Cooperative Tax Pricing for Sustainable Tourism: The Case of the Algarve

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Abstract

O setor do turismo é fundamental para diversas economias ao redor do mundo. Contudo, também está associado a vários desafios, sendo um deles a concentração em massa de turistas em polos turísticos populares, que resulta em uma distribuição desigual não apenas dos benefícios, mas também dos encargos sobre os recursos públicos locais e infraestrutura dentro das regiões turísticas. Nesta tese, utilizamos o caso da região do Algarve para explorar o potencial uso da tributação do turismo para redistribuir fluxos turísticos, a fim de mitigar o problema e tornar o setor mais sustentável. Os padrões de consumo dos turistas e a pressão do turismo sobre os serviços públicos de água, saneamento, energia e recolha de resíduos urbanos foram quantificados para cada município, e foi desenvolvido um algoritmo para identificar as melhores estratégias de fixação de preços. Confirmamos a viabilidade do uso da tributação do turismo para reduzir as discrepâncias na pressão turística nos vários municípios, sem comprometer o desempenho do setor na região. Além disso, foram identificados vários fatores que devem ser levados em consideração ao definir as políticas de preços, como é o caso dos preços de alojamento e a elasticidade-preço da procura turística. Concluímos que um esquema cooperativo entre as várias autoridades municipais é fundamental para alcançar uma distribuição mais equitativa da pressão turística na região, dado que o rigor na diferenciação dos preços na tributação do turismo é a chave para o sucesso da abordagem sugerida.

Palavras-Chave: Taxa turística, Sustentabilidade, Algarve, Cooperação, Política de Preços
Título: Cooperação na Fixação de Taxas para um Turismo Sustentável: O Caso do Algarve
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Abstract

The tourism sector is fundamental for many economies around the world. However, it is also associated with several challenges, one of which is the mass concentration of tourists in popular hubs, resulting in an uneven distribution of not only the benefits but also the burdens on local public resources and infrastructure within destinations. In this thesis, we use the case of the region of the Algarve to explore the potential use of tourism taxation to redistribute tourism inflows in order to mitigate the issue and turn the sector more sustainable. Tourist consumption patterns and tourism pressure on public water services, wastewater, energy, and solid waste collection were quantified for each municipality, and an algorithm to identify the best pricing strategies was developed. We confirmed the viability of using tourism taxation to reduce discrepancies over the different municipalities' tourism pressure without compromising the sector's performance in the region. Furthermore, various factors that should be taken into account when defining pricing policies were identified, such as accommodation prices and price elasticity of tourism demand. We concluded that a cooperative framework within all local municipal authorities is fundamental to achieve a more equitable distribution of tourism pressure in the region, as a correct price differentiation of tourism taxation is the key to the success of the proposed approach.

Keywords: Tourist Tax, Sustainability, Algarve, Cooperation, Pricing Policy
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List of Acronyms

AI	Artificial Intelligence
UNWTO	United Nations World Tourism Organization
VAT	Value Added Tax
INE	Instituto Nacional de Estatística

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1 Introduction

Although tourism activities may be seen as a source of joy and leisure by those who consume them, those who work to provide these experiences often view the industry as the backbone of their economic stability. In fact, many economies worldwide rely heavily on the tourism sector, with some presenting it as the main contributor to overall production levels. This occurs especially in regions that benefit from favorable weather conditions that inherently attract larger tourism inflows. Particularly in the European Union, this natural advantage is evident when southern European countries show relatively higher contributions from the travel and tourism sector to their economy compared with the other member states.

While it certainly plays a crucial role in generating local jobs and strengthening local businesses, the sector also faces lots of uncertainty as it relies on various external factors, such as tourist preferences. Additionally, its excessive volume combined with high fluctuations between low and high seasons may result in unsustainable pressure on the community's public services, resources, and even on its socio-cultural identity. Popular tourist destinations often see their population numbers more than double during peak seasons, which also implies the demand for the region's resources and services to experience extreme shifts as well. Administrations worldwide have been trying to find a solution, or at least a way, to mitigate overtourism as the issue seems to worsen over the years, and protests against it have started to emerge.

One solution proposed and widely adopted by many destinations is the implementation of tourism taxation. Municipalities worldwide employ a range of approaches to levy charges on tourists, but the most common approach is a fixed per-night fee for each individual staying in tourist accommodations. Local authorities often justify this taxation as a way of offsetting the costs incurred with the tourist's presence in the region. Many also say to allocate the revenue to local environmental protection projects. These local applications of the revenue are likely the reason why this type of tax is often managed and decided not by central authorities, but rather by municipalities.

Researchers have actively investigated the efficiency of tourism taxation (Sheng, 2017) (Hughes, 1981). Some issues arise as additional costs may reduce the region's competitiveness and redirect tourists to other alternative destinations. Additionally, estimating the value of tourism's externalities is most likely impossible, which may result in unfair taxation (Yang et al., 2023). Furthermore, municipalities must ensure transparency when determining the tax price and honor the commitment of allocating the revenue gathered to the agreed-upon initiatives. This does not always hold true. Cavallero and Zagler (2024) acknowledged that neighboring municipalities on the Italian coast were competing with each other using the tax, falling into a race to the bottom with progressive tax reduction. This goes directly against the core purpose of tourism taxation. However, it also sheds light on the potential use of tourism taxation to manage and redistribute tourism flows.

In this thesis, we investigate whether and how tourism taxation can be used to mitigate the

unevenness in tourism pressure distribution within a region. To explore this, we use the case of the Algarve, a popular tourist destination in the south of Portugal characterized by heavy reliance on its coastal areas and concentrated tourist hubs. We introduce to the field of tourism taxation a new perspective of inter-municipal cooperation to test how the region could benefit from a collaborative framework where local authorities seek to achieve a more equitable distribution of the sector's burdens and benefits within the region's municipalities.

Given the regional context, we believe that our future findings will be particularly relevant, especially considering the recent surge of interest among the Algarve´s local authorities in introducing and studying the effects of tourism taxation. At the moment, only seven of its sixteen municipalities have implemented tourism taxation so far, five of which did so very recently. However, it is expected that more municipalities of the region will be introducing it soon, as most have voted in favor of its introduction.

As previously suggested, tourism across the region is far from being evenly distributed, with the three most popular municipalities (Albufeira, Loulé, and Portimão) accounting for more than 60% of the total overnight stays in the region in 2023. This has led parts of the region to face concerns regarding mass tourism, both in terms of economic dependency and resource management, with campaigns aimed at promoting responsible behavior, such as recycling and responsible water consumption, starting to emerge.

A successful pricing approach of tourism taxes in the region could help mitigate over-tourism by redirecting part of the tourist inflows to less pressured municipalities. After estimating the tourism pressure faced by each municipality on key resources and infrastructure, we proceed with the development of an algorithm aimed at determining the tax prices that would result in the minimization of disparities in tourism pressure among municipalities. We expect the plausibility of the prices to be dependent on tourists' sensitivity to price changes. However, we believe that even if not entirely favorable, the algorithm's decisions could still serve as a valuable guide for adjusting tax rates across municipalities.

2 Literature Review

2.1 Tourism Impacts and Taxation Policies

Tourism's positive influence on the prosperity of many regions worldwide is widely recognized, particularly in economies where the industrial sector is relatively weaker. Unlike other industries, tourism has the ability to bring additional external revenue to local communities by attracting visitors who spend directly on local businesses. This spending not only creates employment and fosters entrepreneurship (Farinha et al., 2021) but also continues to benefit the local economy even after the visitor's departure.

Previous research on tourism effects primarily focuses on its positive and negative externalities rather than on its direct observable effects. The positive effects extend beyond just economic gains, especially when the sector is well managed. They can, for instance, be extended to benefits on cultural (Besculides et al., 2002) and even environmental aspects when in the case of ecotourism (Torsney and Buckley, 2025). Curiously, the negative effects of tourism often align with the same areas where positive effects are identified but arise in circumstances of weaker management. Both cultural and environmental aspects can also be harmed when tourism leads to the erosion of the local heritage and environmental degradation. This highlights that the effects ultimately depend on balancing demand and supply and that overtourism may be a result of local authorities setting prices too low in an attempt to boost tourist inflows (Seraphin and Ivanov, 2020).

Discouraging tourism is often viewed negatively by the sector's stakeholders and residents who benefit from its positive impacts, and might be the reason why most destinations continue to prioritize attracting the highest number of tourists possible (Oklevik et al., 2019). In this context, tourism taxation appears as a solution to offset the additional costs associated with tourism without harming the industry and local communities. Additionally, taxing tourists also serves as a way of shifting some of the tax burden to non-electors, which may be appealing to local authorities (Durbarry, 2008; Hughes, 1981). However, it must be ensured that the introduced tax burden is primarily taken by the tourists and not absorbed by hotels, residents, or other local businesses, as this could decrease profitability and, consequently, further investment in the industry (Gooroochurn and Sinclair, 2005), (Hughes, 1981).

In fact, fully exporting the tax effects without harming domestic welfare is extremely challenging (Gooroochurn and Sinclair, 2005), and the extent to which this is achieved is often how previous research measures the efficiency of this sort of tax. Its efficiency is also highly dependent on market conditions such as the region's demand elasticity and market structure (Sheng, 2017). If demand is strongly elastic, and there is evidence that tourism demand tends to be (Hughes, 1981; do Valle et al., 2012; Gooroochurn and Sinclair, 2005), higher taxes can result in a drastic drop in demand, while in more competitive markets, hotels may choose to absorb the tax burden in order to remain competitive.

Governments should therefore focus on identifying the most effective taxation approach and clearly define the "what", "how" and why of its implementation. If the goal is to cover additional costs, a fair approach would be to levy a tax in a way that ensures that the burden is placed on those responsible for the costs, the tourists. This raises the issue of determining which activities should be taxed. It's evident that if the objective is to charge tourists, the tax should target sectors or activities that ideally only tourists consume (Gooroochurn and Sinclair, 2005).

However, none of the more than 40 types of tourism taxes identified by the United Nations World Tourism Organization (UNWTO) seem to fully resolve this issue, and there seems to exist a trade-off between addressing it and the number of tourists reachable. Taxes on restaurants and other services work better in reaching tourists, but also impact residents who consume them. On the other hand, taxes on airport arrivals may primarily affect non-residents but only target tourists who travel by air, excluding those who arrive by other means of transportation.

Most destinations, including the Algarve, opt to impose tourism taxation through accommodation services. While it doesn't resolve completely the previously discussed trade-off, it still performs relatively well, falling short when residents use accommodation services and when non-residents avoid the tax by staying in rented properties or relatives' houses. Additionally, this type of tourism tax is relatively easier to administer and implement (Gooroochurn and Sinclair, 2005) as most frequently, hotels are the intermediaries who collect the tax from tourists and remit it to local authorities, avoiding the necessity of creating a public national or local entity responsible for that (Hughes, 1981).

To guarantee that the tax is properly implemented in the field, local authorities should clearly define the rules and state penalties to avoid tax evasion (Hughes, 1981), additionally, in the case of hotel taxes, governments should have a comprehensive registry of all the business subject to taxation and realize random audits, which may be challenging in some cases of destinations with informal and unregistered rentals (Hughes, 1981). Moreover, decision makers should debate whether the tax will be collected in an ad valorem or a fixed way. There is ongoing discussion on which one is the best approach, with destinations using one or other form (Dwyer et al., 2020). While some defend a specific value because of easier administration, others state the benefits of an ad valorem tax in terms of easing the burden on lower budget travelers (Hughes, 1981).

After deciding on the type of tax to charge, it is crucial to clearly define the objectives of its implementation, especially if fairness and transparency are a priority. If used merely as a way of getting funds to compensate for tourism-related costs, accurately estimating these costs is essential to fairly determine the tax price. If the revenue is intended for infrastructure or environmental projects, it should be strictly allocated to those purposes rather than diverted to other matters.

2.2 Machine Learning in the Context of Tourism

Machine learning and artificial intelligence have played a crucial role in redefining processes, increasing efficiency, and automating daily tasks across various sectors. Tourism is no exception and has particularly benefited from these advancements (Patrichi, 2024). Artificial intelligence has a crucial role in enhancing customer service and improving the overall tourist experience (Sansone et al., 2024). Tourists benefit from personalized recommendation systems, translation tools, and easier processes for hotel and ticket booking, which all contribute to higher customer satisfaction (Sansone et al., 2024).

Moreover, artificial intelligence has promoted the sustainability of the tourism sector (Hussain and Arsalan, 2024). Itinerary planning tools allow for lower unnecessary fuel consumption by enabling tourists to reach their destinations more efficiently when driving. Better monitoring and surveillance of natural ecosystems are also possible through the usage of AI, which may play a crucial role in identifying potential threats (Patrichi, 2024). However, previous literature suggests that the greatest opportunity lies in artificial intelligence's ability to derive real-time actions for efficient resource management, which allows for a reduction in the tourism footprint of destinations (Hussain and Arsalan, 2024). Moreover, predictive models are becoming more precise in forecasting tourist inflows, allowing the tourism sector to better prepare for fluctuations in demand and allocate resources more effectively, mitigating overall environmental impacts (Patrichi, 2024).

These benefits in operational efficiency are what we intend to explore in the context of optimizing resource consumption across municipalities. Previous research shows that AI has been successful in optimizing resource-related problems (Vázquez-Canteli and Nagy, 2019). It helped in optimizing electricity costs and reducing carbon emissions in hotels and resorts (Patrichi, 2024). It also has helped prevent the overconsumption of water, food, and waste generation through predictive analytics, which enabled the identification of trends and fluctuations, allowing businesses to adapt their strategies accordingly (Hussain and Arsalan, 2024).

