Municipal Solid Waste Generation in Algarve, Portugal: Challenges of Seasonal Tourism

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ABSTRACT

Regions with strong tourism seasonality, like the Algarve in Portugal, face major challenges in municipal solid waste (MSW) management. This study quantifies tourism-induced waste using data from 2017–2024, in collaboration with Algar, the regional MSW utility. In 2024, the Algarve experienced six times more overnight stays in the high season than in the low season, accounting for 25% of Portugal's total overnight stays. However, only 9 of its 16 municipalities host 76% of residents and 95% of overnight stays. Regression models reveal strong links between tourism and waste generation. Tourists produce an estimated average waste intensity of approximately 3.4 kg per overnight stay, conditional on observed aggregate patterns—twice that of a resident's daily output—with approximately 3.1 kg of unsorted waste and glass waste, which is approximately four times higher than that of residents. Although tourism accounts for only 27% of annual MSW, it drives over 41% of capacity needs due to seasonality. Findings support fairer, data-driven cost-sharing and system improvements for more effective waste management.

Keywords: Tourism; Seasonality; Municipal Solid Waste (MSW); Algarve Region; Waste Generation; Statistical Modelling; Waste Management.
JEL Codes: Q53, Q56, L83, Q58, C23, R11.

I. Introduction

Waste generation presents a significant challenge in many regions. It tends to increase along with population growth and urbanization, shadowing economic activity as an unintended by-product of consumption and production. Unless it is adequately managed, waste will accumulate in the environment, with dire consequences for the human health and ecosystems. Municipal solid waste (MSW), in particular, consists of the refuse of households, retailers and similar sources. People continuously produce

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MSW, and therefore, it must be regularly collected and dealt with (UNEP, 2024). Trends in global waste generation and management aren't encouraging, with no relevant improvements from 2010 to 2020 (UNEP, 2015, 2024). By 2050, in business-as-usual scenarios, global MSW flows are expected to reach between 3.4 and 4.6 billion tonnes (Kaza et al., 2018; UNEP, 2024), representing a drastic increase from the 2.01 billion tonnes estimated for 2016. Better policies are needed to achieve the necessary decoupling between MSW generation and economic activity. Even in the European Union, where MSW is safely collected and there is rigorous legislation in place enshrining the waste hierarchy (namely the Waste Framework Directive 2008/98/EC, the Circular Economy Action Plans COM/2015/0614 and COM/2020/98 and the European Green Deal COM/2019/640), key material flow indicators have been mostly flat for the last decade[1]: in the EU-27, waste generation has stagnated at around 0.5 t/capita/year while the waste recycling rate has fluctuated by around 45% since 2012. To tackle the problem decisively, all sectors of economic activity must be involved in efforts to improve waste management, and tourism is no exception. Although tourism has a clear impact on MSW generation, "the waste from tourism remains hidden behind residential waste flows" (Diaz-Farina et al., 2020, p.588), requiring more focused analysis. Regions with strong tourism seasonality face an additional problem of highly variable waste flows, as the incoming visitors strain local service provision and compel extraordinary investments in capacity in order to handle peak MSW quantities (Greco et al., 2018). Furthermore, some studies have noted that the weight of waste generated per guest-night tends to be larger than the daily per-capita waste for a resident (Mance et al., 2020), while tourists may contribute less to the separation of recyclable waste flows (Styles et al., 2013), although there is often a lack of robust information.

Although their impact on overall waste generation varies depending on location, incoming visitors generate much of the waste in some tourist destinations, and this excessive waste generation is one of the problematic aspects of the "overtourism" phenomenon[2]. Moreover, tourism has been increasing worldwide, resuming a growth trend that was interrupted by the COVID-19 pandemic (World Tourism Barometer, 2025), and Portugal has been one of the fastest growing destinations.(de Oliveira et al., 2023). It is therefore paramount to assess the impact of tourism on MSW indicators, both in terms of volumes and costs, as well as to promote policies that can reduce waste flows and improve cost allocation.

This paper contributes to the literature by estimating the role of tourism activity (assessed by overnight stays) in total MSW generation in the Algarve, a region in Southern Portugal where seasonal tourism is considerable, albeit unevenly distributed. We also assess the impact on various selectively collected waste flows and compare the

[1] https://www.eea.europa.eu/en/analysis/publications/europes-circular-economy-in-facts
[2] https://sustainabletravel.org/what-is-overtourism/

per capita values obtained for tourists to those estimated for year-round residents. The analysis combines data from the regional MSW utility, Algar, with data on population and overnight stays in tourist accommodation establishments from the National Statistics Institute (INE) as well as Eurostat data on online booking platforms.

II. Tourism and MSW in the Literature

The environmental impacts associated with tourism include its direct contributions to greenhouse gas emissions and resource use, including energy, freshwater, land and food (Gössling & Peeters, 2015). While some impacts, such as CO_2 emissions, arise mostly from transportation choices, MSW generation is closely linked to tourist accommodation. Waste must be collected, transported, processed and disposed of, generating additional greenhouse gas emissions; it also creates pressures on local ecosystems through habitat destruction and contamination, especially if it is inadequately handled (UNEP, 2024).

