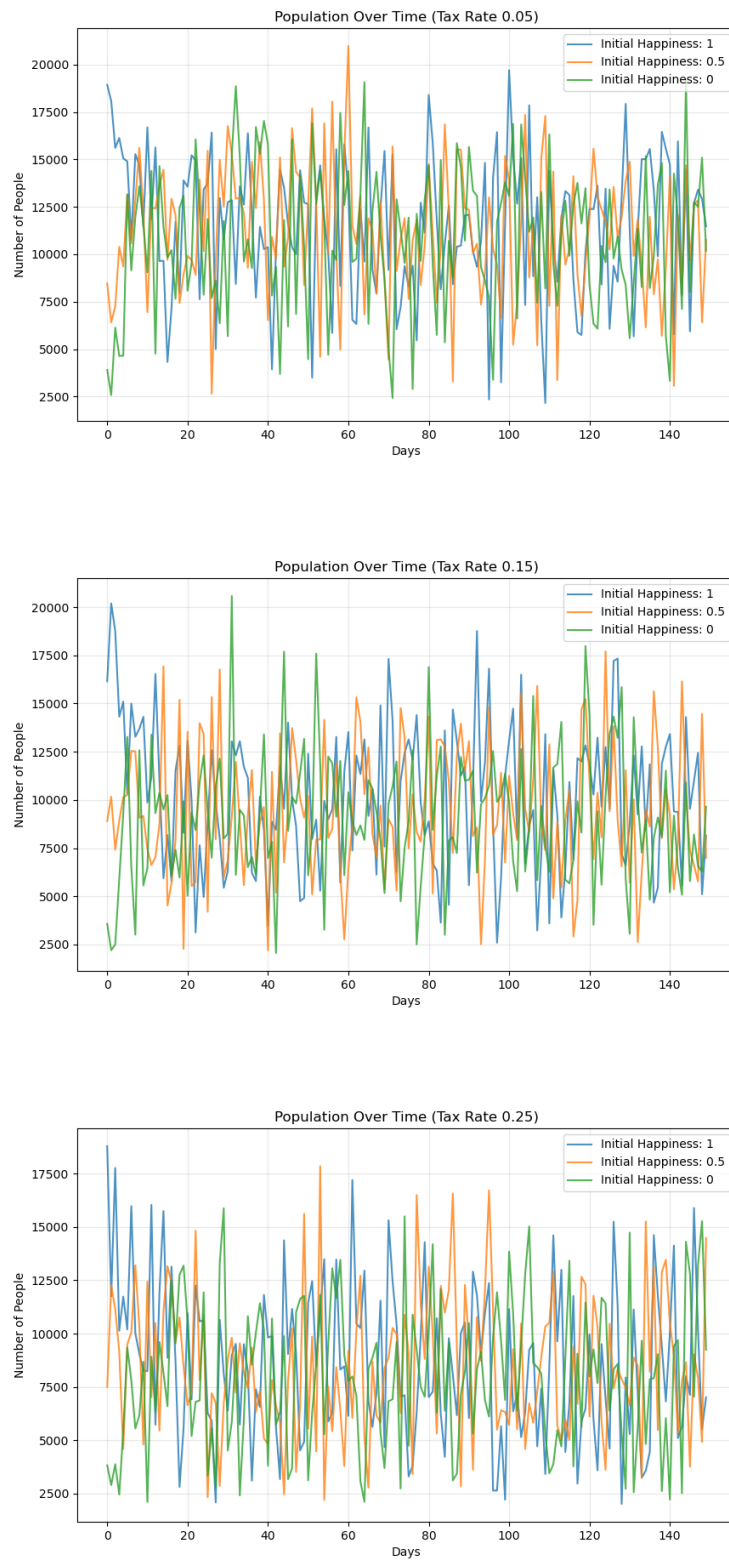


Figure 7: Population Comparison