Fundamentally, algorithms helped in creating policies that detect overconsumption and apply solutions to mitigate it. Research in tourism and resource management indicates that the most common approach to handling resource-related challenges is dynamic pricing, which adjusts costs based on demand fluctuations. This technique is widely popular in the travel industry, with companies like Uber and many airlines using it to balance supply and demand while also increasing profits (Sansone et al., 2024). It also has the potential to reduce waste and energy consumption in industries such as energy and agriculture (Araf et al., 2025). Regarding the tourism sector, dynamic pricing can be used to adjust prices based on the current tourist pressure of a destination (Patrichi, 2024) by incentivizing diversification and dispersion through time-based rerouting (Koens and Postma, 2017). All this means that machine learning can be a valuable tool for managing overtourism (Sansone et al., 2024), not only through dynamic pricing but also through other tools such as recommendation systems that consider peak visitor hours at

attractions and suggest less known activities.

Nonetheless, there are also challenges associated with the use of machine learning in tourism. Since the industry is highly impacted by fluctuations, predictive models in this field may be relatively less precise. Tourism demand may be hard to forecast given the high number of factors and indicators impacting it, even when using sophisticated models such as deep learning (Law et al., 2019). Additionally, artificial intelligence can contribute to overtourism, especially through social media algorithms where popular destinations tend to be more frequently shared and promoted (Sansone et al., 2024).

Moreover, ethical concerns related to the use of AI in tourism are widely discussed (Hussain and Arsalan, 2024). These models often rely on private data for training, raising issues on data privacy and security. Additionally, models may fall into biases and unfairness in decision-making. In this regard, explainable AI may be the solution. If models fail to maintain transparency, consumers may feel betrayed and offer resistance especially when asked to share personal data (Araf et al., 2025). Furthermore, equitable access should also be guaranteed, as the importance of technology for an enhanced tourism experience could exclude those without the necessary digital tools.

2.3 The Case of the Algarve

The Algarve is the southernmost region of Portugal and one of Europe's most popular tourist destinations. Accounting for nearly 26% of the total overnight stays in Portugal, the region continues to attract tourists who search primarily for its stunning coast, golden beaches, and dramatic cliffs. In 2024, this relatively small region of 4966 km^2 recorded an impressive nearly 21 million stays in accommodation services and the tendency suggests this value to continue to rise. Despite the coastline of nearly 150 km that allows for quick access to high-quality beaches throughout most of the region, tourism remains unevenly distributed, even along the coast. In 2024, the region's three most popular destinations, Albufeira, Loulé, and Portimão, accounted for 64.3% of the total overnight stays, with contributions of 37.2%, 14%, and 13.1%, respectively.

On the other hand, the least popular municipalities, Alcoutim, São Brás de Alportel, and Monchique, accounted for less than 1% of the total overnight stays in the region. These municipalities are also the only three out of the 16 municipalities that don't have direct access to the coast, highlighting the relevance of the coastline for the tourism sector in the region. This relevance not only leads to an uneven distribution of tourists but also contributes to the high seasonality of tourism levels in the region. The warmer months of June, July, August, and September in 2024 accounted for 52% of the total overnight stays recorded throughout the year, while the period from November to February recorded only 13.8% of the overnight stays in the same year. These highly seasonal patterns of tourism influxes, combined with the local economy's high dependency on tourism lead to additional challenges such as hard-to-predict fluctuations

in demand for public services and seasonal unemployment.

Residents' perceptions on the impacts of tourism in the region have been discussed in previous research. Residents believe that tourism creates more job opportunities and develops new and different local businesses (Roberts, 2021). In fact, 40% of the jobs in the region come from hotels, restaurants, transportation, and local businesses which rely heavily on tourism (Coelho, 2024). Moreover, residents agree that tourism contributes to the recognition and prestige of local culture (Pinto et al., 2023) by stimulating cultural activities, festivals, and traditions (Roberts, 2021).

On the other hand, residents also highlight the downsides of mass tourism in the region, which include an increase in the cost of living, transit congestion, pollution, noise, increased waste, and increased consumption of alcohol and drugs (Roberts, 2021; Pinto et al., 2023). In fact, the Algarve has been slowly evolving into a mass tourism destination, especially following the construction of the Faro Airport (Pereira et al., 2024). Additionally, residents feel that authorities are not managing tourism well (Pinto et al., 2023) as the sector has not brought significant improvements in public services, security, parks, or the protection of the environment and natural resources (Roberts, 2021), contradicting the benefits suggested by sustainable tourism research. This fact, aligned with growing tourism levels, has raised concerns regarding the sustainability of the sector in the region, with its greatest impact being on water resources, as low rainfall and increased consumption have led to recurring critical low dam levels.

Building on this concern, stakeholders and residents believe that the region's long-term water supply is not protected, which could negatively affect tourism activity in the future (Farinha et al., 2021). Ensuring the engagement of stakeholders and understanding the supply side of the equation is fundamental to achieve high levels of sustainability in tourism management, therefore, the existing consensus on the key importance of biodiversity and natural resources for the performance and development of the sector is highly positive (Farinha et al., 2021). This consensus may be driven not only by general environmental concerns but also by the strong reliance on natural attractions, such as beaches, that tourism in the region presents (do Valle et al., 2012).

Previous research suggests that this consensus is not absolute, as stakeholders apply varying importance to sustainability indicators (Pereira et al., 2024). Additionally, companies view the impacts on the sociocultural dimension as less critical, while municipalities emphasize all sustainability indicators (Pereira et al., 2024). However, the idea that tourism development can be aligned with positive environmental impacts, even if not yet recognized by residents, could serve as a potential opportunity to balance all the different perspectives (Torsney and Buckley, 2025; do Valle et al., 2012).

2.4 Tourism Taxation in the Algarve

Municipalities are aware of the impacts of tourism on infrastructure, the environment, and the additional costs that it brings. However, before the implementation of tourism taxes, local authorities received no direct financial contribution from tourists. Moreover, tourists benefit from a reduced VAT rate of 6% on accommodation in Portugal, indicating a relatively low fiscal burden placed on them.

This reduced taxation might be one of the reasons why Algarve's municipalities recently voted for the implementation of tourism taxation, with only one vote against its introduction. These taxes are still relatively new in Portugal (Carvalho et al., 2024), and many municipalities are still debating and assessing their implementation. By the end of 2024, only 7 out of the 16 municipalities in the Algarve had begun applying the tourism tax, though some of those that have not implemented it yet have publicly stated their intention to do so in the future. Regarding the type of tourism fee proposed, municipalities in the Algarve and throughout Portugal, have followed the global trend of charging a fixed overnight fee. This fee is collected by all the accommodation services and redirected to local authorities, either directly or through online platforms (Carvalho et al., 2024).

In Portugal, municipalities are required to publish decrees in the official gazette of Portugal, *Diário da República*, in order to establish any municipal tax. In these documents are stated the legal basis and the purpose of the tax, allowing for an idea of what municipalities intend to achieve with its implementation. Several aspects of the tourism tax regulations are shared among the seven decrees published by Algarve's municipalities. All state that the tax is intended to compensate for the increased strain that tourism places on public services and infrastructure, including natural resources and landscape.

Most municipalities attach an economic-financial justification in the decree. In this section, municipalities measure the costs incurred for tourism promotion, events, and key infrastructures, aiming to determine the cost per stay. Moreover, municipalities estimate the expected revenue from the tax. By comparing the reported values, it is evident that none of the municipalities seek to fully cover the total expenditure with tourism through the tax. Instead, most opt to take a 60% burden of the total costs, meaning tourists contribute with less than half of their costs through the tourism tax. This is consistent with the national tendency that municipalities tend to charge less than the actual cost in order to avoid excessive burden for the tourists (Carvalho et al., 2024).

It is also evident that none of the municipalities follows an approach of using the tax as a tool to reduce competitiveness, indicating no extreme situations of critical overtourism levels. Instead, the tax may actually aim to enhance competitiveness in the long run, as the collected revenue is intended to be reinvested to improve the sector's sustainable growth and enhance citizens' prosperity (Farinha et al., 2021). Municipalities continue trying to keep tourists unaware of their externalities in the region (do Valle et al., 2012), except regarding water consumption,

where awareness campaigns to encourage more responsible usage towards tourists have recently emerged. This reinforces the critical state of the region's water resources and the significant impact that tourism activity has on its consumption. Tourism activities, particularly in coastal areas, are a special threat to water resources as they intensify water use through swimming pools, frequent showers, and attractions like golf and water parks (Gössling et al., 2012). An efficient water distribution and management system is essential to reduce water consumption in a significant way (Gössling et al., 2012). Therefore, local authorities in the region have started to take actions such as replacing pipelines and regulating activities that require high levels of water, such as golf, water parks, and public spaces irrigation.

Municipalities have significant flexibility in deciding whether to apply the tax and setting its price. Initially, the first two municipalities implementing the tax, Vila Real de Santo António and Faro opted for a constant value throughout the year of 1€ and a high season value of 1.5€, respectively. The trend has now shifted towards a pricing strategy where municipalities charge a low-season tax of 1€ from November to March and a high-season tax of 2€ during the rest of the year. At the moment, the municipalities of Lagoa, Loulé, Faro, Olhão, and Portimão apply this strategy. Albufeira differs by only charging 2€ during the high season, and Vila Real de Santo António by keeping the 1€ approach throughout the whole year. This observed national trend of low tax price variation across municipalities (Carvalho et al., 2024), combined with the fact that tourism is not evenly distributed across the seven municipalities, suggests that the prices are most likely not being decided based on current municipalities' levels of tourism or sustainability indicators, meaning no tourist rerouting approaches are being implemented.

Specific impacts of the tax on the region have not been researched yet, as it is still a recent application in the region. However, tourists' willingness to pay for a tourism tax in the Algarve was previously discussed before its introduction (do Valle et al., 2012). The findings showed that when asked about willingness to pay for a tax that would be used to fund environmental protection projects, the typical tourist who seeks the beach is not so environmentally friendly, suggesting that the coastal Algarve might not attract deeply environmentally concerned tourists. Older people who had already donated to similar causes and tourists who preferred activities related to walking and enjoying the landscape were those who presented the highest willingness to pay. The study also highlights the common challenge of hotels' resistance to the implementation of such taxes. We believe that the previously referred consensus among stakeholders and municipalities could have impacted the acceptance rate when tourism taxation was initially proposed. This further reinforces the necessity for municipalities to be transparent and clearly state the purpose of the revenue gathered through the tax.

2.5 Tax Related Opportunities

Adopting a different approach to set tax prices across municipalities could benefit the Algarve region and its tourism sector by promoting a more balanced distribution of resource consump-

tion and mitigating mass tourism circumstances (Yang et al., 2023). These sustainability-related challenges cannot be tackled by the actions of a single municipality alone (Yuval, 2022), therefore inter-municipal cooperation is essential. Previous research on municipal cooperation focuses on highly popular cities and how their counties can work together to spread tourism over the year and over the city space to reduce its impacts (Yuval, 2022). Moreover, it has been demonstrated, mainly through game-based theory, that inter-municipal actions promote more sustainable tourism in the long run (Vlès, 2016).

Competition among municipalities has also been discussed in previous research (Cavallero and Zagler, 2024). Competition is the result of municipalities exploring the existing cross-municipal price elasticity of demand in order to attract higher numbers of tourist inflows to their territory.

This demand elasticity, if also present in the Algarve, could serve as an opportunity to better distribute tourists across the region, provided that municipalities adopt a strategy of cooperation rather than competing. When it comes to inter-municipal cooperation, the most popular municipality of a region, Albufeira in the Algarve's case, plays a crucial role in defining its effectiveness (Yuval, 2022). This is because the municipality facing the most critical levels of mass tourism should ideally have higher taxes to reduce its competitiveness, so that tourists move to the neighboring municipalities.

Currently in the Algarve, most municipalities are charging the same price on tourism taxation, which can be perceived as cooperation, but misses the opportunity of using the tax to better distribute tourists in the region. For tourism taxation to serve as a tool for balancing visitor flows, implementing a proper price differentiation will be essential.

3 Methodologies

3.1 Data Collection

Building on previous research on the impacts of tourism, we aimed to collect data on the Algarve region and its municipalities' consumption of resources that were identified as potentially threatened by tourism. We searched for the relevant and necessary data on public databases such as those from *Instituto Nacional de Estatística* and *Pordata*, as these are the most reliable institutions for collecting and distributing the majority of the official statistics in Portugal. Many challenges arose during the data collection process, especially due to lack of monthly data. Furthermore, not all series were available for the same time period, and many, especially those related to tourism, present missing values for older data points in municipalities with lower tourism levels. Table 1 provides an overview of the variable areas essential to understanding the regional dynamics.

Variable Name	Source	Source URL
Number of Residents	PORDATA	pordata.pt
Overnight Stays	Instituto Nacional de Estatística (INE)	ine.pt
Collected-Solid-Waste	Instituto Nacional de Estatística (INE)	ine.pt
Energy Consumption	Instituto Nacional de Estatística (INE)	ine.pt
Water Distributed	Instituto Nacional de Estatística (INE)	ine.pt
	Águas do Algarve	aguasdoalgarve.pt
Drained Wastewater	Instituto Nacional de Estatística (INE)	ine.pt
	Águas do Algarve	aguasdoalgarve.pt
Hotel Room Revenue	Instituto Nacional de Estatística (INE)	ine.pt
Tourism Tax Policy History	Decrees published in Diário da Républica	diariodarepublica.pt

Table 1: Collected variables and respective data sources

Data was found for energy and water consumption, as well as for solid waste and wastewater generation. Our analysis will be focused on reducing disparities in tourism pressure on the consumption of these public resources and services across the municipalities of the Algarve. Other factors, such as road traffic and sociocultural impacts, won't be incorporated in our analysis due to nonexistent measurements, mainly driven by the inherent difficulty in quantifying such externalities. To measure tourism pressure and price sensitivity of tourism demand, data on regional demographics and the tourism sector were also collected. These include data on the number of residents and overnight stays, tourism tax values, and revenue per room in accommodation services.