Tourism quantification methods in the literature are broadly consistent, although several variables can be used depending on the goal. The primary metric for assessing tourist accommodations is the number of guest-nights, also known as overnight stays. Seasonal variability should also be considered as it can bring about particular pressures, hindering efficiency in solid waste management systems by forcing utilities to operate at non-optimal scales (Caponi, 2022). However, several studies do not take this aspect into account. For instance, (Arbulú et al., 2015) provide a country-level analysis linking yearly MSW generation to tourism arrivals, expenditures and economic specialization, pointing out that tourism tends to produce more MSW than other economic activities. A more recent study (Yuxi et al., 2023) provides a survey of the literature then tackles data for China's provinces, showing a strong correlation between yearly tourist arrivals and MSW generation. Comerio et al. (2021) use data on overnight stays in Wakayama Prefecture (Japan) to show that the observed waste generation increase has occurred in spite of a decrease in resident population, pointing to tourism as a driver, both direct (visitor numbers) and indirect (taxable income).

On the contrary, some studies look at seasonal variations in MSW without explicit consideration of tourism ((Denafas et al., 2014; Gómez et al., 2009). A study that looks at both aspects is Mance et al.'s (2020), which assesses the effects of tourism on waste generation in coastal Croatian municipalities, using monthly data for a single year, 2019, and regressing population and tourists (overnight stays) on total waste generation. The findings detail that one tourist (overnight stay) produces between 22% and 55% more waste than a resident, although waste flows for specific materials are not analysed (Diaz-Farina et al., 2020; Mateu-Sbert et al., 2013). On the other hand, the impact of tourists in terms of waste in kg/day is found to be lower than that of residents in their case studies in the Canary Islands (Tenerife) and Balearic Islands (Menorca), respectively. A similar disparity is noted in a study of Ibiza, Spain (Arbulú et al., 2024), which uses the STIRPAT model to find that per capita generation of total and non-sorted waste has decreased despite an increase in volume. Note that these archipelagos are the two regions of Spain

with the highest values of waste generation per capita (Diaz-Farina et al., 2020), while the challenges of managing waste in island destinations tend to be more severe.

Mendes et al. (2013) evaluate MSW performance indicators for Loulé municipality (in the Algarve), checking for seasonal fluctuations in solid waste generation and recycling rates, among other indicators. Their findings underscore the importance of monitoring performance indicators in destinations with seasonal variability to enable more efficient waste management, yet they did not explicitly consider any data on tourist accommodation.

In order to estimate the impact of tourism activities on MSW collection costs, Greco et al. (2018) gather cost data from 68 Italian municipalities and regress this on tourism indicators and other variables and find that higher overnight hotel stays and tourist spending increase waste collection costs for paper, multi-material (glass, plastic and metal) and residual undifferentiated waste, but not for organic waste. Seasonality is mentioned but not considered in the estimations.

In a very different setting, Manomaivibool (2015) and Suma et al. (2019) perform field studies in Chiang Rai province, Thailand, estimating the weight and composition of waste in locations near tourist spots. The first paper finds that three-quarters of mixed tourist waste sent for disposal was recyclable or compostable waste that could have been separated if appropriate practices were implemented in the area, while the second paper confirms that waste separation is low, with a prevalence of plastic bags in mixed waste and a general lack of waste reduction and recycling practices. Careful consideration of the costs and potential revenues of improved collection schemes, and a strengthening of environmental awareness campaigns, is recommended.

Following the introduction and review of the literature discussing the role of tourism in MSW generation, Section 3 presents our case study and methodological approach, while Section 4 discusses the results. The main conclusions are set out in Section 5.

III. Context, Data and Method

A. Study Area

The Algarve, situated at the southernmost tip of mainland Portugal, is bordered by the Atlantic Ocean to the south and west, and the Guadiana River to the east, which marks the border with Spain. The region is organized into two sub-regions: Barlavento (Western Algarve), comprising municipalities such as Aljezur, Vila do Bispo, Lagos, Portimão, Monchique, Lagoa, Silves, and Albufeira; and Sotavento (Eastern Algarve), which includes Loulé, Faro, São Brás de Alportel, Olhão, Tavira, Vila Real de Santo António, Castro Marim, and Alcoutim. Most municipalities are located along the coastline, enhancing their appeal for tourism and resulting in a higher concentration of both population and overnight stays (as detailed in Figure A1 in Appendix A). Among Sotavento's key attractions is the Ria Formosa Natural Park, a protected lagoon system that draws nature-oriented visitors.

Coastal municipalities account for over 90% of the region's overnight stays (PMETA, 2024), a pattern confirmed by MONITUR (2023), which identifies Albufeira, Lagoa,

Portimão, and Vila Real de Santo António as having the highest tourist density and lodging capacity per 1,000 residents. The dominant tourist profile is international—especially from the UK, Germany, the Netherlands, and France—though domestic tourism is growing. Visitors are mostly aged between 35–64, traveling as couples (over 40%) or families (around 35%), and primarily motivated by beach holidays, followed by golf, nature, gastronomy, and cultural experiences. While hotels and resorts remain common lodging options, short-term rentals (STR) or local accommodation (Alojamento Local, AL) are increasingly preferred, particularly by families and independent travelers. The Algarve thus faces a diversification of both motivations and tourism patterns.

