

Is there a long-term relationship between tourism inflows and waste generation? A seasonal cointegration approach

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Abstract

Most likely tourism and waste generation go hand in hand, particularly in economies dominated by tourism-related activities. This paper examines whether a sustained relationship exists between tourism measures such as the number of guests or total overnight stays, and waste generation on São Miguel Island (Azores, Portugal), using a seasonal cointegration method. This empirical approach is suitable given the high seasonality of tourism in many destinations. The results reveal a sustained link between tourism activity and municipal solid waste (MSW) production, as well as between tourism and glass waste. While cointegration is a widely used method in econometrics, we found few applications in literature that address cointegration in the presence of seasonality. Nevertheless, when working with seasonal data there is a risk of obtaining statistically significant results due to spurious relationships if such a feature is not properly addressed. The findings reveal that seasonal cointegration offers a reliable method for capturing the dynamics between tourism and waste generation and can thus serve as a useful tool for planners and policymakers seeking to optimize waste management in touristic destinations.

Keywords: municipal solid waste generation; tourism; seasonal cointegration; error correction model; Islands.

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1. Introduction

Tourism is among the most significant industries globally and plays a vital role in socioeconomic development across various regions, particularly in countries rich in cultural, historical, and natural assets. However, it is important to note that tourism is an energy and water-intensive activity that also results in the generation of substantial amounts of solid waste stemming from both accommodation and recreational pursuits (Muñoz & Navia, 2015). As a result, the challenge of sustainable waste management is becoming increasingly critical in many tourist destinations (Murava & Korobeinykova, 2016).

Waste production is a significant externality of tourism, leading to notable ecological consequences in sensitive and vulnerable areas, especially in small island locations. This context underpins the motivation for the present study, where we explore the connection between tourism and waste generation on São Miguel Island, which is part of the Azores archipelago. This Portuguese archipelago is "situated in the North Atlantic Ocean" and has experienced substantial growth in tourism over the past two decades (Vieira *et al.* 2019). The primary attractions for visitors are the landscape and marine-related activities (Vieira & Antunes, 2017; Vieira *et al.*, 2018). Consequently, understanding the connection between tourism and waste generation is a critical concern in this context.

To model the direct impact of tourism on the economy, researchers have considered two main approaches: a demand-side approach, based on visitors' consumption, and a supply-side approach, focused on tourism-related activities. Most studies analyzing tourism's contribution to municipal solid waste (MSW) adopt the demand-side perspective, using tourist flows to estimate their environmental impact (see, for example, Díaz-Fariña *et al.*, 2020).

To better capture the effects of both quantitative and qualitative characteristics of tourism on MSW, Arbulú *et al.* (2015) included several explanatory variables in their analysis. These include: the volume of tourism, measured by inbound tourist arrivals; the qualitative aspect of tourism, represented by the tourism expenditure per tourist index; a set of socioeconomic variables such as the unemployment rate, the percentage of the population with at least upper secondary education, and the percentage of the population living in rural areas; and an indicator of institutional quality, such as the government effectiveness index.

Dynamic regression models have also been employed to estimate tourism's impact on MSW generation. These models offer two key advantages. First, they capture the fact that the current value of a variable may depend on its past values, meaning that MSW trends in each region are partially self-determined. Second, they enable the inclusion of independent explanatory variables (Mateu-Sbert *et al.*, 2013).

However, when dealing with time series data, particularly in economics and finance, many variables of interest are non-stationary, meaning their statistical properties such as mean, and variance change over time. Applying standard regression models like ordinary least squares (OLS) to such data can lead to misleading results, known as spurious regression. This occurs when two non-stationary series are regressed against each other and appear to have a significant relationship, even if they are unrelated. In contrast, cointegration offers a more robust framework for modeling relationships between non-stationary time series. If a group of non-stationary variables are cointegrated, it implies that there exists a linear combination of them that is stationary. This stationary combination indicates a long-run equilibrium relationship, which standard regression models cannot detect or handle properly without additional modifications (Engle & Granger, 1987).

One of the key advantages of cointegration is its ability to distinguish between short-term fluctuations and long-term equilibrium relationships. Once cointegration is established, an error correction model

(ECM) can be constructed to capture both the short-run deviations and the speed at which the system returns to its long-run equilibrium. This dynamic modeling approach is particularly valuable in economics, where temporary shocks often affect variables, but long-run economic principles eventually reassert themselves.