Other additional variables were collected when modeling the region's resource consumption and price elasticity. These included potential auxiliary variables such as water losses, substitute destinations' prices, tourists per source market, and tourists' revenue. These variables were tested in alternative models that proved unsuccessful or lacked explanatory power and, as a result, were not included in the final specifications.

To address eventual missing data issues, we focused on periods with consistently complete records, which led to the exclusion of older data points from the analysis as well as recent

entries where data was still unavailable. Additionally, some essential variables were found to be not available on a monthly basis despite being available at a regional level. In such cases, we assumed monthly variations at the municipal level to follow the same pattern as regional data, and generalized accordingly.

The necessary data was collected and organized using Excel. Two datasets were created: one for yearly data structured by municipality and year, and another for monthly data structured by municipality, year, and month. Subsequently, Python was employed for all further analysis, figure generation, and development of the final algorithm.

3.2 Tourists' Consumption

Since our datasets have a panel structure, as they are time-based and concern entities, our analysis on tourist consumption will focus on methods appropriate for panel data, particularly regression models with fixed effects. This type of models help in isolating the impact of tourists in our analysis, as they account for municipal and time-specific characteristics such as infrastructure and time-related variations that could reduce the accuracy and reliability of our results. This approach revealed essential given the reliance on overall consumption levels, as data on sector-specific consumption is not available.

Regarding consumption levels, our goal will be to establish an average profile of tourist consumption for each municipality. However, as suggested by the literature, tourists are unlikely to spend equally across all municipalities, as consumption strongly depends on different contexts. There are many distinct tourism offers across the region, such as rural activities, popular beach recreation, famous festivals, as well as premium luxurious activities, all attracting different types of tourists with distinct consumption patterns.

Category	Municipalities	Description
Interior	Alcoutim, Monchique, São Brás de Alportel, Castro Marim, Silves and Aljezur	Municipalities with little or no access to the popular southern coastal area. Tourism is primarly rural, with minimal or no dependency on coastal activities.
Beach - Focused	Lagoa, Lagos, Vila do Bispo and Vila Real de Santo António	Contrary to the previous group, tourism in these municipalities relies primarily on beach recreation and coastal activities.
Urban	Faro, Tavira and Olhão	These municipalities, despite their coastal location, present relatively low levels of tourists per resident, which may make tourism impacts less significant.
Popular	Albufeira and Portimão	In addition to the high dependency on coastal activities and beach recreation, these municipalities are characterized by their high popularity and famous festivals that attract visitors from all around the world. These are the closest to mass tourism destinations in the region.
Luxurious	Loulé	Loulé stands out as the biggest outlier in water consumption. The three most luxurious hubs in the Algarve (Quinta do Lago, Vale do Lobo, and Vilamoura) are located in its area and often report consumption levels that surpass 10 times the national average daily consumption.

Figure 1: Groups of municipalities according to key characteristics

This led us to organize the region's municipalities in different groups, considering the differences in tourist activities, type of tourist, stays per resident, and geographical location. We grouped municipalities based on their similarities on these levels using hierarchical cluster analysis, combined with firsthand knowledge on the type of tourism offerings and types of tourists they attract when in circumstances of indecision. In Figure 1 are presented the resulting groups.

The absence of data for auxiliary explanatory variables commonly used in conventional consumption models made it necessary to adopt a different approach to model tourist consumption. We began by assuming that total consumption is the sum of both residents' and tourists' consumption, and proceeded with:

$$\text{Consumption}_{it}^{k} = N_{\text{res}}^{it} \times C_{\text{res,k}}^{it} + N_{\text{tour}}^{it} \times C_{\text{tour,k}}^{it} \tag{1}$$

Where:
N_{res}^{it} = Number of residents in municipality i at time t
$C_{\text{res}}^{it,k}$ = Resident's per capita consumption of resource k
N_{tour}^{it} = Number of tourists in municipality i at time t
$C_{\text{tour}}^{it,k}$ = Tourist's per capita consumption of resource k

Which leads to:

$$\frac{\text{Consumption}_{it}^{k}}{N_{\text{res}}^{it}} = C_{\text{res,k}}^{it} + \frac{N_{\text{tour}}^{it}}{N_{\text{res}}^{it}} \times C_{\text{tour,k}}^{it} \tag{2}$$

Based on this equation, we regress the fixed effects model:

$$\frac{\text{Consumption}_{it}^{k}}{N_{\text{res}}^{it}} = C_{\text{res,k}}^{it} + \frac{N_{\text{tour}}^{it}}{N_{\text{res}}^{it}} \times C_{\text{tour,k}}^{it} + \alpha_i + \lambda_t + \varepsilon_{it} \tag{3}$$

Where residents' and tourists' consumption will be given respectively by β_0 and β_1.

Following the same approach, we re-estimated the models including binary variables representing the previously defined groups to assess how consumption patterns differ based on the different group characteristics.

This allowed us to use existing and collected data to estimate the daily annual average consumption of both a single tourist and a single resident, and to identify differences between consumption patterns across the defined groups, which will be crucial to correctly estimate the different pressure levels faced by each municipality.

3.3 Price Elasticity of Tourism Demand

Finding price elasticity levels for the Algarve region is particularly challenging and remains largely unexplored in previous literature. Initially, we attempted to explore the effects of the current tourism tax prices on the number of overnight stays for the municipalities that already

charge them, but without success, as low variability and few instances of positive tax values led to inconclusive results.

We then adopted the more common literature approach of using log-log models that consider own-price levels, substitute destination prices, and tourists' source market income to explain overnight stays. However, this also proved unsuccessful as unrealistic positive levels of price elasticity showed up, which likely are the result of prices adjusting to demand rather than demand responding to prices.

This led us to change our approach regarding elasticity estimation by testing a range of plausible values rather than relying on a single estimate. This will allow us to later observe how the algorithm's performance changes based on different elasticity levels and to anticipate how local authorities should react when the response of tourists to taxation becomes clearer. We will focus on testing values between -0.1% and -1% as the expected result lies within these values, given previous literature's insights.

Since testing elasticity assumes simulating changes in a given price, we use data on municipal room revenue and overnight stays to compute the average price per night in each municipality. This proved to be an essential step, as the relative change in price resulting from different tourism tax rates depends on existing accommodation prices, which also vary across municipalities.

3.4 Defining the Algorithm

To achieve our final objective of reducing tourism pressure discrepancies over municipalities, we need to develop an algorithm that will be used to identify the optimal combination of tourism taxes, while keeping the overall regional tourism levels the most steady as possible.

To measure discrepancies over municipalities, we use how much tourist pressure deviates from the average pressure while penalizing larger deviations through:

$$\text{discrepancy} = \frac{1}{M} \sum_{m:m\in M} \left|\text{pressure}_m - \overline{\text{pressure}}\right|^2 \tag{4}$$

where tourism pressure is defined as the average percentage of total consumption attributed to tourists across the different municipalities:

$$\text{pressure}_{\text{m}} = \frac{1}{k} \sum_{k\in\{\text{resources}\}} \frac{c_{k,\text{m}} \times \text{overnight stays}_{\text{m}}}{\text{total consumption}_{k,\text{m}}} \tag{5}$$

This approach considers the average pressure across all resources on each municipality, giving equal importance to each resource pressure. Given that water resources face a more critical situation in the region, we first ran the algorithm using only water pressure. Then we run the model using water, wastewater, and energy pressure levels to assess how tax decisions vary depending on the set of resources considered. Solid waste ended up not being included in the

algorithm's analysis as monthly values on this resource were not found, both at the municipal and regional levels.

We guide our algorithm to reduce discrepancies without significantly altering overall tourism levels by minimizing:

$$\alpha \times \frac{\text{discrepancy}(t)}{\text{discrepancy}_0} + \beta \times \frac{\sum_{\text{mun} \in M} \left|\text{overnight\_stays}_{\text{mun}}(t) - \text{overnight\_stays}_{\text{mun},0}\right|}{\text{total\_overnight\_stays}_0} \quad (6)$$

where α and β are changed based on the relevance of minimizing discrepancies over keeping tourist levels steady. To allow the algorithm to work under different scenarios, we allow for additional hyperparameter adjustments, which are described below:

- **Range of Taxes** – Defines the minimum and maximum tax rates that can be applied. Ensures taxes remain within feasible and permitted bounds.
- **Step** – Specifies the incremental change (e.g., 0.01 for 0.01€ increment).
- **Allowable Change** – The maximum percentage by which tourist levels are allowed to change in each municipality (e.g., 2%).
- **Elasticities** – Defines the list of price elasticity levels to be tested.

Since price effects will be considered in a linear way, we developed the model to work by reducing or increasing tourism taxes across municipalities by the given step until no improvement is found. A pseudo-code representation of the algorithm's functioning is presented in Appendix A. While this represents a limitation of our approach, as price elasticity is likely not linear, it also ensures that the algorithm doesn't get stuck in a local minimum. This is essential to keep our algorithm simple and efficient without needing to exhaustively test all possible combinations of different taxes.

We will be testing the algorithm by simulating how it would have set tourism tax rates in 2023, as this is the most recent year with complete data required. Moreover, nothing atypical happened during this period, allowing us to assume that similar decisions would apply to other typical years. Given that our consumption models rely on yearly data to estimate daily average consumption, we still needed to estimate tourists' monthly variations in consumption. To achieve this, we assumed tourism consumption to follow the same monthly variations of overall municipal consumption, as lack of data didn't allow to determine monthly consumption directly.

We conclude the analysis by investigating how the algorithm performs under different circumstances by testing different combinations of hyperparameters. We also observe how the algorithm establishes price differentiation across municipalities and how decisions change based on different months of the year, in order to assess whether the model aligns with the current practice of charging different prices given different seasons.

4 Data Overview

Tourism in the Algarve has been growing in popularity over the years. This increase in the sector's levels is the result of ongoing efforts to attract larger tourist inflows by maintaining the region's competitiveness as one of the most unique coastal tourism destinations in southern Europe. Local authorities recognize that achieving higher levels of tourism demand for the region is fundamental, especially given the local economy's reliance on the sector. However, these authorities also show increased interest in minimizing the sector's negative impacts on the region. Especially in recent years, there has been an increased focus on improving the efficiency of how the necessary resources for the sector are provided, as well as diversifying the activity across municipalities in order to expand the economic benefits throughout the whole region. Examples of these efforts include the emergence of awareness campaigns on water consumption targeting tourists, growing interest in promoting less popular forms of tourism, and investments aimed at improving the efficiency of public services infrastructure. We believe that, with the help of data analysis methods and machine learning tools, it is possible to estimate the impacts of tourism with sufficient precision to guide local authorities in making better-informed decisions regarding defining priorities and policy planning. This highlights the relevance and usefulness of our future findings. In this section, we take the first step into data analysis by using the collected data to better contextualize the sector's activity and identify historical trends in consumption levels and tourist inflows.

4.1 Trends and Challenges

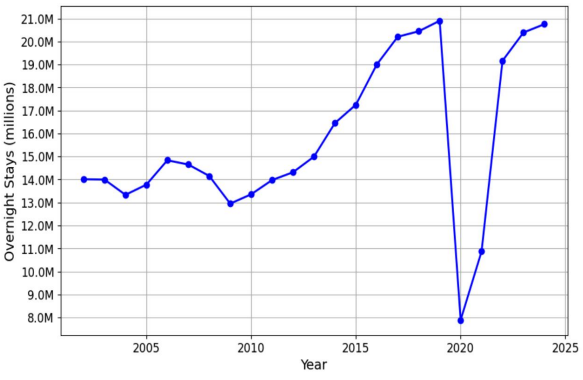

Figure 2: Annual overnight stays (2002–2024)

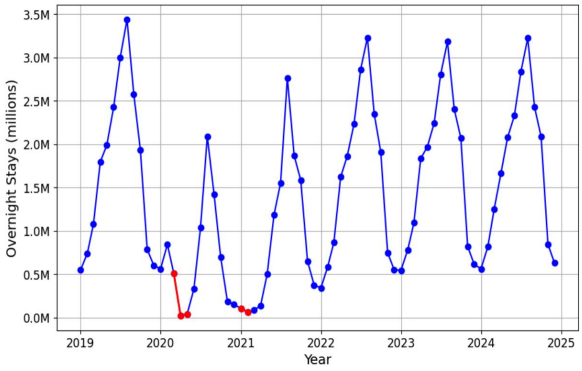

Figure 3: Monthly overnight stays (2019-2024)

The number of overnight stays confirms the region's growing popularity over the years, showing an upward trend that led the region to surpass the 20 million annual stays milestone. However, the number of stays also reflects the sector's sensitivity to significant disruptions such as economic crises and, most recently and dramatically, sanitary crises. The COVID-19 pandemic became the most extreme challenge that the region's economy has ever faced, as it

involved the complete suspension of the sector. Airports were closed, as well as hotels and restaurants, during the official lockdowns, which inevitably led to extreme drops in tourism inflows.