Peak tourism activity occurs between June and September, while low activity is observed between November and February. In 2024, the Algarve hosted 29.9 million overnight stays, representing 26% of Portugal's total tourism, with 22 million stays (74%) occurring during the high season (May-Oct). Renowned as Portugal's most popular tourist destination, the Algarve's seasonal fluctuations have been consistent throughout the period of this study (2017–2024). Seasonal variations significantly impact on municipal solid waste (MSW) production, with waste generation surging during peak season due to the influx of tourists. Waste management in the Algarve follows a comprehensive system of segregation, recycling, and treatment. Within the region, municipalities provide the collection of unsorted waste and selective bio waste, themselves or through concessionaire companies, and deliver the collected waste to Algar's facilities for treatment and/or preparation for the recycling industry. Algar is responsible for selective collection in the region, with some minor exceptions. Large waste producers (those generating a daily average of over 1,100 litres) are serviced by licensed transport providers, which deliver unsorted and bio waste at Algar´s facilities and other recyclables to licensed operators. This evolving profile underscores the need for adaptive, sustainable tourism and waste management strategies.

B. Development of Statistical Models for Waste generation

B.1. Data Collection

Figure A2 (Appendix A) on supplementary materials section presents the study's methodology, integrating the inputs to develop of the statistical model to analyse waste generation, population dynamics, and tourism. The model was designed to segregate the waste generated by the population and by tourism activities, both in high and low seasons.

The present study uses data on MSW generation, the resident population, and overnight stays in the Algarve region from 2017 to 2024. Key details about the datasets are provided below.

MSW Data and Categories

MSW data includes both total MSW and selectively collected waste, categorised as follows: Plastic/Metal; Paper/Cardboard; Glass; Unsorted MSW (UMSW); Total MSW. This categorization reflects the waste sorting practices used in the Algarve and across Portugal. Total MSW encompasses the four primary categories and additional waste types, such as furniture, green waste, and textiles.

Reporting and Units

The data were collected from the monthly waste data reported by Algar, the regional waste management entity, operating under a state public service concession. Each category is measured in tonnes.

Resident Population Data

The resident population is defined as individuals who live or intend to live in a specific area for at least 12 months (INE, 2021). Annual population estimates for the Algarve were obtained from the National Statistics Institute (INE) from 2017 to 2023. These data, with some adjustments for seasonality as described below, allow us to compare waste generation by residents and tourists.

Tourism Activity Data

Tourism activity is estimated from monthly reports on overnight stays, as reported monthly by INE and Eurostat. Overnight stays are a reliable proxy for tourism activity, although figures from the INE do not include visitors staying in short-term rentals (STR or AL) with a capacity under 10 beds; to address the resulting underestimation, additional data collected from Eurostat (non-statistical data), covering online booking platforms, were included to account for smaller AL establishments, as described in Section 4.

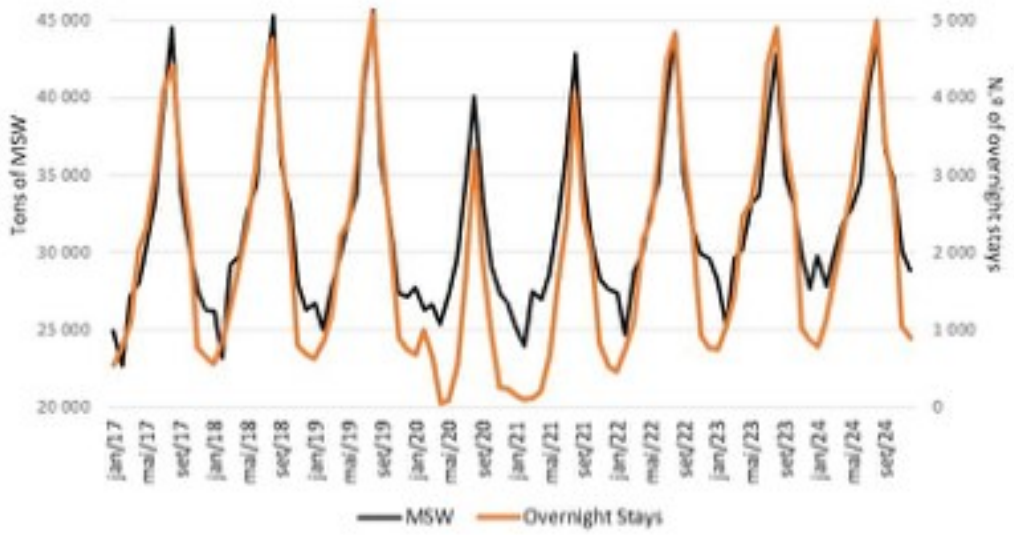
Seasonality

A key challenge in modelling MSW generation from tourism activities in a region such as the Algarve is the inherent seasonality of tourism. As shown in Figure 1, a clear seasonal pattern emerges, with peak tourism months (June–September) showing much higher overnight stays than the off-season period (November–February). While resident population and overnight stays are both explanatory variables for MSW generation, the use of annual population figures—constant across months—would attribute all seasonal variation in waste to overnight stays, although part of it may stem from fluctuations in the consumption pattern of the local population throughout the year.

To mitigate this issue, we indirectly estimated seasonal population variation by referencing MSW patterns in 32 municipalities from the Alentejo and Beira Baixa—regions with similar climate but minimal tourism activity (excluding, e.g., Évora, Odemira and Vila Viçosa). We tested for seasonality across waste types and found it significant only for glass waste, likely reflecting the increased consumption of beverages during warmer months.