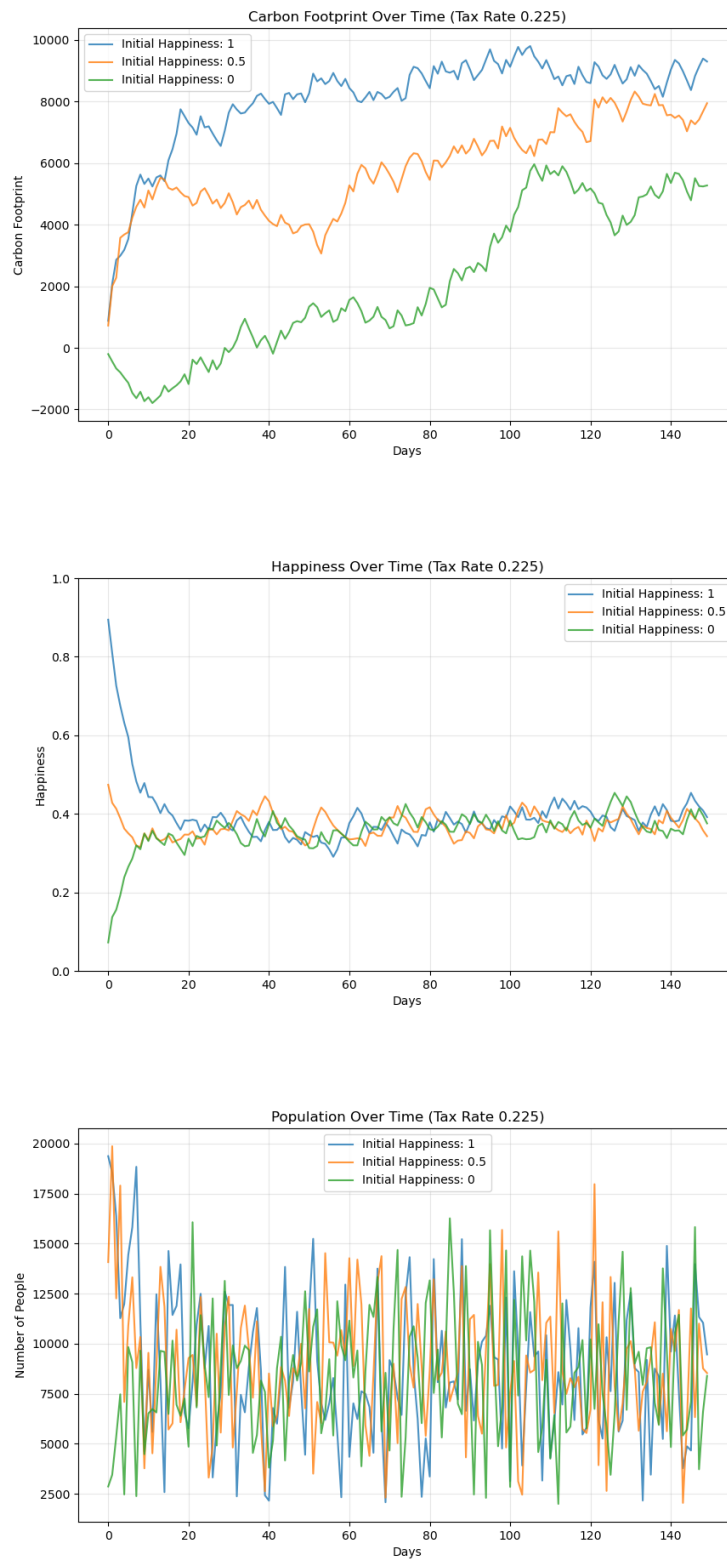


Figure 8: Stable Carbon Footprint ($T = 0.225$)