This had a devastating impact on the region, as the economy heavily relies on activities that were not only forced to shut down during the most critical phases of the pandemic but were also later discouraged until the situation normalized. At the moment, the levels of overnight stays in the region still haven't fully recovered to 2019 levels, despite the tendency suggesting the region will soon return to these levels. In terms of our analysis, the pandemic also introduces further challenges as it introduces noise related to impacts beyond the sector's scope, especially for 2020 and 2021 data. It particularly affects monthly data, as lockdowns consistently occurred out of the high season as emphasized in Figure 3, which could lead to erroneous findings such as unrealistic levels of seasonality. For this reason, we remain cautious when dealing with data from this period.

4.2 Cross-municipal Distribution

The distribution of residents and overnight stays across the Algarve's municipalities is highly uneven, which is most likely the result of an also uneven distribution of infrastructure, key economic hubs, and tourism attractions throughout the region.

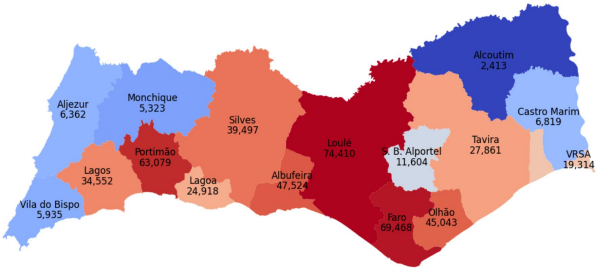

Figure 4: Number of residents (2023)

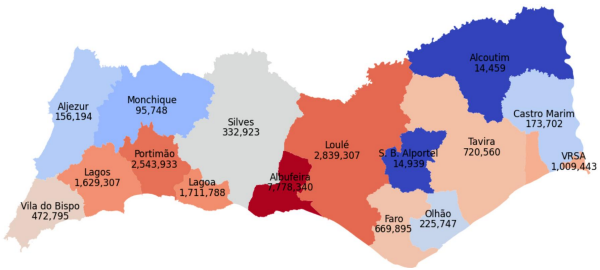

Figure 5: Number of overnight stays (2023)

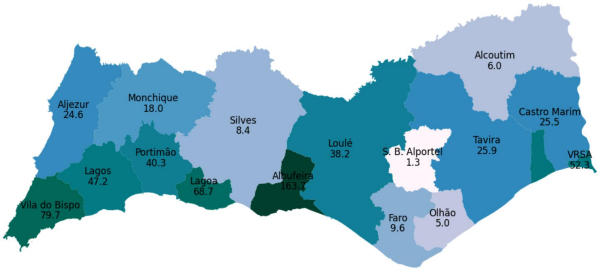

Figure 6: Overnightstays per resident (2023)

The relatively higher concentration of economic activity along the coast, compared with the interior, is a broader issue in Portugal, which not only affects the Algarve. In the regional context, municipalities with little or no access to the southern coast have consistently presented lower numbers of residents and overnight stays. These interior municipalities are also the areas

that tend to be predominantly rural and have less infrastructure, including tourist facilities, which reduces competitiveness and attracts lower numbers of tourists compared to coastal areas. On the other hand, the growing interest of local authorities in promoting rural and other different forms of tourism has attracted further investments to these areas, particularly in the municipalities of Monchique and Aljezur, resulting in a recent increase in visitor inflows to these locations.

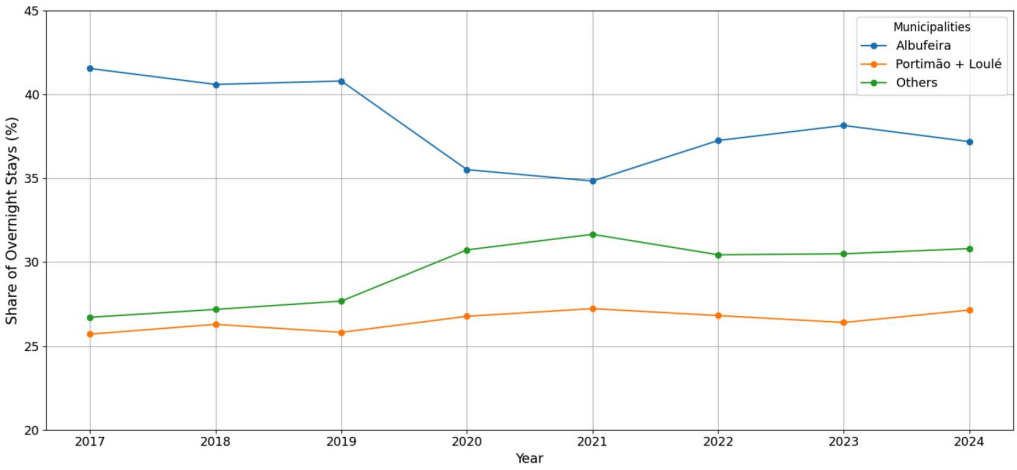

Figure 7: Overnight stays share across major Algarve hubs

Throughout the years, the municipalities of Albufeira, Loulé, and Portimão had consistently attracted more than 60% of the total overnight stays in the region, driven by their superior infrastructure, self-promotion capabilities, and events offered. However, the share of these three municipalities has been decreasing in the last few years, which might have led to a slight improvement in how tourism is distributed in the region. Figure 7 shows that this reduction in the relevance of the main poles is a result of the loss in Albufeira's share, which has been aggravated particularly during the COVID-19 pandemic. Especially after this crisis, less popular municipalities have become more relevant in the tourism context, though the municipalities of the interior present a relatively lower increase. Nonetheless, the dominance of the most popular hubs is far from being surpassed.

4.3 Seasonality Levels

The heavy reliance on beach recreation and favorable weather makes tourism in the Algarve highly seasonal, with most travelers arriving in the region in the warmer months of June to September. Conversely, significantly fewer visitors arrive during the winter months of November to February, resulting in challenges for the region involving the necessity of adjusting capacity and resource distribution according to the existing sharp fluctuations in demand. This seasonal pattern can lead not only to social problems in the region, such as seasonal unemployment, but also impose risks to the sector's level of sustainability, especially when resources are wasted and underutilized.

Figure 8 illustrates the evolution of seasonality over time, considering three different seasons: high season (June to September), low season (November to February), and mid season (March to May and October).

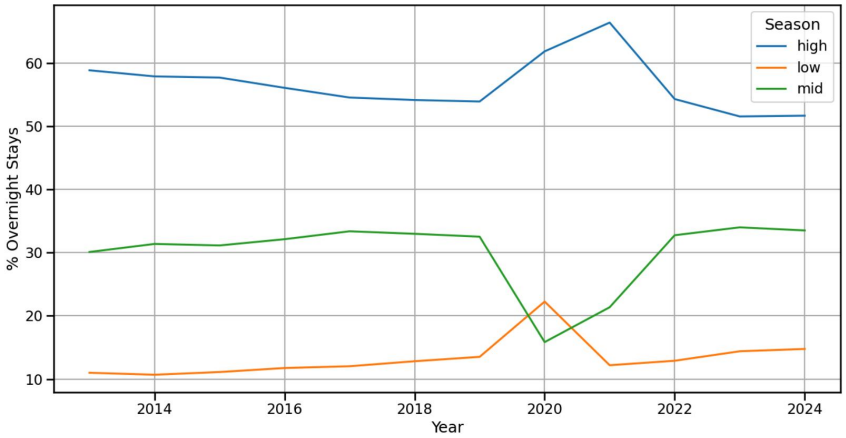

Figure 8: Annual evolution of share per season

Despite the continued high reliance on high season, the problem of seasonality seems to have gradually lowered, with the share of mid and low seasons increasing over time. This may be the result of tourists seeking more competitive prices and trying to avoid overcrowding by choosing less popular periods to travel, such as those just before and after the peak season. Moreover, Figure 8 reinforces the pandemic effects, as lockdowns caused a sharp decline in tourism, particularly during mid-season months.

Municipalities have long adapted to tourism seasonality and are aware of the costs that the associated fluctuations bring. For this reason, most of them opt to charge different tourism tax values, adjusting them according to different seasons. At the moment, all municipalities that have implemented the tax, except Vila Real de Santo António, are considering the months of April to September as high season, with the remaining months categorized as low season, ranging from the values illustrated in Figure 9.

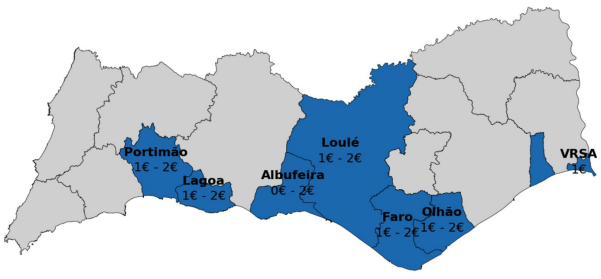

Figure 9: Tourism tax value per municipality

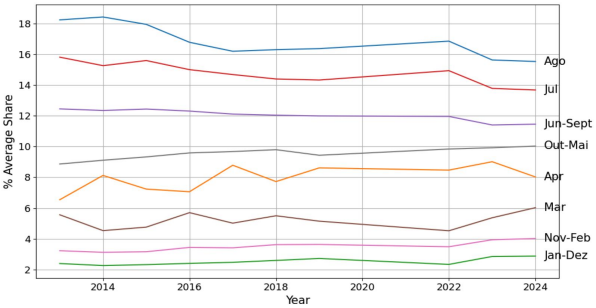

Figure 10: Overnight stays share per month (2020 and 2021 excluded)

We believe that tax efficiency could be enhanced by introducing more price differentiation throughout the year, as most months are associated with different levels of overnight stays share,

and consequently, varying tourism impacts, as illustrated in Figure 10 where similar months have been grouped. This could be achieved simply through a mid-season rate or more ambitiously, through a more dynamic pricing system. This approach could not only serve as a way for municipalities to get a revenue that better reflects their level of expenditure, but also as a further incentive for tourists to travel out of the most popular season, which could lead to an attenuation of the seasonality problem. However, while improving tax efficiency, this could also lead to other challenges, such as more complex implementation and administration.

4.4 Resource Consumption

Different numbers of residents and tourists inevitably lead to differences in absolute resource consumption. These are not solely based on the number of consumers, as may also depend on the infrastructural level of efficiency and other municipality-related factors. To measure tourists' impact on total consumption, we would ideally need data that distinguishes their consumption from that of residents. However, such data does not exist. Therefore, we rely on per capita and absolute consumption values to estimate how much each resident and tourist consumes, and how they differ. Below are the 2022 average per capita consumption of each resource, given both residents' and tourists' numbers in each municipality. This is the most recent year with complete consumption data available.

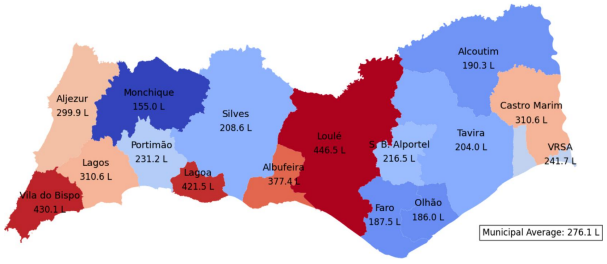

Figure 11: Daily water consumption per capita (2022)

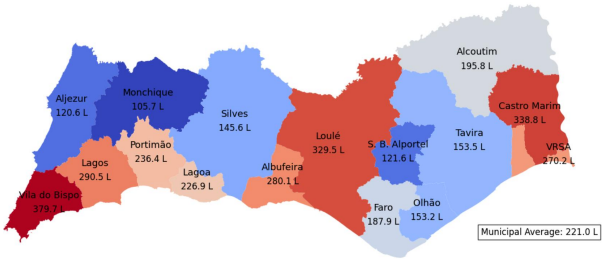

Figure 12: Daily wastewater generation per capita (2022)

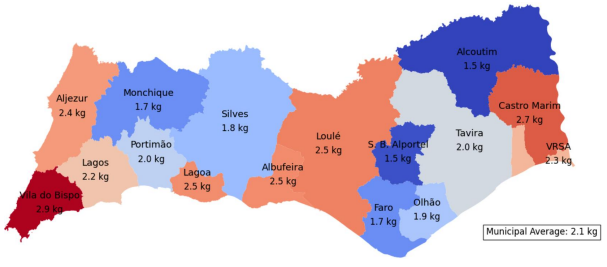

Figure 13: Daily solid waste collection per capita (2022)

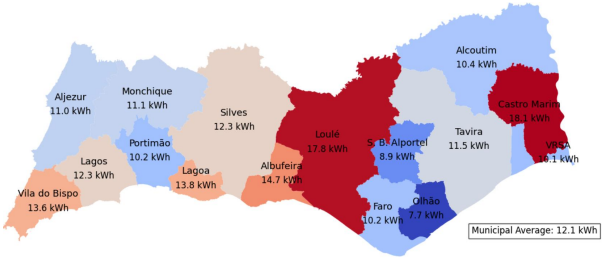

Figure 14: Daily energy consumption per capita (2022)

When compared with the levels of overnight stays per resident shown in Figure 6, a positive correlation with per capita consumption levels becomes evident, with few exceptions. While the presented data on overnight stays per resident pertains to 2023, it is expected, and it has

been confirmed, that these values do not differ substantially from those of 2022, as the tourism paradigm remained stable.

This means that it's not the number of travelers visiting the region that pushes these values up, but rather the density of tourists relative to the local population, which may reflect higher individual consumption levels among tourists. This may explain why per capita levels may be abnormal in municipalities with high tourism levels but fewer residents, such as the case of Vila do Bispo, where high tourist density combined with less prepared and efficient infrastructure may push these values up. On the opposite side, municipalities with fewer stays per resident tend to present lower per capita levels of consumption. This is consistent across all resources, especially in the municipalities of Faro, Tavira, and Olhão, where the higher number of residents may bring economies of scale and disguise tourist impacts.