Seasonality coefficients were therefore applied to the resident population for August (1.73) and September (1.52) in glass waste models. These adjusted figures were also proportionally included in models for total MSW, as glass is one of its components. Data were provided by the Portuguese Environment Agency (Agência Portuguesa do Ambiente – APA).

Figure 1
Graph depicting tourism as measured by overnight stays and Total Municipal Solid Waste (MSW) production (tonnes), 2017–2024



B.2. Municipal Solid Waste Generation: Statistical Model

Data analysis was performed to evaluate the impact of tourism on MSW production, and composition, in the Algarve region between 2017 and 2024. Using Stata software (Version 18.0), linear regression models were applied to analyse five waste flows as dependent variables: plastic/metal, paper/cardboard, glass, unsorted MSW, and total MSW.

Each regression included two independent variables—resident population and overnight stays—examined at the regional level. The models were estimated with a suppressed constant term, ensuring that all predicted waste is directly attributable to the explanatory variables—population and tourism activity—and the introduction of artificial baseline waste unrelated to human presence is avoided. The general regression equation used for the analysis is as follows:

$$MSW_t = \beta_1 Population_t + \beta_2 OvernightStays_t + \varepsilon_t$$

where *MSW* represents the municipal solid waste generated per each one of the five categories listed above; *Population* is the seasonally-adjusted resident population; *Overnight Stays* is the number of tourist overnight stays; β_1 and β_2 are the estimated coefficients; and ε_t is the error term for time period *t*. The coefficients derived from these regressions were used to estimate waste generation based on variations in population and overnight stays, offering insights into the influence of tourism on MSW dynamics in the region.

Therefore, the purpose of the model developed in this study is to attribute observed aggregate municipal solid waste (MSW)flows to resident population and tourism intensity,

as proxied by overnight stays, under conditions of seasonality. The model is designed primarily for predictive and attributional purposes at the regional level, rather than for identifying all possible micro-level behavioral determinants of waste generation. Its parsimonious specification reflects both data availability and the objective of capturing the dominant drivers of MSW variation over time.

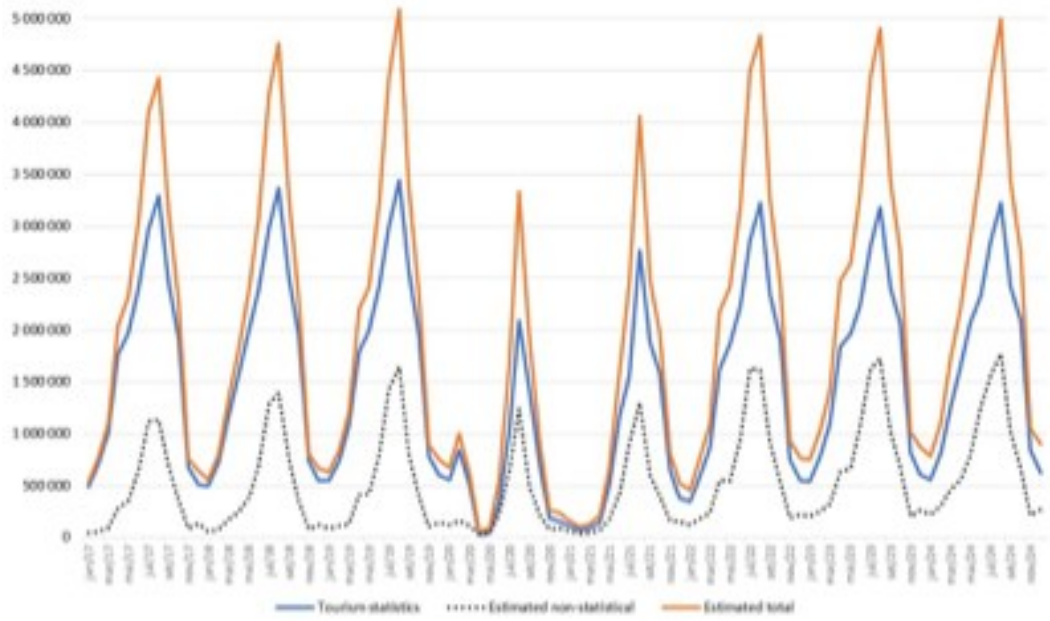
IV. Results and Discussion

To understand the implications of tourism activity on urban waste management in the Algarve, quantitative data were collected and used to develop a statistical model of MSW generation, as described in the previous section.

The initial step was to ensure that the tourist count in the Algarve region was accurate. According to EU Regulation 692/2011 and Decree-Law No. 76/2024, establishments with fewer than 10 beds are classified as AL or STR. Establishments with this classification threshold are excluded from national statistics, so that official data for overnight stays may not fully reflect the actual situation. This discrepancy underscores the challenges in capturing the full scope of short-term rental activity (de Almeida et al., 2024).

In 2024, INE reported a total of 20.8 million overnight stays in the Algarve (INE, 2025). However, STRs, not included in official statistics, accounted for an additional 9.1 million overnight (Figure 2).

Figure 2
Monthly trends in the Algarve region, illustrating the number of overnight stays reported by INE (blue line), total estimated overnight stays (orange line), and the unregistered overnight stays in local accommodation according to Eurostat data (dotted line).