Moreover, many economic theories naturally imply cointegrating relationships. Economic theories suggest that certain variables should move together in the long run. Cointegration directly tests these theoretical expectations, whereas regression models may not align structurally with these economic intuitions.

In this paper, we employ a seasonal cointegration approach. This methodology is chosen for two main reasons. First, while cointegration is a widely used method for examining long-term relationships between variables, we have not identified any existing research that applies this technique to assess the relationship between tourism and waste generation. Nevertheless, it is reasonable to assume that these variables may fluctuate at a similar rate. When this occurs, the series are considered cointegrated, allowing us to differentiate between a long-term connection and short-term fluctuations. The long-term relationship describes how the variables move together over time, whereas the short-term dynamics focus on the variations of the dependent variable relative to its long-term trend in relation to deviations in the independent variable. Second, given that tourism is characterized by high seasonality in many regions, it is essential for cointegration analysis to explicitly account for this aspect. In fact, cointegration methods have been broadened to incorporate other dimensions beyond just the long-term, or zero-frequency, relationships between economic variables. For example, Hylleberg *et al.* (1990) addressed seasonal frequencies in quarterly time series, and Engle *et al.* (1993) introduced a procedure for estimation and testing with seasonal data, thereby expanding the framework proposed by Engle and Granger (1987).

The structure of the paper is as follows: Section 2 reviews the literature on tourism-related waste generation. Section 3 provides an overview of the study site, data, and statistical method. Section 4 reports empirical findings. Section 5 discusses the results; Section 6 provides the conclusions and final remarks; and Section 7 outlines the study's limitations.

2. Literature review

The literature has identified numerous adverse environmental externalities associated with the overexpansion of tourism (Comerio *et al.*, 2022). Among these, the challenges related to municipal solid waste (MSW) management constitute a relatively under-researched domain (Comerio *et al.*, 2022). Remarkably, waste generation is among the most perceptible environmental pressures exerted by tourism activities (Dolnicar *et al.*, 2020). This issue has increasingly attracted global attention from policymakers, particularly concerning the mechanisms of waste generation, its logistical handling, and strategies aimed at its mitigation.

2.1. The tourism industry and waste generation

Tourism is a significant contributor to urban solid waste, yet much of this waste is often masked within the broader category of residential waste (Diaz-Fariña *et al.*, 2020). Because the waste generated by tourists typically shares characteristics with urban solid waste, it is generally collected, transported, and processed alongside residential waste, as noted by Murava and Korobeinykova (2016). Thus, tourism-generated waste tends to be aggregated within general residential waste data, lacking dedicated tracking metrics. As a result, key tourism activities often lack specific metrics for the waste they generate, which in turn limits the incentives available for reducing their waste output. Consequently, this integration within general waste streams leads to comparatively lower recycling rates for waste from tourism-related activities (Styles *et al.*, 2013).

During visits, tourists produce a range of solid waste types - such as newspapers, plastic and glass bottles, aluminum cans, and paper - leading to a diverse mix of waste that broadly falls into recyclable, organic, and hazardous categories. Research by Pirani and Arafat (2014) found that most of this waste is generated within accommodation and food service establishments.

Despite limited data on the precise volume and composition of waste generated by tourism, understanding waste production metrics for each producer is essential for effective waste management planning and system optimization (Beiglet *et al.*, 2008). Developing accurate metrics for waste generation per producer type is also vital to creating incentive structures that minimize waste and increase recycling rates, such as pay-as-you-throw programs (Diaz-Fariña *et al.*, 2020).

However, detailed monitoring of waste generation can often be challenging. Municipalities are thus encouraged to prioritize the reduction of solid waste from tourism in future waste management efforts. Reducing the costs associated with waste collection, transportation, and disposal can, in turn, help make tourism more sustainable by enhancing the value of the territory for tourists (Muñoz & Navia, 2015).

The literature includes mixed findings on the relationship between tourism and municipal solid waste (MSW). Some researchers, such as Arbulú *et al.* (2016), have argued that tourism growth does not necessarily increase MSW per resident. This may be due to technological advancements that offset some waste impacts or changes within tourism-related businesses that align with environmentally conscious practices. Other research has examined environmentally preferable purchasing and waste management practices in the tourism sector, such as the demand for reusable materials and an emphasis on recycling (Qian & Schneider, 2016).