Loulé stands out as the municipality with the highest overall levels of consumption, consistently surpassing all others in total consumption levels and appearing at the top in per capita consumption, despite few exceptions. We expect these higher levels to be partially explained by the concentration of premium tourism offers in this municipality, which have been linked by previous literature with higher consumption levels.

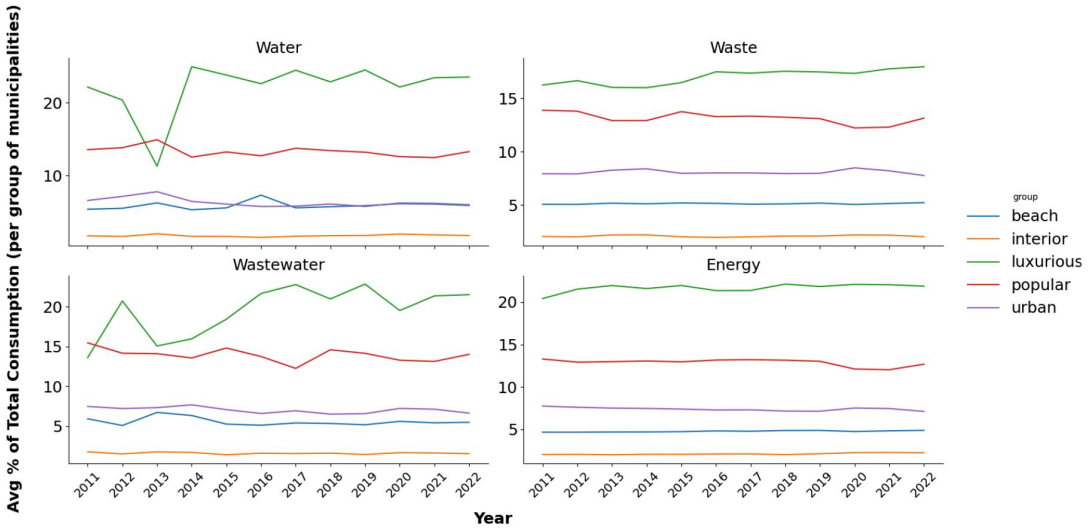

Figure 15: Average municipality share of consumption per group

Absolute levels of resource consumption in the region have been increasing over time. However, as made evident in Figure 15, the share of consumption of each of the previously defined groups of municipalities remains stable and distinct. Over the last years, the municipalities of the luxurious and popular groups consistently show the highest shares of total consumption across all types of resources, and on the other hand, municipalities in the interior group present the lowest. Despite not being illustrative of tourism pressure levels among the different groups, there is a possible indication that municipalities with higher tourism influxes or premium tourism activities are associated with relatively higher consumption of resources, which supports the need for differentiated policy measures.

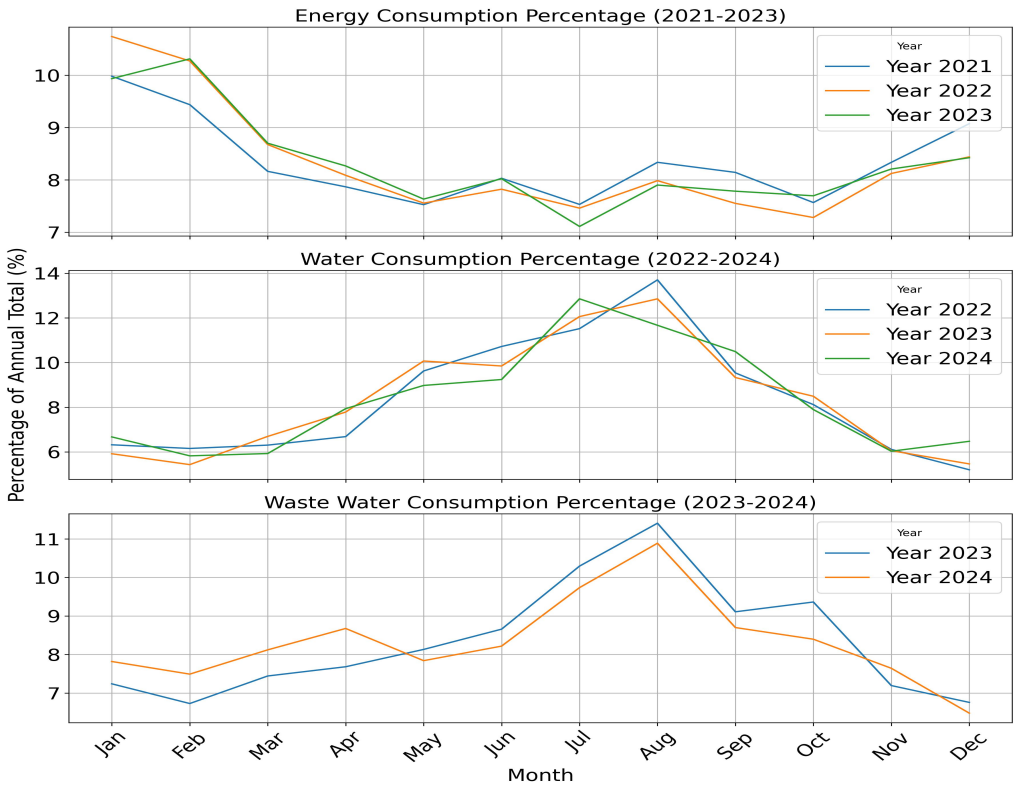

Figure 16: Share of annual consumption per month for the available years

Figure 16 provides clear evidence that seasonality in the region extends to resource consumption patterns, which remain relatively consistent across the years for which monthly data is available. For all types of resources, the proportion of total consumption progressively increases until it reaches a peak, after gradually declining to a minimal level. Energy differs by presenting the highest consumption in colder months, while water and wastewater present their peaks in the popular month of August. Knowing that consumption levels follow a relatively constant pattern throughout the year is important for the reliability of estimated monthly variations when addressing gaps in data.

5 Main Findings

5.1 Tourist's Consumption

As previously mentioned, the employed consumption models are built assuming urban resource consumption to be totally driven by tourists and residents, therefore, we expected the estimated consumption levels to be higher than the per capita levels commonly ascribed to domestic consumption. This is the result of attributing the consumption of other municipal activities to these two groups of consumers, which may lead to deviations from expected consumption depending on the relevance of domestic use within the urban context. Table 2 shows the average estimated daily consumption levels in the region, disaggregated by residents and tourists.

Average Daily Resource Consumption				
Category	Water	Wastewater	Waste	Energy
Residents	274L***	217L***	2,11Kg***	11,51 kWh***
Tourists	427L***	259L**	2,34Kg***	15,08 kWh***

Table 2: Average regional daily consumption of resources per resident and tourist

The models' results confirm the previously stated expectation, but remain consistent with the per capita consumption levels reported by *Instituto Nacional de Estatística* for the region. This approach guarantees that residents' and tourists' consumption levels remain comparable, allowing for a reliable basis for determining good estimates of tourism pressure in the subsequent steps.

The results confirm that tourists consistently consume more than residents on average in the region. The difference between the two is especially higher for water resources, where tourists are estimated to consume 56% more than residents. These differences found in consumption are consistent with the literature expectations, despite values being higher than the average consumption expected.

We continued the analysis by incorporating the previously defined groups of municipalities and re-estimating the models to examine how tourists' consumption patterns differ across them. The results are illustrated in Table 3.

Average Daily Consumption of a Tourist by Group				
Group	Water	Wastewater	Waste	Energy
Beach	729L**	651L	2.91Kg***	15.19kWh***
Urban	515L	170L	2.63Kg	12.49kWh
Popular	364L***	184L***	2.22Kg***	14.92kWh***
Interior	748L	-1142L	3.57Kg**	42,58kWh***
Luxurious	1768L***	1478L**	4.63Kg ***	29.53kWh***

Table 3: Tourist's average daily consumption per group of municipalities

Considering the values resulting from the separation of municipalities into the different groups, we confirm that tourists staying in luxury hotels and beach recreation contexts consume

a higher absolute quantity of resources. A tourist in the municipality of Loulé, which represents our luxurious group, presents consistently higher consumption levels across all resources except for energy, where a tourist in the interior group presents a higher absolute burden on the consumption of this resource.

Municipalities that receive the higher levels of tourist inflows, represented in the popular group, present consistently significant values across all resources. Despite being the most visited municipalities, the combination of a high number of residents and tourist volume, aligned with greater tourist infrastructure capacity, might be influencing per capita values in a way that levels get comparatively lower. Despite also relying heavily on beach recreation, tourists in these municipalities are associated with smaller consumption levels compared with those from the beach recreation group, which might indicate stronger per capita efficiency benefits from a more developed and higher-quality infrastructure.

The correlation between water consumption and wastewater generation was smaller than expected, given literature insights. This may result from activities affecting water consumption more significantly than generating wastewater, such as urban irrigation, swimming pools, and also other factors, such as water losses. Additionally, especially in the interior municipalities, many residences are not connected to the sewage system, meaning that water consumption does not translate into higher wastewater levels.

In some instances, tourists' consumption shows up as not statistically significant. This is the case for all entries in the urban group, where the effects of tourism might be diluted by the higher proportion of residents, and where more capable infrastructure may be inducing economies of scale.

It is not only this non-significance that suggests benefits from economies of scale in the region. Other circumstances can be found especially in the instances of the interior group on waste generation and energy consumption levels, where the lower number of both residents and tourists might induce relatively higher levels of losses per capita and, consequently, reduced infrastructural efficiency.

There are instances of insignificant results, which, in addition to not allowing us to find the consumption level of tourists, present anomalous or unexpected values. Of particular concern, despite its statistical insignificance, is an abnormally high negative value for wastewater generated in the interior group. Although it is difficult to pinpoint the exact reason for this value, the relatively low level of tourists in the municipalities that categorize this group, aligned with lower infrastructure on sanitation, may be affecting the model's performance in estimating this outcome. To maintain the focus of our analysis, and given that it is expected that tourist consumption should be at least the same as residents' levels, in further analysis, we assume that in circumstances where tourism consumption is insignificant, it should not differ from the average resident consumption.

Understanding the differences in tourist consumption patterns across the region, revealed to be an essential step of our analysis, as knowing these differences is essential to correctly deter-

mine the tourism pressure faced by each municipality across the different resources. Assuming that a tourist has the same impact in all municipalities would have led, for instance, to the overestimation of the pressures faced in the popular municipalities while underestimating those on the beach and luxurious groups.

5.2 Distribution of Tourist Pressure

With estimates of tourist consumption levels and data on the number of overnight stays and total consumption, we proceed to estimate tourism pressure faced by each municipality on each resource. As the reported models' results are daily averages based on annual data, we adjusted these values based on the pattern of consumption observed for each resource throughout the year of 2023 to adjust for monthly variations.

To measure the average tourism pressure across the different municipalities, we estimated the proportion of total consumption attributable to tourists and obtained the results presented in Table 4.

Municipality	Water (%)	Wastewater (%)	Energy (%)
Albufeira	22.2	20.0	34.5
Alcoutim	1.5	1.9	7.7
Aljezur	3.9	10.4	25.4
Castro Marim	3.1	4.3	16.5
Faro	2.9	3.1	3.0
Lagoa	19.7	19.2	18.2
Lagos	17.9	9.3	14.5
Loulé	33.4	66.3	16.2
Monchique	19.5	11.4	17.4
Olhão	1.7	2.0	2.0
Portimão	12.5	8.3	14.5
São Brás de Alportel	0.3	0.5	1.7
Silves	1.9	3.3	8.5
Tavira	7.3	9.1	7.0
Vila do Bispo	32.3	18.5	19.9
VRSA	29.4	10.9	19.3

Table 4: Average tourist pressure by resource type in 2023

Despite water being the resource that concerns local authorities the most, it is not the resource that tourists consistently put the most pressure on. In fact, each resource appears as the most pressured in at least one municipality. We see a natural tendency for tourist pressure to present higher values in municipalities that present more overnight stays per resident, such as Vila do Bispo and Albufeira, and in those where tourism consumption has been estimated as higher, such as in the municipalities of the beach and luxurious groups.

In this step of the analysis, we confirm the uneven distribution of tourism pressure in the region and identify that there is significant potential for the algorithm to reduce these discrepancies. Based on the levels of pressure found, we anticipate our algorithm to set prices that will attract tourists to municipalities such as São Brás de Alportel, while discouraging tourism in

municipalities such as Vila do Bispo until discrepancies are minimized.

Tourism pressure across the region is not only uneven across municipalities, but also throughout the year, given tourism seasonality. These monthly variations are presented in Table 5.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water	4.5	6.4	8.8	13.5	14.8	17.0	21.5	24.3	18.0	15.7	7.3	5.4
Wastewater	4.4	6.2	8.3	12.9	13.7	15.8	20.5	23.6	17.2	14.6	6.8	5.0
Energy	4.8	6.7	9.4	15.1	15.5	18.0	23.6	27.9	20.0	16.6	7.0	5.3

Table 5: Average monthly pressure by resource type in 2023

Despite the differences in the monthly variations of total consumption across the different resources, we see that the average tourism pressure in the region follows a bell-shaped curve with peaks in August and minimal values in January for all resources. This pattern comes from the also present bell-shaped trend in the regional number of overnight stays as previously illustrated in Figure 3.

Based on the observed monthly pressure variations, we expect the future algorithm's pricing policy to establish price differentiation throughout the year. We anticipate this differentiation to be more complex than the two seasonal periods currently applied by most municipalities on tourism taxes, as pressure levels vary to some extent in every month.