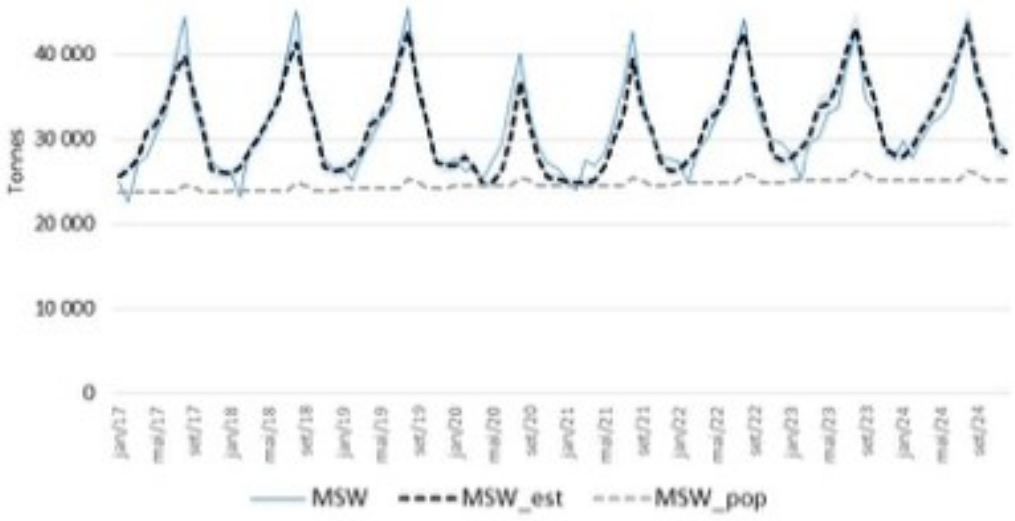


During peak tourism months, such as August, the INE-unregistered overnight stays represent a substantial part (up to 36%) of the effective tourism activity. For example, in 2024, the month of August saw an additional 1.78 million unregistered overnight stays, while January, typically a low season for tourism, had 221,924 INE-unregistered stays.

Although additional overnight stays in local accommodations are not fully captured by official tourism statistics, this does not appear to compromise the robustness of our model. The strong correlation between INE data and Eurostat figures on local accommodation (Pearson coefficient of 0.968) and the consideration of Eurostat data support this conclusion. Nevertheless, the estimated share of local accommodation—37% in 2024—highlights the need for further analysis of the profiles of these tourists, as they may generate more waste than those staying in hotels. In hotel settings, waste management is typically handled by facility managers, with limited direct involvement from guests.

Figure 3 depicts the estimated and registered values of MSW production in the Algarve region over the period of 2017-2024. The graph reveals distinct seasonal peaks and troughs, occurring consistently each year. Peaks are observed mid-year (around summer), while troughs are evident during the late and early months of each year (around winter).

Figure 3
Total MSW production. Comparison between the observed Total MSW production data (solid blue line) and the model-estimated total MSW (dashed line). The dashed line represents MSW estimated production by local residents.



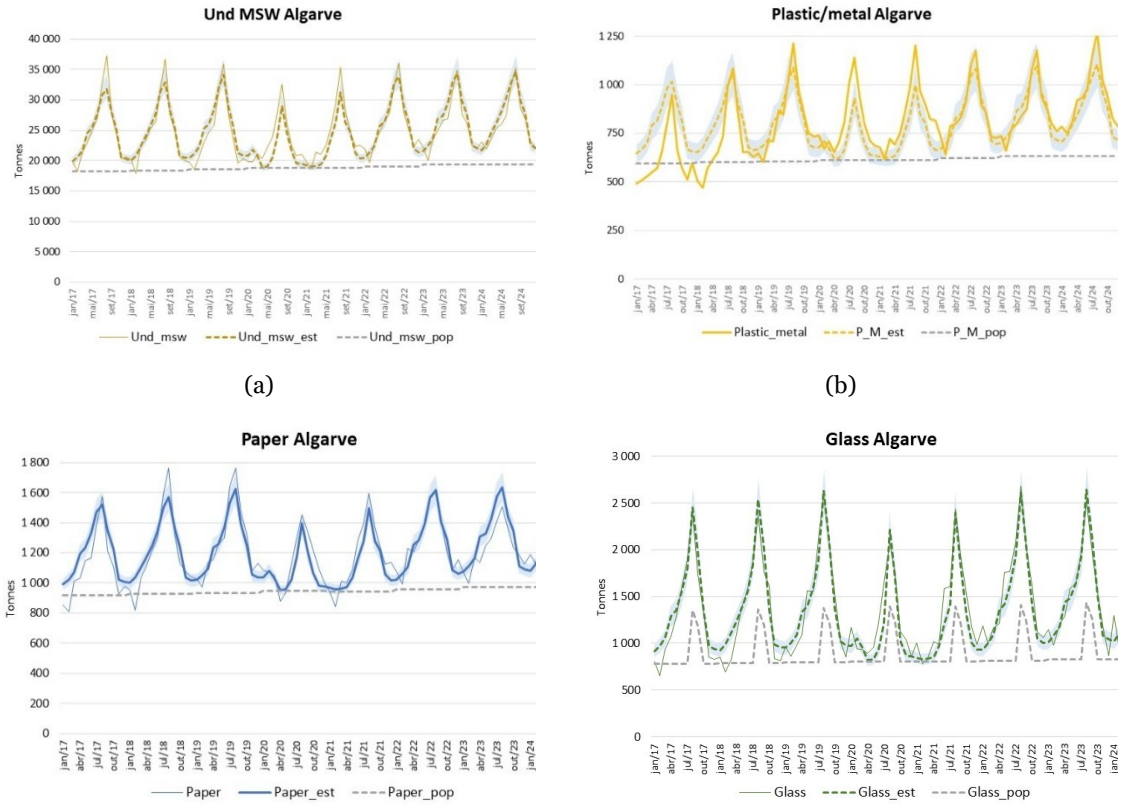
Seasonal factors clearly influence waste generation in the Algarve, with tourism as the most likely driver since it significantly alters the population dynamics of the region. Supporting this premise is the data for the 2020–2021 period, when peak levels were notably lower than in other years. This decline coincides with the global COVID-19 pandemic, during which restrictions on travel led to restrictions in tourism-related waste generation.