Conversely, studies like those by Greco *et al.* (2018) highlight a positive association between tourism and MSW. They found that a 1% rise in tourist numbers in Italy led to a 0.23% increase in paper collection costs and a 0.11% increase in the cost of multi-material waste collection per resident.

Various studies have explored the link between tourism and food waste. For instance, Alsuwaidi *et al.* (2022) demonstrated how socio-demographic factors, values, and anticipated reactions can influence tourists' efforts to reduce food waste. Research by Li and Wang (2020) indicates that food waste is a common issue among cruise passengers in China, largely influenced by an abundant supply of food, all-inclusive packages, and cultural norms. Liu *et al.* (2022) created a framework for understanding food waste practices across different cultural and contextual environments, while Kim *et al.* (2020) found that the perceived value of sustainability influences consumer attitudes and norms around waste reduction. Talwar *et al.* (2021) explored diners' attitudes and intentions around taking leftovers from restaurants. Other studies in this area include Filimonau and Sulyok's (2021) work on food waste in Hungarian restaurants and Filimonau *et al.* (2019) study in Bulgaria.

Some studies have also focused on how tourism service providers work to reduce waste. For example, Radwan *et al.* (2010) investigated solid waste management in smaller hotels, noting that operators often lack awareness about waste reduction methods specific to hotel settings. Visser-Amundson (2020) demonstrated the effectiveness of cross-sector collaborations in tackling food waste at scale. Qian and Schneider (2016) examined waste minimization practices across tourism businesses in Minnesota, USA, while Radwan *et al.* (2012) provided empirical support for environmental management systems as a key factor in promoting eco-friendly practices within smaller hotels.

Other research on tourism and waste generation includes studies on untreated waste along trails used for ecotourism and trekking (Kuniyal, 2005), and on social and personal norms affecting waste

reduction intentions among young travelers (Han *et al.*, 2018). Additionally, Cummings (1997) examined waste reduction as a pillar of sustainable urban tourism.

2.2. *Tourism and waste in island destinations*

Managing waste in island destinations poses unique challenges, as these areas often lack the integrated waste treatment infrastructure found on the mainland (Diaz-Fariña *et al.*, 2020). Ezeah *et al.* (2015) note that islands frequently face waste management constraints such as limited treatment and disposal facilities, insufficient land to develop additional landfill sites, difficulties in achieving economies of scale, and seasonal peaks in waste generation driven by tourism. These island environments experience specific challenges in waste management due to their distinct climatic conditions, geographical constraints, and fluctuating populations.

The remoteness of many islands further complicates waste management, as most materials used on the islands must be imported, often without a sustainable plan for managing the waste they produce. This reliance on imports strains local waste systems, revealing the limitations of existing infrastructure and highlighting unsustainable practices in waste collection and management (Ezeah *et al.*, 2015).

Several studies have analyzed waste impacts of tourism on small island regions. For instance, Mateu-Sbert *et al.* (2013) found that each 1% rise in Menorca's tourist population correlates with a 0.282% increase in municipal solid waste (MSW). Similarly, Diaz-Fariña *et al.* (2020) reported that tourism in a municipality in Tenerife generates approximately 0.4 kg of MSW daily per tourist, with 0.33 kg linked to accommodation facilities and 0.07 kg originating from the food and beverage sector. Roughly 6.4% of this area's total MSW output from the food and beverage industry is directly attributable to tourists. Estay-Ossandon and Mena-Nieto (2018) also explore how tourism impacts solid waste production in island tourism settings.

Muñoz and Navia (2015) highlight that inadequate waste management can lead to negative outcomes for tourism-dependent islands, such as higher operating costs and environmental degradation from litter and contaminated water. This degradation can decrease the appeal of these destinations, diminishing their value as attractive tourist locations.

On many islands, landfilling remains the primary method of waste disposal, despite the potential benefits of recycling for local communities and governments (Diaz-Fariña *et al.*, 2020). Waste separation is still rare on smaller developing islands, and recycling systems are often underdeveloped. This is largely due to several constraints: the small population and limited size of these islands prevent the achievement of economies of scale, the volume of recyclables is typically low, and local recycling markets are limited. Transporting materials to external recycling facilities is also costly due to geographic isolation.