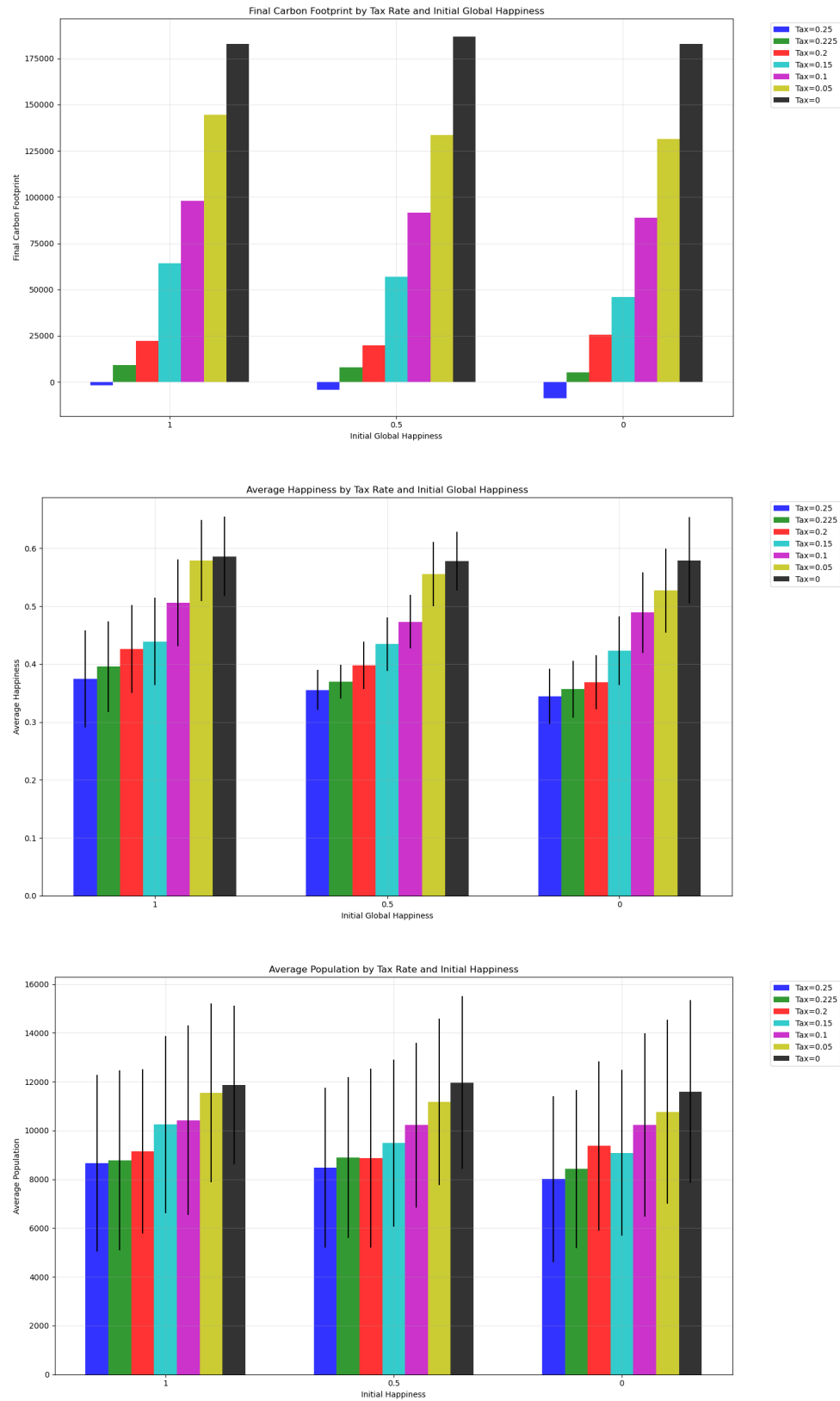


Figure 9: Final Carbon Footprint, Happiness & Population Averages

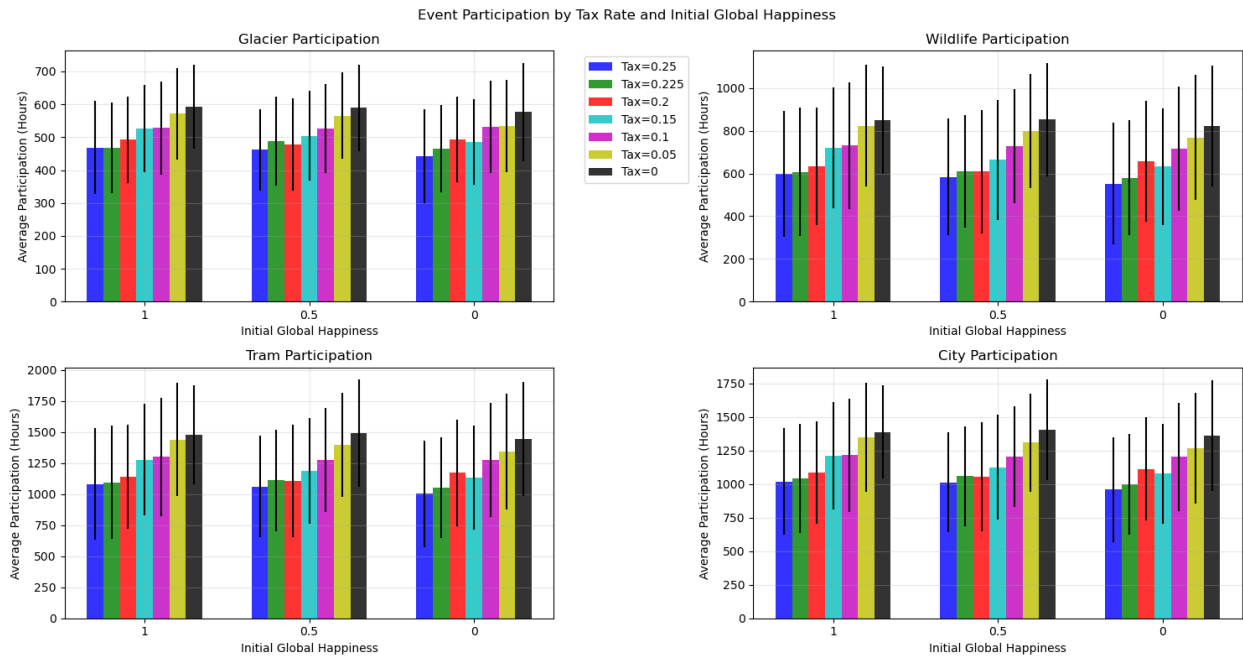


Figure 10: Event Participation by Hour

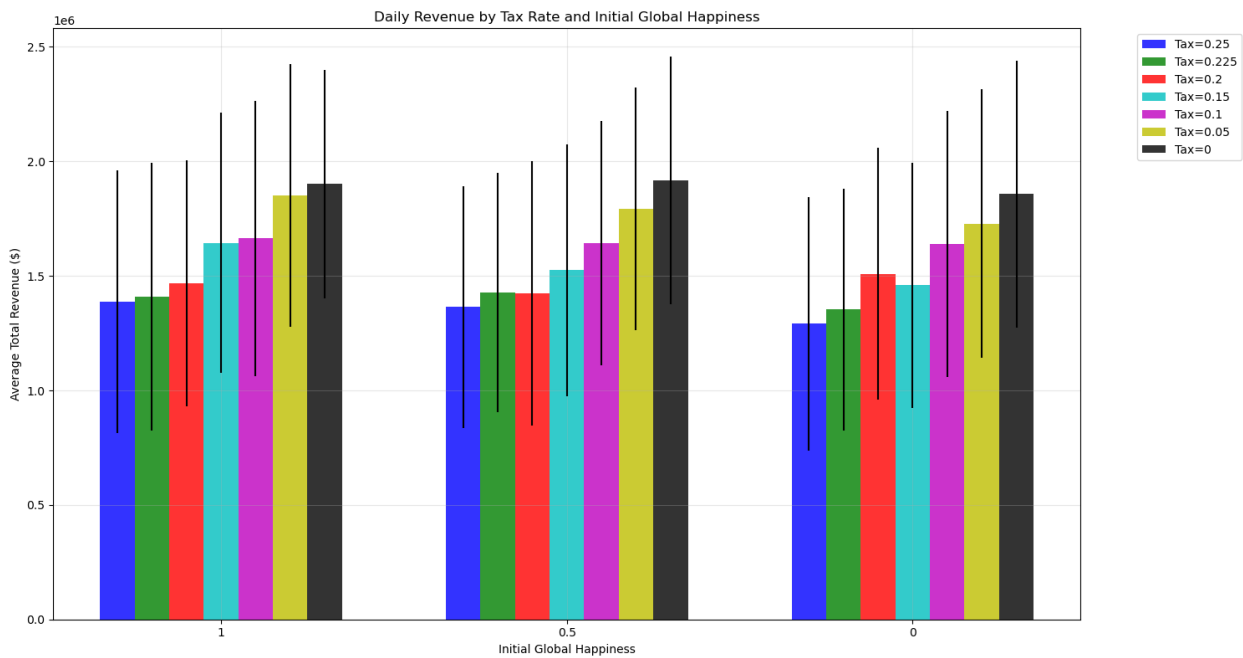


Figure 11: Daily Revenue

4 Conclusion

Our model shows that as you increase taxes, you lose revenue but lower the carbon emissions. Based on real world data we found an idealistic spot for taxation and carbon emissions was 0.225, 22.5% tax. At this rate, the carbon emissions were a substantial decrease from what [8] stated in 2023. A decrease in revenue is prevalent with the tax rate of 22.5%. Our model showed profits for the season at ~210 million dollars, which is a -44% increase from the 375 million dollars in 2023 [4]. The most sustainable tax option for the city would be from 0.15 to 0.20 as it has the lowest carbon footprint per dollar made, with revenue being between 1.4 to 1.55 million dollars per day. A tax rate between 0.15 and 0.20 shows a higher population for each event compared to a tax rate of 0.225. With a 0.2% taxation rate the carbon emission was 22500 ± 2500 metric tons and showed a small but increasing trend. This is a minimal amount compared to 2023 with 140000 metric tons. 0.225% taxation yielded a final emission of 8000 ± 2000 metric tons and was stable.