5.3 Hotel Night Price

As most literature on tourism taxation pricing does not consider its potential to manage tourism influxes, the resulting price shifts given different tax rates are often ignored. In our analysis, as we consider the price elasticity of demand, accounting for these price shifts is fundamental to estimate the effects that a given tax value has on tourism influxes.

The effects of tourism taxation of a given value will depend on the current prices that tourists are paying. The higher the accommodation prices, the smaller the relative impact of a tourism tax of a given amount. Therefore, we analysed accommodation prices in the Algarve municipalities by calculating room revenue per overnight stay. In Table 6 are illustrated the results for the year of 2023.

Accommodation availability, type, and quality strongly vary across the Algarve municipalities, which, combined with different levels of demand, might contribute to the observed differences in prices across municipalities. We expect our future algorithm to be more conservative in setting higher prices for municipalities where accommodation is relatively cheaper, as this would result in stronger effects on tourism influxes. On the other hand, tourists in municipalities where prices are relatively higher will be less sensitive to taxes of the same absolute value, which may lead the algorithm to need to assign higher tax values to disincentivize tourists from going to these municipalities.

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albufeira	33 €	32 €	35 €	35 €	40 €	50 €	62 €	70 €	55 €	39 €	36 €	36 €
Alcoutim	10 €	14 €	17 €	26 €	38 €	45 €	50 €	55 €	43 €	39 €	17 €	17 €
Aljezur	68 €	62 €	46 €	49 €	57 €	80 €	93 €	86 €	71 €	54 €	40 €	45 €
Castro Marim	23 €	23 €	37 €	51 €	73 €	76 €	75 €	74 €	74 €	71 €	85 €	54 €
Faro	18 €	22 €	28 €	47 €	54 €	73 €	98 €	104 €	73 €	52 €	24 €	22 €
Lagoa	49 €	41 €	49 €	50 €	56 €	68 €	79 €	89 €	75 €	51 €	50 €	53 €
Lagos	35 €	37 €	37 €	48 €	49 €	60 €	76 €	84 €	64 €	47 €	35 €	38 €
Loulé	33 €	35 €	46 €	62 €	69 €	86 €	107 €	119 €	94 €	69 €	38 €	42 €
Monchique	53 €	67 €	50 €	45 €	51 €	51 €	50 €	53 €	59 €	46 €	28 €	44 €
Olhão	31 €	36 €	40 €	54 €	64 €	85 €	96 €	95 €	86 €	65 €	37 €	34 €
Portimão	36 €	37 €	41 €	44 €	48 €	58 €	65 €	66 €	54 €	42 €	38 €	41 €
Silves	18 €	19 €	26 €	37 €	39 €	52 €	63 €	70 €	52 €	51 €	51 €	53 €
São Brás de Alportel	51 €	45 €	40 €	60 €	65 €	72 €	107 €	71 €	55 €	49 €	53 €	79 €
Tavira	26 €	23 €	27 €	36 €	43 €	55 €	68 €	78 €	53 €	39 €	29 €	28 €
VRSA	15 €	18 €	29 €	45 €	53 €	62 €	77 €	81 €	65 €	52 €	26 €	22 €
Vila do Bispo	48 €	50 €	50 €	63 €	74 €	89 €	110 €	120 €	93 €	60 €	40 €	35 €

Table 6: Average monthly accommodation price in 2023

5.4 Applying the Algorithm

As a final step, we test our developed algorithm using the collected and estimated data for the different municipalities of the Algarve. We begin by testing it using solely pressure on water resources, as we expect this resource to be particularly relevant given the regional scarcity context and local authorities' interests. Following this, we introduce pressure on wastewater and energy in the analysis by working with average pressures on these resources combined. As the model allows for numerous combinations of hyperparameters, we focus in more detail solely on those combinations with more realistic approaches and will investigate how the algorithm's decision changes based on changes in a given hyperparameter, while keeping others constant.

The first interactions with the algorithm led us to conclude that before the analysis, we must decide on how to control for changes in tourism influxes. We found that despite both the Allowable Change and β hyperparameters aiming to control tourism influxes, both penalize fluctuations differently, leading to the algorithm taking different approaches when setting prices. When using β, the algorithm's approach is very conservative in setting tourism taxes in municipalities with high tourist volumes, while allowing higher tax rates in municipalities with low tourist inflows, particularly in municipalities that face greater tourism pressure. This occurs because β penalizes changes in tourism influxes at the regional level, while overlooking changes within individual municipalities. In terms of tourism volume, increasing prices in popular municipalities produce higher fluctuations than increasing prices in those with lower tourism influxes. This led the algorithm to make decisions that would theoretically result in dramatic changes in tourism influxes in less-visited municipalities.

In contrast, when using the Allowable Change hyperparameter, municipalities were treated more equitably as this hyperparameter differs by imposing an equal threshold for each municipal influx change. Compared to β, this hyperparameter produced more plausible and balanced results, which led us to focus primarily on it during our analysis. While using a combination of

both hyperparameters is possible, in the following analysis we set the allowable change to 2% and keep $beta = 0$, as this allows for greater interpretability of the algorithm's results.

5.4.1 Targeting Pressure on Water Resources

To investigate how the algorithm deals with the minimization of the discrepancies over the municipalities' tourist pressure on water, we started by testing how the algorithm sets prices based on different price steps and different elasticity levels. We tested this for the months of 2023, given the following set of hyperparameters:

- Step: 1€ and 0.01€
- Price Range: 0-20€
- $\alpha = 1$
- $\beta = 0$
- Maximum change: 2%
- Elasticities: 0.1%, 0.5% and 1%

As expected, as long as elasticity keeps getting higher, the prices set by the algorithm get progressively lower, eventually reaching a level where all prices are set to zero. This is the result of higher elasticity levels meaning lower tourists' tolerance to increases in prices, resulting in progressive violations of our allowable change constraint of 2% per municipality. In contrast, lower elasticity levels result in the algorithm setting higher tax prices without this resulting in extreme changes in tourism influxes, as lower elasticity levels indicate that tourists are less sensitive to price changes. In this case, the algorithm's ability to reduce discrepancies across municipalities is diminished. This highlights a trade-off between minimizing discrepancies across municipalities and maintaining stable tourism levels when dealing with different levels of price elasticity of demand.

Regarding the effects of different price step sizes, we observed that allowing changes in cents rather than whole euros allowed the model to find better solutions. Letting the model determine price changes at the cent level allows for an increase in the possible combinations of prices, which allows for better exploration of the allowable change restriction. This higher flexibility results in the model generating solutions that keep all municipal deviations closer to the 2% threshold, which was not achievable when using unitary price changes.

Testing a smaller than unitary step also allowed price differentiation across municipalities to become clearer, as prices were allowed to adjust more gradually and precisely in response to each specific municipality's condition. It also allowed to observe the consequences of dealing with elasticity in a linear way, as the model's decision on prices for the -0.1% level where exactly 10 times higher than the -1% level. While being a limitation of our approach, it also demonstrates that knowing the exact estimate of the region's price elasticity of demand would not change our findings related to price differentiation across municipalities. However, a good estimate is essential to define the optimal tax prices.

In Table 7 are presented the algorithm's price decisions for the months of 2023 under a

unitary step and a price elasticity of −0.5% when addressing discrepancies in municipalities' pressures on water resources:

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albufeira	1	1	1	1	1	2	2	2	2	1	1	1
Alcoutim	0	0	0	0	0	0	0	0	0	0	0	0
Aljezur	0	0	0	0	0	0	0	0	0	0	0	0
Castro Marim	0	0	0	0	0	0	0	0	0	0	0	0
Faro	0	0	0	0	0	0	0	0	0	0	0	0
Lagoa	1	1	1	2	2	2	3	3	3	2	1	2
Lagos	1	1	1	1	1	2	3	3	2	1	1	1
Loulé	1	1	1	2	2	3	4	4	3	2	1	1
Monchique	2	2	2	1	2	2	1	2	2	1	1	1
Olhão	0	0	0	0	0	0	0	0	0	0	0	0
Portimão	0	0	0	0	0	0	2	2	2	0	0	0
São Brás A.	0	0	0	0	0	0	0	0	0	0	0	0
Silves	0	0	0	0	0	0	0	0	0	0	0	0
Tavira	0	0	0	0	0	0	0	0	0	0	0	0
Vila do Bispo	1	1	1	2	2	3	4	4	3	2	1	1
VRSA	0	0	1	1	2	2	3	3	2	2	1	0
Δ Discrepancies (%)	-1.49	-1.63	-2.86	-3.18	-3.33	-3.73	-3.80	-3.70	-3.58	-3.42	-3.15	-1.97
Δ Tourists (%)	-0.94	-0.97	-1.00	-1.13	-1.05	-1.42	-1.53	-1.40	-1.57	-1.08	-1.06	-0.95

Table 7: Algorithm's price decisions on water resources for 2023

We find the algorithm to be capable of reducing discrepancies in tourism pressure at a greater rate than the associated loss in the region's influxes, even though all positive pricing decisions result in some level of tourism loss. We also observe that the algorithm is more effective in reducing discrepancies in months with higher tourism influxes, despite the trade-off with keeping tourism levels stable. Notably, we find price differentiation within the year to be relevant, particularly in municipalities that face higher pressure levels. However, we find the algorithm's recommended policies on this matter to be far more complex than the current municipalities' approach, as it suggests different seasons across municipalities and also a higher level of price differentiation within the year, with some municipalities being attributed with up to four distinct seasons.

We find the model supporting price differentiation with peaks on the most popular months, following in most cases the same pattern as overnight stays. Exceptions are observed in Lagoa, and more markedly in Monchique, which are likely the result of deviations from a bell-shaped distribution of the estimated accommodation prices made evident in Table 6, which presents the distribution of estimated accommodation prices.

Regarding the comparison of the recommended policies and those currently applied by municipalities, we find that local authorities are far from completely diverging from the algorithm's recommendations. Most municipalities that the algorithm defined positive tax values are already charging tourism tax in the region, except Lagos, Monchique, and Vila do Bispo. In contrast, only Faro and Olhão are going against the model recommendation of not charging tourism tax.

The algorithm decisions reveal that municipalities with sufficient capacity or lower tourist pressure should not charge tourism taxation, so as not to deter tourists from municipalities where

their effects are relatively weaker. This is the case for most municipalities of the urban and interior group. Conversely, the model showed to consistently attribute positive values to the municipalities that face higher tourist pressure on water resources.

This analysis allowed us to conclude that local authorities should follow the price differentiation recommended by the algorithm and its hierarchy, from lower to higher values across municipalities. That would be sufficient to reduce discrepancies in water pressure as long as the price elasticity of demand is positive. Furthermore, municipalities should reconsider their approach regarding price differentiation during the year and investigate the trade-offs of a more complex approach on this matter. Moreover, municipalities should remain cautious regarding implementing the exact prices presented in Table 7 as the values would be optimal for a -0.5% price elasticity of demand, which, despite being reasonable, has not been proven to be the reality of the region.

A further application of the algorithm is to identify tourism promotion opportunities in municipalities that are relatively less pressured, given that our current approach penalizes both below and above average deviations equally. From a sustainability perspective, reducing discrepancies should not come at the expense of penalizing low-pressure municipalities. However, promoting tourist influxes in these municipalities might be the best way to compensate for tourist losses caused by the introduction of positive tax rates. We found that municipalities where it was decided not to impose taxes correspond to those where tourism pressure tends to be lower, which can result from both lower tourist influx or lower tourist per resident ratio. To investigate which municipalities should promote tourist influxes and to what degree such efforts should be pursued, we allow for negative values of tourism taxation. We believe that an assigned negative value should not be interpreted as a subsidy for tourists to stay in a given municipality, but instead as an indication that local authorities should promote tourism in those municipalities and invest in their tourist infrastructure and capacity if needed.

Table 8 shows the results for the same set of hyperparameters, with a unitary step, allowing tourism tax price to range between -20€ and 20€.

We find that most entries that the model previously attributed zero tax value are now confronted with negative price values. Additionally, we observe cases where municipalities are recommended to both redirect and promote tourism influxes within the same year, highlighting the importance of monthly price differentiation. Being suggested with a negative price indicates that these municipalities should not only avoid tourism tax to not reduce their influxes, but also that instead they should promote the tourism sector.

We observe the algorithm assigning negative prices for most municipalities of the interior and urban groups. The not-so-popular municipalities of the interior group present a relatively lower number of tourism influxes, which leads to decisions to increase their influxes. On the other hand, municipalities of the urban group, despite presenting relatively higher levels of visitors, are also suggested to implement measures to increase tourism levels, as they possess the infrastructure and capacity to accommodate additional demand.