The Model Total MSW Estimation (dashed black line) closely follows the MSW Data

Series (solid blue line), which represents the registered values reported by Algar for total MSW production, suggesting that the model is highly effective in predicting waste trends. Additionally, the values for MSW production by local residents (MSW population, dashed grey line) remained relatively stable throughout the period. This stability indicates that the sharp increases in waste generation during the high tourist season, particularly in August, are attributable to tourism activities. For example, in August 2023, 41% of the MSW generated could be attributed to tourism-related activities, a stark contrast to the estimated annual contribution of 27%.

As shown in Figure 4 (a-d), the production of various waste types in the Algarve region, including unsorted MSW, glass, plastic, and paper/cardboard, exhibits pronounced seasonal variability, mirroring trends observed for Total MSW. Seasonal peaks are evident across all waste types, typically occurring during the summer months (July/August), with troughs during the winter months (January/February).

Figure 4
Comparison between the observed (a) Unsorted MSW; (b) plastic/metal; (c) paper and cardboard; (d) glass production data (solid lines) and the model-estimated MSW (dashed lines).The dashed lines represent MSW estimated production by local residents.



For all waste flows, there is close alignment between observed values and model estimates. The estimation of the population-related waste generation does not reflect any

seasonality, except for the glass flow for the above-mentioned reasons. This non-seasonal population-related waste generation is consistent with the general perception by professionals in the sector. In Portugal, MSW generation by locals remains relatively stable throughout the year, with only slight fluctuations (e.g., Christmas, local holidays, and religious celebrations), which, however, do not form a distinct seasonal pattern.

Error! Reference source not found. Table 1 summarises the regression results for the five dependent variables: Total MSW, Unsorted MSW, Paper/Cardboard, Glass, and Plastic/Metal waste. Key metrics such as R^2, Adjusted R^2, F-statistics, coefficients, and standard errors are presented to assess the models' performance and the significance of the predictors.

Table 1– Regression results.

	R^2	Adj. R^2	*F*-statistics *F* (2,94)	Independent Variables	Coefficients of Ind. Variables	Std. Err.
Total MSW *(MSW)*	0.997	0.997	14,283	*Population* (Seasonal_MSW)	0.052565	0.000702
				OvernightStays	3.436482	0.135893
Und. MSW *(Und_MSW)*	0.995	0.995	10,173	Population	0.040153	0.000654
				OvernightStays	3.054129	0.125660
Paper/ Carton *(Paper)*	0.995	0.995	8,698	*Population*	0.0020212	0.000035
				OvernightStays	0.1353876	0.006624
Glass *(Glass)*	0.989	0.989	4,155	*Population* (Seasonal_Glass)	0.001721	0.000062
				OvernightStays	0.247429	0.013434
Plastic/ Metal *(Plastic_Metal)*	0.983	0.982	2,634	*Population*	0.001311	0.000041
				OvernightStays	0.095040	0.007958

For Total MSW, the regression equation produced a highly significant model, with an R^2 value of 0.997 and an overall F-ratio of 14283. This indicates that the independent variables (*Population* (Seasonal_MSW) and *OvernightStays*) collectively explain 99.67% of the variation in the dependent variable (*MSW*). The small difference between R^2 and Adjusted R^2 values indicates that the model does not suffer from overfitting. Regarding the regression models for other waste flows, all Adjusted R^2 are above 0.98, and the lowest F-statistic is 2634 ($p < 0.01$), demonstrating the excellent predictive power of all of them. Additionally, estimated coefficients are always statistically significant ($p<0.01$), confirming the contribution of population variables and overnight stays explaining the variability of all waste flows.

We conducted several robustness checks to validate the consistency of our regression results. These included alternative model specifications, such as panel data models for different municipalities or groups of municipalities, and models incorporating the typology of accommodation in which overnight stays were recorded. However, many of

these alternative specifications were limited by fragmented data series or failed to improve model performance.

We also considered including regional economic indicators — such as per capita disposable income in the Algarve, adjusted for the regional consumer price index — as a proxy for purchasing power, which could serve as a mediating factor in household waste generation, following the rationale of STIRPAT models commonly found in the literature. Nonetheless, these data were not available at the required level of temporal disaggregation. Despite these limitations, our models demonstrated strong explanatory power, as reflected in their adjusted R^2 values and statistical robustness.