Our model can be fitted to other environmentally sensitive tourist destinations that struggle with overcrowding and high carbon emissions. The model we made uses taxation to keep overcrowding balanced and uses a percentage of tax for environmental resources to keep carbon emissions down. Base happiness of tourist attractions can be changed to fit other destinations provided they have historical data about how many tourists visit each attraction per unit of time. To promote attractions that have fewer tourists, you can reduce taxation on specific events and raise the preferred amount of people and maximum number of people at the event while increasing taxation on more popular events. More attractions can be added to accommodate larger tourist centres.

5 Letter To Juneau

Dear Juneau,

The glaciers of Juneau are some of the most beautiful places on the planet. They bring hundreds of thousands of people to the city to see them and other attractions each year. However, the sustainability of the attractions is a concern. Each attraction is highly affected by the increase in greenhouse gas emissions. From 2005 to 2019, the total area of the glacier ice field has decreased 10% and lost 63 of its 1050 glaciers. Tourism is the largest contributor to your economy, and without the glaciers and other attractions, hundreds of millions of dollars of income would be lost, and an international treasure would be destroyed. The receding of the glacier ice fields affects not only tourism but also the residents of Juneau. The melting glaciers cause mass floods in the city, causing individual homes and lives to be ruined. We have worked to develop a mathematical model to help find a solution to this problem.

Our model was constructed around the city with a baseline of 5% sales tax rate, with 20% of that tax going towards environmental resources. Our findings showed that the tax rate of 5% is not enough to offset the emissions of greenhouse gases. We found that a taxation of 22.5%, with 20% of that going towards environmental resources, was enough for the city to become carbon sustainable. Our model incorporated current numbers of tourists and cruise ships and newly imposed limits on these numbers. The longevity of Juneau's tourist economy and attractions requires a change. We hope that our model can help find the best way forward for the environment, the tourists and the population of Juneau.

Yours sincerely,

MCM Team: 2528439

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