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albufeira	1	1	1	1	1	2	2	2	2	1	1	1
Alcoutim	0	0	0	-1	-1	-1	-2	-2	-1	-1	0	0
Aljezur	-2	-2	-1	-1	-2	-3	-3	-3	-2	-2	-1	-1
Castro Marim	0	0	-1	-2	-2	-3	-3	-2	-2	-2	-3	-2
Faro	0	0	-1	-1	-2	-2	-3	-4	-2	-2	0	0
Lagoa	1	1	1	2	2	2	3	3	3	2	1	2
Lagos	1	1	1	1	1	2	3	3	2	1	1	1
Loulé	1	1	1	2	2	3	4	4	3	2	1	1
Monchique	2	2	2	1	2	2	1	2	2	1	1	1
Olhão	-1	-1	-1	-2	-2	-3	-3	-3	-3	-2	-1	-1
Portimão	-1	-1	-1	-1	-1	0	2	2	2	-1	-1	-1
São Brás A.	-2	-1	-1	-2	-2	-2	-4	-2	-2	-1	-2	-3
Silves	0	0	-1	-1	-1	-2	-2	-2	-2	-2	-2	-2
Tavira	-1	0	-1	-1	-1	-2	-2	-3	-2	-1	-1	-1
Vila do Bispo	1	1	1	2	2	3	4	4	3	2	1	1
VRSA	0	0	1	1	2	2	3	3	2	2	1	0
Δ Discrepancies (%)	-1.63	-1.73	-3.15	-3.46	-3.59	-4.03	-4.11	-4.04	-3.89	-3.69	-3.33	-2.15
Δ Tourists (%)	-0.70	-0.81	-0.63	-0.85	-0.77	-1.24	-1.37	-1.21	-1.38	-0.76	-0.79	-0.70

Table 8: Algorithm's price decisions on water resources considering negative tax values

Regarding the efficiency of the new decisions taken, we were presented with better solutions both in maintaining tourism levels and reducing discrepancies in the region. This is the result of having a tool that allows attracting tourists to the region, which compensates tourism losses and allows correcting below-average pressure on certain municipalities.

5.4.2 Targeting Pressure on Combined Resources

We proceed our analysis by incorporating the levels of tourism pressure on wastewater generation and energy consumption, and re-run the model using the same set of hyperparameters. Table 9 shows the algorithm's results while highlighting the changes in its decisions relative to the water-only scenario.

The new results proved to be very similar to the previously discussed case using solely water resources. The few changes in the results might suggest that, despite varying pressure levels across each different resource, the average pressure might align with patterns of lower or higher tourism influx. In fact, shifts in tourism volume influence the pressure levels of all resource types in the same direction.

However, there are instances of changes in the algorithm's decisions. We observe Aljezur start being recommended with positive tax values in the months of March to November, with breaks in June and July. The combined average tourism pressure levels in this municipality might be relatively higher in these months, when pressure in other municipalities may increase at a lower rate. Moreover, there are instances of municipalities being now recommended to forgo tourism taxation, reflecting less relevant levels of combined tourism pressure. This is the case for Lagos and Monchique, which are now suggested to suspend tourism taxation in months associated with lower volumes, and for Portimão, where taxation is now recommended solely in August.

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albufeira	1	1	1	1	1	2	2	2	2	1	1	1
Alcoutim	0	0	0	0	0	0	0	0	0	0	0	0
Aljezur	0	0	1	1	2	0	0	3	2	2	1	0
Castro Marim	0	0	0	0	0	0	0	0	0	0	0	0
Faro	0	0	0	0	0	0	0	0	0	0	0	0
Lagoa	1	1	1	2	2	2	3	3	3	2	1	2
Lagos	0	0	1	1	1	2	3	3	2	1	0	0
Loulé	1	1	1	2	2	3	4	4	3	2	1	1
Monchique	0	0	0	1	2	2	1	2	2	1	1	0
Olhão	0	0	0	0	0	0	0	0	0	0	0	0
Portimão	0	0	0	0	0	0	0	2	0	0	0	0
São Brás A.	0	0	0	0	0	0	0	0	0	0	0	0
Silves	0	0	0	0	0	0	0	0	0	0	0	0
Tavira	0	0	0	0	0	0	0	0	0	0	0	0
Vila do Bispo	1	1	1	2	2	3	4	4	3	2	1	1
VRSA	0	0	1	1	2	2	3	3	2	2	1	0
Δ Discrepancies (%)	-2.62	-2.61	-2.74	-3.53	-3.28	-4.01	-3.94	-3.75	-3.79	-3.39	-3.04	-2.44
Δ Tourists (%)	-0.83	-0.87	-1.00	-1.14	-1.07	-1.42	-1.33	-1.41	-1.33	-1.10	-0.95	-0.85

Table 9: Algorithm's tax suggestions given all resource types (highlighted changes)

In order to make informed decisions, it is crucial for the region to assess the urgency of reducing inconsistencies on each resource pressure levels. Further analysis led us to find that taking different resources into the analysis can lead to decisions in opposite directions, as there are instances, for the same month and municipality, where the algorithm's suggestion may be both to promote and to discourage tourism influxes.

We conclude by emphasizing the importance of not developing tourism management strategies in isolation. Regional cooperation among all municipalities is essential to ensure that policies benefit the region as a whole, as each municipality's decisions not only affect its pressure levels but also might affect its neighbors. This is particularly important if future research proves that tourists redirected from municipalities with positive tourism taxation are partially redirected to neighbouring municipalities. By aligning priorities and coordinating decisions, municipalities can collectively manage tourism influxes to balance resource pressures and avoid situations of overcrowding or underutilization.

6 Limitations

Despite the success in determining plausible values for tourism taxation that align with both literature expectations and the perceived tourism pressure situation of the Algarve, there are several factors that may limit the precision of our approach. Additionally, our analysis relies on a few assumptions that could constrain its implementation in the field.

More notably, our algorithm relies on various estimates, such as on accommodation prices and consumption levels, that could be more precise, or even unnecessary, if complete datasets for all municipalities and months were available. Estimating consumption metrics and tourism impacts is a complex topic in itself that requires specific research. To maintain the focus on the primary goal of setting pricing policies, we simplified this aspect in some circumstances, such as when assuming monthly variations to be equal on all municipalities when data was lacking on a municipal level, which might compromise the precision of estimates and consequently the quality of the algorithm's decisions.

Our analysis relies on several assumptions, such as linear effects of price changes. Furthermore, it also depends on two non-conventional expectations of tourist behavior. First, the algorithm decisions are built assuming that tourists consume most resources in the municipality where they are accommodated. Second, we assume price variations to affect the tourist who consumes the average amount of resources. These results in the algorithm not accounting for the tourists' freedom to move to other municipalities, particularly to those that offer more activities, and not accounting for price changes potentially affecting more the lower budget tourists, who are expected to consume relatively fewer resources.

Another limitation that we face with our approach is that it considers a very limited set of resources and infrastructure used by tourism. Moreover, the algorithm does not consider each municipality's tourist capacity, even though it has been proven that its results can be used to identify capacity extension opportunities. Ideally, capacity on each municipality would be set as another infrastructure where we seek to minimize discrepancies in its pressure. Promoting a balance between the different municipalities' pressure on accommodation services is also a way of making the sector more sustainable by avoiding situations of overcrowding and underutilization.

Furthermore, we anticipate challenges regarding administrative concerns in the practical implementation of the approach. A cooperative environment and the centralization of tourism tax price decisions are necessary for our approach to be possible, which may face resistance, particularly from municipalities that are asked to reduce or eliminate tourism taxation. Municipalities would lose a tool that allows them to get direct compensation from their expenditures and would instead have to rely on a centralized system of revenue distribution. Additionally, we anticipate further operational costs incurred, as the algorithm depends on constant assessment of the region's accommodation prices, tourist consumption patterns, and tourist behavior.

7 Conclusion

Our research contributes with meaningful insights to the tourism taxation literature, particularly regarding its potential use to redistribute tourism inflows. In addition, we provide further understanding of the tourism impacts in the Algarve region, with our findings supporting and extending the notion that beach-related and premium tourism offers are associated with higher public resource consumption and infrastructure use. Furthermore, after measuring tourism consumption pressure across the different municipalities of the region and confirming its highly uneven distribution, we reinforced the importance of not mistaking tourism pressure levels with tourism inflows.

Concerning our central goal, we proved to be possible to use tourism taxation as a tool to reduce regional imbalances in tourism consumption pressure levels across the different municipalities of the region without compromising the overall performance of the tourism sector. We identified the key determinants that should drive both price differentiation and price level decisions related to tourism taxation, and established that following a price differentiation strategy that is aligned with the algorithm's recommendations is sufficient to improve how tourism pressure is distributed in the region.

Our findings provide several recommendations for the region's local authorities. In particular, municipalities of Olhão and Faro should consider ceasing the application of tourism taxation in their territories, as such measures may be diverting tourism influxes away from their areas where tourism pressure on the focused resources is relatively lower. This is especially important if it is confirmed that tourists perceive other municipalities as substitutes, as these decisions could result in the redirection of tourists to other municipalities where tourism pressure is more critical. In contrast, we suggest Lagos, Monchique, and Vila do Bispo to consider accelerating the introduction of tourism taxation, as it could assist in redirecting a portion of their tourist flows and approximate their relatively higher pressure levels closer to the region's average.

As we find price differentiation, both across municipalities and throughout the year, to be the key to the success of our approach, we underscore the urgency of taking pricing decisions within a cooperative framework where all municipalities' decisions are aligned with each other. This would require nearly all municipalities to reconsider both their pricing strategies and how they define seasons, with a renewed objective of viewing and benefiting the region as a whole.

As this cooperative perspective within pricing decision-makers is completely novel to the field of tourism taxation, we open the door to numerous other contexts and regions where a similar approach could be applied.

In further analysis, it would be interesting to test how the model performs in other regions similar to the Algarve that also exhibit uneven distribution of tourists within their territory. The analysis would be even more insightful in circumstances where tourism taxation has been implemented for a longer period, as its effects would be more evident and easier to assess. In such cases, we would test adopting more complex approaches, such as considering the potential

cross-municipality price elasticity of demand, if tourists are found to perceive municipalities as substitutable destinations. Additionally, we also encourage the use of more sophisticated modeling techniques to improve the accuracy and efficiency in determining optimal tourism tax rates. Particularly when dealing with extensive datasets, advanced state-of-the-art dynamic pricing methodologies, such as with reinforcement learning, could potentially offer more robust conclusions for further implementation in this domain.

When replicating the same approach in different locations, it would be valuable to test how the model would perform under other forms of tourism taxation, such as an ad valorem tax. An ad valorem tax would have simplified our approach by eliminating the need to examine relative changes in accommodation prices, since tax rates could be directly interpreted as percentage changes. Moreover, a tax of this form would mitigate how changes in tax levels could disproportionately affect lower-budget tourists rather than the average tourist in the region.

Regarding future analysis for the Algarve, further research on the situation of the region could be largely valuable for the algorithm's precision. The region lacks research and data to quantify the broader impacts of tourism, assess priority pressure situations, and identify price elasticity levels. Later studies would undoubtedly benefit from more precise and updated estimations, as well as insights from local authorities, who have special knowledge of the challenges that each municipality faces.

Additionally, further analysis could focus on testing different operational modes and enhancing the algorithm logic. Further research to rank the urgency of different tourism effects in the region could lead to a reassessment of how we compute pressure. Currently, pressure is defined as the average pressure on all resources, assigning equal importance to each, which may not align with local authorities' goals. Alternatively, we could attribute different weights to each resource, given the relative importance of reducing discrepancies over them. Moreover, we can test adding other functionalities to the algorithm, such as penalizing positive and negative influx changes differently, or adding revenue restrictions to keep the collected level above a certain threshold.

The cooperative perspective that our proposed strategy brings is key to enhancing social cohesion and promoting sustainability, aligning with the United Nations Sustainable Development Goals, particularly 11 - Sustainable Cities and Communities and 12 - Responsible Consumption and Production. Despite aiming at maintaining tourism influxes, the strategy brings a more sustainable way of addressing tourism by seeking to mitigate disproportionate impacts on regional resources and infrastructure.

References

M. S. I. Araf, S. F. Hoque, M. A. Chowdhury, M. Rahman, and M. Z. Alam. Can artificial intelligence (ai) based pricing achieve sustainability? a systematic review from business, customer amp; policymaking perspectives, 2025.

A. Besculides, M. E. Lee, and P. J. McCormick. Residents' perceptions of the cultural benefits of tourism. *Annals of Tourism Research*, 29:303–319, 4 2002. ISSN 01607383. doi: 10.1016/S0160-7383(01)00066-4.

L. Carvalho, E. Pinheiro, M. Martins, and C. S. Costa. Local tourist taxes in portugal: A systematic review of municipal regulations. *European Journal of Tourism, Hospitality and Recreation*, 14:285–298, 12 2024. ISSN 2182-4924. doi: 10.2478/ejthr-2024-0021.

C. Cavallero and M. Zagler. The beach: tourism tax competition along the italian coasts. *Journal of Economics*, 11 2024. ISSN 0931-8658. doi: 10.1007/s00712-024-00890-x.

L. S. Coelho. O papel do algarve no contexto económico nacional, 3 2024. URL https://www.sapo.pt/opiniao/artigos/o-papel-do-algarve-no-contexto-economico-nacional.

P. O. do Valle, P. Pintassilgo, A. Matias, and F. André. Tourist attitudes towards an accommodation tax earmarked for environmental protection: A survey in the algarve. *Tourism Management*, 33:1408–1416, 12 2012. ISSN 02615177. doi: 10.1016/j.tourman.2012.01.003.

R. Durbarry. Tourism taxes: Implications for tourism demand in the uk. *Review of Development Economics*, 12:21–36, 2 2008. ISSN 1363-6669. doi: 10.1111/j.1467-9361.2008.00432.x.

L. Dwyer, P. Forsyth, and W. Dwyer. *Tourism Economics and Policy*. Multilingual Matters, 12 2020. ISBN 9781845417338. doi: 10.21832/9781845417338.

F. Farinha, D. Bienvenido-Huertas, M. D. Pinheiro, E. M. J. Silva, R. Lança, M. J. Oliveira, and R. Batista. Sustainable competitiveness of tourism in the algarve region. critical stakeholders' perception of the supply sector. *Sustainability*, 13:6072, 5 2021. ISSN 2071-1050. doi: 10.3390/su13116072.

N. Gooroochurn and M. T. Sinclair. Economics of tourism taxation. *Annals of Tourism Research*, 32:478–498, 4 2005. ISSN 01607383. doi: 10.1016/j.annals.2004.10.003.