Additionally, we conducted trend analysis by including time variables for each of the eight years (2017–2024) in our main model, which proved not to be statistically significant. To test for possible structural effects in the post-COVID period, we introduced dummy variables for the years 2022 to 2024 as interaction terms with the remaining explanatory variables in our model, but none were statistically significant. These results do not suggest a systematic trend or structural break occurred in the waste generation pattern during the analyzed period. We also considered including explicit seasonal dummies, but given the nature of our variables—monthly waste data adjusted for both resident population and overnight stays—and the fact that only glass waste showed a significant seasonal pattern (already accounted for in the model), further seasonality controls were deemed unnecessary.

The main findings of our robustness checks — available from the authors upon request — consistently align with the results reported in the paper, particularly in terms of coefficient signs, magnitude, and statistical significance, and help reinforce the robustness of our model.

Tourism significantly increases waste generation across all categories, with particularly strong effects observed concerning unsorted waste and for glass. This impact is not solely due to the presence of tourists (a quantity effect), but also reflects an intensity effect, as the quantity of waste generated by tourism activities per day is clearly higher than the daily production of a local resident (Table 2).

Table 2– Comparison of MSW production rates between local residents and tourist activities in the Algarve region.

Note. Values are presented in kilograms per person per day, along with the relative overproduction (%) in waste generation due to tourist activities.

	Residents (kg/person/day)	**Tourism Activity** (kg/person/day)	**Relative overproduction**
Total MSW	1.68	3.44	205%
Unsorted. MSW	1.32	3.05	231%
Paper/ Cardboard	0.066	0.135	204%
Glass	0.062	0.247	396%
Plastic/ Metal	0.043	0.095	221%

Residents are estimated to produce an average of 1.68 kg of Total MSW per person per day. In contrast, tourists generate significantly more waste, with approximately 3.44 kg per person per night, reflecting a differential impact of 205%, when compared to the

local population. The relative increase in Unsorted MSW due to tourism is even higher than the total MSW increase, at 231%, corresponding to 1.32 (kg/person/day) for local residents and 3.05 (kg/person/day) for tourists. This indicates that tourists generate proportionally more undifferentiated waste, suggesting a gap in recycling infrastructure or practices among tourists and/or tourism operators. Regarding paper/cardboard, tourists generate 0.135 kg/person/day, which is approximately double the amount generated by residents (0.066 kg/person/day), with relative increases of 204%. Tourist production of glass waste is significantly higher (0.247 kg/person/day) compared to residents (0.062 kg/person/day), resulting in the largest relative overproduction of 396%. A possible explanation for this is that tourist activities, such as dining and entertainment, typically contribute significantly to glass waste generation (Suma et al., 2019). Lastly, considering plastic/metal, residents and tourists produce 0.043 kg/person/day and 0.095 kg/person/day, respectively, representing a relative overproduction of 221%, more than double that of residents.

An important caveat is that a significant part of the housing stock in the Algarve is not occupied year-round. According to the 2021 Census data from the INE, the Algarve is by far the region with the most secondary residences, with only 49,4% of residential stock occupied as a primary residence and 38,6% classified as secondary residence (for Portugal as a whole, the numbers are 69,4% and 18,5%, respectively). The seasonal inflow of population not captured in the resident population or tourism statistics could be relevant. As this inflow seasonal pattern is most likely correlated with the tourism statistics pattern, not accounting for it in our models will significantly affect the estimation of tourism-related waste generation. However, it would reduce MSW attribution to overnight stays as it would result in lower coefficients associated with the explanatory variables of overnight stays.

Our findings nonetheless align broadly with studies in other tourist-heavy regions. Mance et al. (2020) observed that regional variations show the influence of local policies, cultural practices, and income levels on waste generation in Croatia. Rural municipalities produce significantly less waste per capita compared to more urbanized areas: rural residents generate 0.63 kg of waste per day, while rural tourists generate 0.95 kg per day. In contrast, tourists in average coastal municipalities generate about 1.2 kg per day, with local residents producing slightly less than 1 kg per day. In wealthy municipalities with robust waste management policies, waste generation is lower for both locals and tourists, averaging around 0.84 kg per person per day. As in the present study, seasonality is highlighted by Arbulú et al. (2024) for Ibiza, Spain, finding that tourists generate substantially more waste during the high season, at 1.77 kg per day, compared to 1.41 kg per day in the midseason. These results are similar to findings by Mateu-Sbert et al. (2013) for Menorca, who reported comparable seasonal variations. In the Balearic Islands, high-season waste generation accounts for 47% of the annual total, while midseason and low-season waste generation account for 32% and 21%, respectively. The composition of waste also varies seasonally, with glass generation peaking in the high season (55% of total glass waste). Additionally, over time, there has been a noticeable reduction in per capita non-sorted waste generation in the Balearic Islands, alongside an increase in recycling rates. Between 2003 and 2019, monthly waste generation per

person decreased from 49.78 kg to 45.12 kg, while recycling increased by 6.51 kg per person per month. Such a downward trend is not yet visible in the Algarve, stressing the need for better policies to be implemented in the region. After all, reduction is the first step in the waste hierarchy according to EU legislation.

Overall, the data observed across studies and regions underscore the complex interplay among income, seasonality, local policies, and cultural practices in shaping waste generation. These findings emphasise the importance of tailored waste management strategies that consider both local and tourist populations to foster sustainability and reduce environmental impacts.