3. **Methodology and data**

3.1. *The study area*

The focus area for this study is São Miguel Island, the largest island within the Azorean archipelago (Portugal), which represents about 2.3% of the total Portuguese population. Located in the North Atlantic Ocean, the Azores lie approximately 1,643 km from Lisbon (Portugal) and 1,925 km from Newfoundland (Canada).

Over the past two decades, tourism has gained recognition as a key sector, with strong public policy backing, particularly from European Union funding. This support has encouraged the expansion of accommodation options and promoted the region as a sought-after tourist destination. Additionally, a revised accessibility model that introduced both regulated and unregulated routes facilitated the entry

of new airlines, particularly low-cost carriers, which in turn drove a considerable drop in airfare costs. Until this change, high travel costs had been a significant obstacle to tourism growth. As a result, both guest numbers and overnight stays have risen consistently across the Azores, especially on São Miguel Island, despite minor fluctuations (Vieira *et al.*, 2019; Jordan *et al.*, 2020).

As in many other island destinations, tourism growth and environmental vulnerability are a matter of concern. Therefore, in recent years, there has been a clear evolution in the approach to solid waste disposal on the island of São Miguel. Sanitary landfills for the disposal of urban waste management and other waste treatment infrastructure were built, and dumps or other illegal waste disposal sites were gradually sealed. Community and national policies have taken an integrated view of waste management, primarily translating into limiting the quantity and danger of waste and maximizing the quantities for recovery.

Disposal, mainly landfilling, continues to be a popular destination for waste management entities in the Azores Islands. However, municipalities and waste processing centers have made efforts to increase the amounts of waste to be recovered, either by material recovery (for example, through increased selective collection) or by organic recovery (for example, through the composting process). The implementation of urban waste management infrastructures has enabled leadership, at an island level, to respond to environmental issues, and it is now a priority to reinforce the importance of waste prevention.

In São Miguel, MUSAMI is an intermunicipal entity that manages the solid urban waste from all the island's municipalities. All this waste is collected directly by each of the six municipalities on the island and delivered, or deposited, to MUSAMI. Collections carried out by the municipalities include door-to-door and container collection of waste produced in homes, commercial establishments, restaurants, and hotels.

3.2. The data

Quantitative data on waste generation on São Miguel Island were provided by MUSAMI. These data corresponded to the values, in tons, of inputs of waste, based on the historic values from January 1, 2009, to December 31, 2019, for urban solid waste, and the records from January 1, 2010, to the second quarter of 2019, for glass packaging waste and paper, plastic packaging and other municipality undifferentiated waste. For this period, quantitative data on guest arrivals and overnight stays were sourced from the official website of the Azorean Statistical Office (SREA). Based on the data obtained from MUSAMI and Azorean Statistical Office, figure 1 shows the graphs drawn up allowed for comparison of the variation over time for the variables used in this study.

The guest counts and overnight stays in São Miguel Island exhibit a strong seasonal pattern, with numbers peaking during the summer, particularly in the third quarter of the year, and reaching their lowest levels in the first quarter. Waste generation follows a similar seasonal trend, with quarterly averages being highest in the third quarter and lowest in the first quarter for all waste categories analyzed in this study. The timing of peak and low values tends to align across guest indicators and the three waste categories. Although sufficient data is accessible, records from 2020 to 2023 were excluded due to the unusual trends observed during this period, which affected the typical progression of the studied indicators.