S. Gössling, P. Peeters, C. M. Hall, J.-P. Ceron, G. Dubois, L. V. Lehmann, and D. Scott. Tourism and water use: Supply, demand, and security. an international review. *Tourism Management*, 33:1–15, 2 2012. ISSN 02615177. doi: 10.1016/j.tourman.2011.03.015.

H. L. Hughes. A tourism tax — the cases for and against. *International Journal of Tourism Management*, 2:196–206, 9 1981. ISSN 01432516. doi: 10.1016/0143-2516(81)90006-2.

K. Hussain and H. Arsalan. Sustainable tourism management: Leveraging ai for enhanced customer satisfaction. Technical report, University of American Samoa, 2024.

K. Koens and A. Postma. Understanding and managing visitor pressure in urban tourism: A study into the nature of and tools used to manage visitor pressure in six major european cities. Technical report, CELTH, 2017.

R. Law, G. Li, D. K. C. Fong, and X. Han. Tourism demand forecasting: A deep learning approach. *Annals of Tourism Research*, 75:410–423, 3 2019. ISSN 01607383. doi: 10.1016/j.annals.2019.01.014.

O. Oklevik, S. Gössling, C. M. Hall, J. K. S. Jacobsen, I. P. Grøtte, and S. McCabe. Overtourism, optimisation, and destination performance indicators: a case study of activities in fjord norway. *Journal of Sustainable Tourism*, 27:1804–1824, 12 2019. ISSN 0966-9582. doi: 10.1080/09669582.2018.1533020.

I. C. Patrichi. Ai solutions for sustainable tourism management: a comprehensive review. *Journal of Information Systems Operations Management*, 18:172–185, 2024.

L. N. Pereira, C. Muhs, J. Andraz, R. Nunes, M. Lança, and J. A. Silva. An assessment model of the algarve as a sustainable tourism destination: A conceptual framework. *Tourism Planning Development*, pages 1–20, 10 2024. ISSN 2156-8316. doi: 10.1080/21568316.2024.2415460.

P. Pinto, M. Guerreiro, A. I. Renda, C. Ramos, J. F. Marques, L. N. Pereira, M. Lança, and H. K. Lai. Atitudes e comportamentos dos residentes: Contributos para o desenvolvimento turístico sustentável no algarve. Technical report, Centro de Investigação em Turismo, Sustentabilidade e Bem-Estar (CinTurs), 2023.

T. Roberts. *Residents' Perceptions on Tourism Impacts and Quality of Life: The Case of Faro*. PhD thesis, 2021.

M. Sansone, A. Colamatteo, M. A. Pagnanelli, and M. D'Agostini. How can artificial intelligence tools help mitigate the phenomenon of overtourism? In *Brands and Purpose in a Changing Era, Atti della XXI SIM Conference*, 2024.

H. Seraphin and S. Ivanov. Overtourism: a revenue management perspective. *Journal of Revenue and Pricing Management*, 19:146–150, 6 2020. ISSN 1476-6930. doi: 10.1057/s41272-020-00241-7.

L. Sheng. Factors determining the success or failure of a tourism tax: a theoretical model. *Tourism Review*, 72:274–287, 8 2017. ISSN 1660-5373. doi: 10.1108/TR-02-2017-0030.

A. Torsney and Y. M. Buckley. Ecological benefits of tourism management and the challenges of habitat classification. *Global Ecology and Conservation*, 58:e03477, 4 2025. ISSN 23519894. doi: 10.1016/j.gecco.2025.e03477.

W. T. O. (UNWTO). *Tourism Taxation in Asia*. World Tourism Organization (UNWTO), 1998.

V. Vlès. *Inter-municipal cooperation and tourism: New local roots*, pages 61–74. Routledge, 2016.

J. R. Vázquez-Canteli and Z. Nagy. Reinforcement learning for demand response: A review of algorithms and modeling techniques. *Applied Energy*, 235:1072–1089, 2 2019. ISSN 03062619. doi: 10.1016/j.apenergy.2018.11.002.

C. Yang, Z. Lin, J. Huang, and T. Cheng. A dynamic tax model based on destination lifecycle for sustainable tourism development. *Journal of Travel Research*, 62:217–232, 1 2023. ISSN 0047-2875. doi: 10.1177/00472875211057596.

F. Yuval. To compete or cooperate? intermunicipal management of overtourism. *Journal of Travel Research*, 61:1327–1341, 7 2022. ISSN 0047-2875. doi: 10.1177/00472875211025088.

Appendices

A. Algorithm's Pseudo-Code

Algorithm 1 Algorithm's Iterative Optimization Process

For each elasticity value being tested:
    Set `best_global_result` to None
    Set `best_global_cost` to infinity
    Initialize `best_tax_rates` = 0 for all municipalities
Optimization loop to iterate and Adjust Tax Rates:
while improvements are still possible (improved = True) **do**
    Set `improved` flag to False
    for each municipality **do**
        Get current `tax_rate`
        Set **initial_cost** using tax rates before adjustments
        Test possible tax adjustments:
        for each adjustment **do**
            `new_tax_rate` $\in$ {`tax_rate` $-\ \delta$, `tax_rate`, `tax_rate` $+\ \delta$}
            Ensure the new tax rate is within valid bounds
            Calculate the new cost using the municipality's `new_tax_rate`
            if new cost is lower than the previous **then**
                Update best tax rates: `best_tax_rate[municipality]` = `new_tax_rate`
                Set `improved` to True
            end if
        end for
    end for
    if no improvements were made during the iteration **then**
        Update `best_global_result` and `best_global_cost`
        Exit the loop
    end if
end while=0

B. Algorithm's Code and Auxiliary Functions

Determining Pressure Function (Adjust Based on Focused Resources)

```
def calculate_pressure(stays_dict):
    pressure = {}
    for mun in municipalities:
        water_use_tourists = water_per_tourist[mun] * stays_dict
            [mun]
        wastewater_use_tourists = wastewater_per_tourist[mun] *
            stays_dict[mun]
        energy_use_tourists = energy_per_tourist[mun] *
            stays_dict[mun]

        water_ratio = water_use_tourists / total_water[mun]
        wastewater_ratio = wastewater_use_tourists /
            total_wastewater[mun]
        energy_ratio = energy_use_tourists / total_energy[mun]

        pressure[mun] = (water_ratio + wastewater_ratio +
            energy_ratio) / 3
    return pressure
```

Determining Discrepancies Function

```
def calculate_discrepancy(pressure):
    mean_value = np.mean(list(pressure.values()))
    return (1 / len(pressure)) * sum(abs(p - mean_value)**2 for
        p in pressure.values())
```

Cost Evaluation Based on Discrepancies and Tourism Variations

```
def calculate_cost_ratio(taxes, elasticity, max_change, alpha,
    beta):

    test_stays = {}
    for mun in municipalities:
        percent_increase = (taxes[mun] / night_price[mun]) * 100
        test_stays[mun] = initial_stays[mun] * (1 - elasticity *
            percent_increase)

    pressure = calculate_pressure(test_stays)
    discrepancy = calculate_discrepancy(pressure)
    discrepancy_ratio = discrepancy / base_discrepancy

    total_absolute_variation = 0
    total_initial_stays = sum(initial_stays.values())

    for mun in municipalities:
        diff = abs(test_stays[mun] - initial_stays[mun])
        if diff / initial_stays[mun] > max_change:
            return float('inf')
        total_absolute_variation += diff

    normalized_variation = total_absolute_variation /
        total_initial_stays

    return alpha * discrepancy_ratio + beta *
       normalized_variation
```

Search Algorithm for Tourist Tax Optimization (Part 1)

```
def optimize_tourist_taxes(possible_rates, step, alpha, beta,
    max_change, elasticities):

    results = {}

    for elasticity in elasticities:
        best_global_result = None
        best_global_cost = float('inf')
        best_rates = {mun: 0 for mun in municipalities}

        while True:
            improved = False

            for mun in municipalities:
                current_rate = best_rates[mun]
                best_local_rate = current_rate
                best_local_cost = calculate_cost_ratio(
                    best_rates, elasticity, max_change, alpha,
                    beta)

                for delta in np.arange(-step, step + step, step)
                    :
                    if delta == 0:
                        continue

                    new_rate = current_rate + delta
                    new_rate = min(max(new_rate, min(
                        possible_rates)), max(possible_rates))

                    temp_rates = best_rates.copy()
                    temp_rates[mun] = new_rate

                    new_cost = calculate_cost_ratio(temp_rates,
                        elasticity, max_change, alpha, beta)
```

Search Algorithm for Tourist Tax Optimization (Part 2)

```
                    if new_cost < best_local_cost:
                        best_local_cost = new_cost
                        best_local_rate = new_rate
                        improved = True

                best_rates[mun] = best_local_rate
            if not improved:
                break

        adjusted_stays = {
            mun: initial_stays[mun] * (1 - elasticity *
                    ((best_rates[mun] / night_price[mun]) * 100)
                       )
            for mun in municipalities}

        pressure_new =calculate_pressure(adjusted_stays)
        discrepancy_new = calculate_discrepancy(pressure_new)
        total_stays_new = sum(adjusted_stays.values())
        total_loss = total_stays_base - total_stays_new

        total_cost_new = alpha * (discrepancy_new /
           base_discrepancy) \ + beta * (total_loss /
           total_stays_base)

        if total_cost_temp < best_global_cost:
            best_global_result = {
                'rates': best_rates.copy(),
                'stays': adjusted_stays.copy(),
                'discrepancy': discrepancy_new,
                'total_loss': total_loss,
                'total_stays': total_stays_new,}
            best_global_cost = total_cost_new
    results[elasticity] = best_global_result
```

Search Algorithm for Tourist Tax Optimization (Part 3)

```
        # Print results
        print(f"\n=== BEST RESULT FOR ELASTICITY = {elasticity} ===")
        print("\n--- BEST RATES PER MUNICIPALITY ---")
        for mun in municipalities:
            print(f"{mun}: €{round(best_global_result['rates'][mun], 2)}")

        print("\n--- DISCREPANCY ---")
        print(f"Before: {base_discrepancy:.6f}")
        print(f"After: {best_global_result['discrepancy']:.6f}")
        print(f"Reduction: {(base_discrepancy - best_global_result['discrepancy']) / base_discrepancy * 100:.2f}%")

        print("\n--- OVERNIGHT STAYS (BEFORE vs AFTER) ---")
        for mun in municipalities:
            before = initial_stays[mun]
            after = best_global_result['stays'][mun]
            pct = (before - after) / before * 100 if before else 0
            print(f"{mun}: {before:.0f} → {after:.0f} ({pct:.2f}% reduction)")

        final_loss_pct = (best_global_result['total_loss'] / total_stays_base) * 100
        print("\n--- TOTAL REGIONAL LOSS ---")
        print(f"Total before: {total_stays_base:.0f}")
        print(f"Total after: {best_global_result['total_stays']:.0f}")
        print(f"Lost tourists: {best_global_result['total_loss']:.0f} ({final_loss_pct:.2f}%)")

    return results
```

Optimize tourist taxes - Example for August (Adjust based on resources and Algorithm's hyperparameters)

```
municipalities = list(overnightstays_aug.keys())
water_per_tourist = water_tourist_aug
initial_stays = overnightstays_aug
total_waterl = water_aug
total_stays_base = sum(initial_stays.values())
night_price = night_price_aug
initial_pressure = calculate_pressure(initial_stays)
base_discrepancy = calculate_discrepancy(initial_pressure)

results = optimize_tourist_taxes(
    possible_taxes=list(range(0, 21)),
    #range(-20,21) when tested negative tax values
    step=1,
    #step = 0.01 when test cents changes
    alpha=1,
    beta=0,
    max_change=0.02,
    # elasticities to be tested in a list format
    elasticities=[0.005]
)
```

Output for August 2023 — Optimization for water-only case

```
=== BEST RESULT FOR ELASTICITY = 0.005 ===
--- BEST RATES PER MUNICIPALITY ---
Albufeira: €2          Monchique: €2
Alcoutim: €0           Olhão: €0
Aljezur: €0            Portimão: €2
Castro Marim: €0       São Brás de Alportel: €0
Faro: €0               Silves: €0
Lagoa: €3              Tavira: €0
Lagos: €3              Vila do Bispo: €4
Loulé: €4              VRSA: €3

--- DISCREPANCY ---
Before: 0.043730
After: 0.042112
Reduction: 3.70%

--- OVERNIGHT STAYS (BEFORE vs AFTER) ---
Albufeira: 1206459 → 1189319 (1.42% reduction)
Alcoutim: 2139 → 2139 (0.00% reduction)
Aljezur: 27526 → 27526 (0.00% reduction)
Castro Marim: 33578 → 33578 (0.00% reduction)
Faro: 84702 → 84702 (0.00% reduction)
Lagoa: 282010 → 277254 (1.69% reduction)
Lagos: 250936 → 246450 (1.79% reduction)
Loulé: 413584 → 406638 (1.68% reduction)
Monchique: 20221 → 19837 (1.90% reduction)
Olhão: 37197 → 37197 (0.00% reduction)
Portimão: 452908 → 446003 (1.52% reduction)
São Brás de Alportel: 3137 → 3137 (0.00% reduction)
Silves: 51168 → 51168 (0.00% reduction)
Tavira: 100090 → 100090 (0.00% reduction)
Vila do Bispo: 69529 → 68369 (1.67% reduction)
VRSA: 146678 → 143951 (1.86% reduction)

--- TOTAL REGIONAL LOSS ---
Total before: 3181862
Total after: 3137358
Lost tourists: 44504 (1.40%)
```