V. Conclusions

Tourism in the Algarve significantly challenges sustainable waste management, particularly during the peak summer season. The region's waste generation is shaped by a sharp contrast between a stable resident population and seasonal influxes of tourists. While residents contribute to a baseline level of MSW generation, the summer months consistently see spikes in waste generation driven by tourism. Data from 2017 to 2024 confirmed this seasonal trend, with regression models exhibiting a high explanatory power, showing that tourist activities have a disproportionately high impact on MSW generation compared to the local population, as shown by the higher coefficients associated with overnight stays. The model yields an average estimated waste intensity of approximately 3.4 kg of MSW per overnight stay, conditional on observed aggregate patterns of population and tourism activity in the Algarve region, which is twice the daily waste generation of a local resident, with glass waste being four times higher. This value should therefore be interpreted as an aggregate regional benchmark, useful for planning, cost allocation, and capacity management, rather than as a precise measure of individual tourist behaviour. Despite these limitations, the robustness of the results across specifications and the strong alignment between observed and estimated waste flows support the relevance of the findings for policy design in regions with pronounced tourism seasonality. These patterns emphasize the importance of designing targeted, seasonally adaptive waste management strategies. Without accounting for the distinct waste intensity of tourism—particularly in unsorted waste and glass fractions—any regional waste policy risks being ineffective. Sustainable practices must engage tourism-sector stakeholders and consider the seasonal and spatial concentration of tourist activities. Failing to do so will compromise the effectiveness of policies aimed at promoting the circular economy goals. In fact, while overnight stays accounted for 27% of the Algarve's total annual MSW production, tourism impacted 41% of the region's waste management capacity due to pronounced seasonality.

Our findings strongly supported the link between tourism and waste generation in the Algarve—not only in terms of annual waste volumes but also in the seasonal fluctuations that put pressure on collection, sorting, and treatment infrastructure. However, several limitations remain. An important limitation of the analysis concerns the omission of certain population groups and socio-economic variables that may influence waste generation. In particular, the Algarve has a substantial share of second homes and

seasonal non-resident occupants who are not classified as tourists in official statistics and are not included in resident population figures. This seasonal population inflow is likely correlated with tourism intensity and may contribute to observed MSW generation, especially during peak months. The omission of this group does not invalidate the model results but may affect the attribution of waste generation between residents and tourism activity. To the extent that part of the waste attributed to overnight stays may be generated by non-resident seasonal occupants, the estimated coefficient associated with tourism can be interpreted as conservative. Incorporating this population explicitly would likely reduce the magnitude of the overnight-stays coefficient rather than increase it.

Although we explored more detailed model specifications, including panel data models across municipalities and those incorporating accommodation types, fragmented time series, and data gaps limited their utility. Similarly, efforts to include regional economic indicators such as per capita disposable income, adjusted by the regional consumer price index—as a proxy for purchasing power, in line with STIRPAT frameworks—were hindered by insufficient temporal granularity. Despite these limitations, our core models remain robust, with statistically significant coefficients and consistent explanatory power. Robustness checks showed that alternative model configurations yielded results consistent in magnitude, direction, and significance, further validating our findings. Additional research could benefit from higher-quality data on large waste producers and more granular accommodation data per municipality. Although our estimates exclude some waste from large producers, due to poor data quality, figures from Agência Portuguesa do Ambiente and Algar suggest these represent no more than 2.5% of total MSW, and are thus unlikely to bias results. Other sources of uncertainty include potential differences in tourist profiles between high and low seasons that may affect waste intensity, as well as untracked outmigration of local residents during peak tourism periods. Conversely, if our seasonal waste proxy underestimates changes in resident behaviour, the impact of tourism may be slightly overstated. These uncertainties point to the need for improved data collection to fine-tune policy tools and more accurately reflect the complexity of tourism-induced waste dynamics. Our study provides a valuable starting point for future research, offering preliminary data that can guide more extensive research into the intricate relationships between tourism and waste management, ultimately paving the way for more effective and sustainable solutions.

Conflicts of Interest: The authors declare no conflict of interest.

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Appendix A

Figure A1
The Algarve Region Map

Figure A2
Methodology illustrating the development process for statistical model

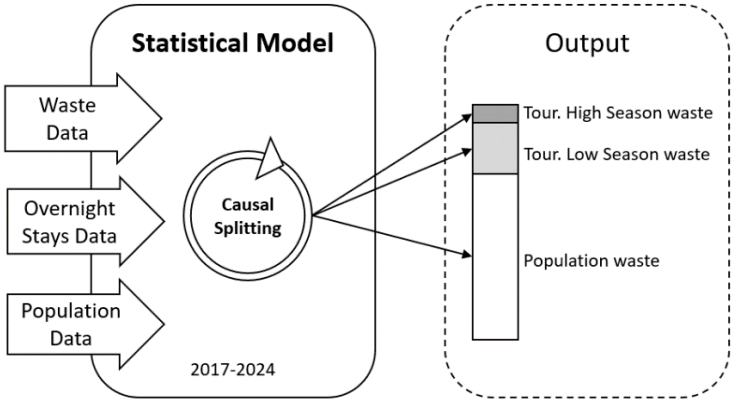

Figure S2 - Methodology illustrating the development process for statistical model.