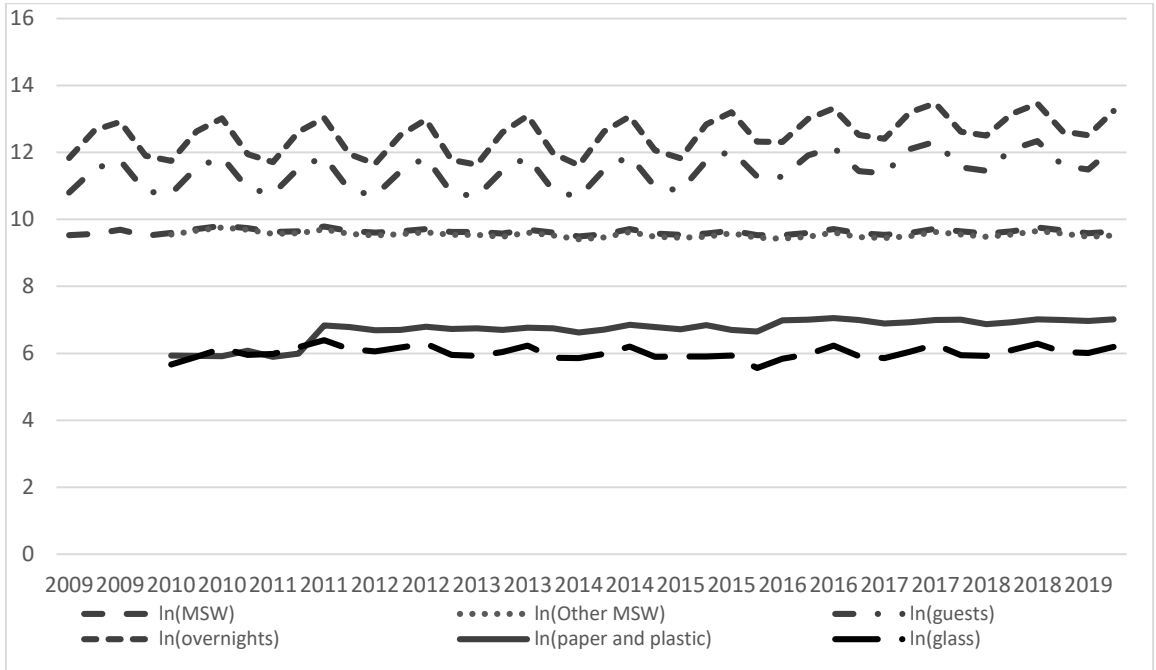


Figure 1. Waste and tourism indicators (in logarithms).

3.3. The statistical method

The statistical technique used in this paper for data analysis was cointegration, which translates into the long-term equilibrium relationship of systematic co-movement between the variables involved. The analysis follows the procedures proposed by Engle *et al.* (1993), which adapted the work of Engle and Granger (1987) to the seasonal case.

3.3.1. Testing for seasonal integration

Dickey and Fuller (1979) developed the well-known unit root test of stationarity for non-seasonal processes. The test considers the null hypothesis that the coefficient of x_{t-1} in equation (1) is zero:

$$\Delta x_t = (\rho - 1)x_{t-1} + \varepsilon_t \quad (1)$$

Where $\Delta x_t = x_t - x_{t-1}$ and ε_t is a stationary process.

This is equivalent to conducting a statistical test of the null hypothesis that $\rho=1$, indicating non-stationarity, in equation (2):

$$x_t = \rho x_{t-1} + \varepsilon_t \quad (2)$$

A non-stationary process can be written as:

$$x_t = x_{t-1} + \varepsilon_t \quad (3)$$

or,

$$(1-B)x_t = \varepsilon_t \quad (4)$$

where B is the lag operator ($B^k x_t = x_{t-k}$).

The polynomial defined in (4) has a single unit root equal to one, which is why the test by Dickey and Fuller (1979) is known a unit root test.

For seasonal processes, it is also possible to test the existence of unit roots in the data. An integrated quarterly process is written as:

$$x_t = \rho x_{t-4} + \varepsilon_t \quad (5)$$

Therefore, a non-stationary quarterly process can be written as:

$$x_t = x_{t-4} + \varepsilon_t \quad (6)$$

and the characteristic equation as

$$(1-B^4)x_t = \varepsilon_t \quad (7)$$

Or, equivalently,

$$(1-B)(1+B)(1+B^2)x_t = \varepsilon_t \quad (8)$$

In this case, the polynomial in B has three roots: 1, -1, and $\pm i$, which correspond to zero frequency, $\frac{1}{2}$ cycle per quarter (or two cycles per year), and $\frac{1}{4}$ cycle per quarter (or one cycle per year). Subsequently, tests for seasonal unit roots tend to be more complex than in non-seasonal situations.

A formal demonstration of the procedures that we follow in this paper can be found in Hylleberg *et al.* (1990), Engle *et al.* (1993), or a more simplified version in Choi (2015). Nevertheless, and in order to facilitate the understating of our results, we introduce some of the main topics in seasonal cointegration.

Considering the following four constructs:

$$y_{1,t} = (1 + B + B^2 + B^3)x_t = x_t + x_{t-1} + x_{t-2} + x_{t-3} \quad (9)$$

$$y_{2,t} = -(1 - B + B^2 - B^3)x_t = x_t - x_{t-1} + x_{t-2} - x_{t-3} \quad (10)$$

$$y_{3,t} = -(1 - B^2)x_t = x_t - x_{t-2} \quad (11)$$

$$y_{4,t} = (1 - B^4)x_t = x_t - x_{t-4} \quad (12)$$

It is easy to show the results in equations (13), (14) and (15):

$$(1 - B)y_{1,t} = \varepsilon_t \quad (13)$$

$$(1 + B)y_{2,t} = \varepsilon_t \quad (14)$$

$$(1 + B^2)y_{3,t} = \varepsilon_t \quad (15)$$

That is, $y_{1,t}$, $y_{2,t}$, and $y_{3,t}$ have roots in 1, -1, and $\pm i$, respectively, where $y_{1,t}$ is the observed series adjusted for all seasonal unit roots at $\theta = \frac{1}{4}, \frac{1}{2}, \frac{3}{4}$, while preserving long-term unit roots (frequency 0); $y_{2,t}$ is the observed series adjusted for the seasonal unit roots at $\theta = 0, \frac{1}{4}, \frac{3}{4}$, while preserving semi-annual unit roots (frequency $\frac{1}{2}$); $y_{3,t}$ is the observed series adjusted for the seasonal unit roots at $\theta = 0, \frac{1}{2}$, while preserving annual unit roots (frequency $\frac{1}{4}$); and $y_{4,t}$ is the observed series adjusted for all unit roots.

To test for a positive unit root against the alternative of stable roots, we may test the null hypothesis $H_0: \rho_1 = 1$ in the regression:

$$y_{1,t} = \rho_1 y_{1,t-1} + \varepsilon_t \quad (16)$$

Or, equivalently, $H_0: a_1 = 0$ in the regression equation

$$\Delta_4 y_t = a_1 y_{1,t-1} + \varepsilon_t, \text{ given that } \Delta_4 y_t = (1 - B)y_{1,t} \text{ and } \Delta_4 = (1 - B^4) \quad (17)$$

against the alternative $H_1: a_1 < 0$.

For a negative unit root, we consider that the null of $H_0: a_2 = 0$ in the regression equation (18):

$$\Delta_4 y_t = a_2 y_{2,t-1} + \varepsilon_t \quad \text{given that } \Delta_4 y_t = (1 + B)y_{2,t} \quad (18)$$

against the alternative $H_1: a_2 > 0$.

For the case of complex unit roots, we consider the null of $H_0: a_3 = 0$ in the regression equation (19):

$$\Delta_4 y_t = a_3 y_{3,t-2} + \varepsilon_t \quad (19)$$

against the alternative of stationarity $H_1: a_3 > 0$.

Engle *et al.* (1993) developed an extension of the Dickey-Fuller test built from the expansion of an autoregressive representation $\phi(B)x_t = \varepsilon_t$ around $\theta = \pm 1, \pm i$. The test is based on the following auxiliary regression equation (20):

$$y_{4,t} = \pi_1 y_{1,t-1} + \pi_2 y_{2,t-1} + \pi_3 y_{3,t-2} + \pi_4 y_{3,t-1} + \varepsilon_t \quad (20)$$

The tests for a unit root at frequencies 0 and $\frac{1}{2}$ are based on the T values for π_1 and π_2 , both of which are distributed as a Dickey-Fuller distribution and for frequency $\frac{1}{4}$ on the F test on $\pi_3 \cap \pi_4$. The critical values can be found in Hylleberg *et al.* (1990).

To test for a unit root at zero frequency, we perform a t test on $\pi_1 = 0$. To test a semiannual cycle root, we use a t test on $\pi_2 = 0$. To test an annual cycle root, we can perform a joint F test of $\pi_3 = \pi_4 = 0$.

A time series contains no seasonal unit roots if the t test on $\pi_2 = 0$ and the F test of $\pi_3 = \pi_4 = 0$ are both rejected. A time series contains no unit roots at all, and it is stationary in a wide sense if each of the t tests are rejected as well as the F test.

3.3.2. Test for seasonal cointegration

Considering the two variables y_t and x_t both integrated of order one in all frequencies, $I_\theta(1), \theta = 0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}$, there may exist one or no cointegrating vector at each frequency. When the cointegration rank for y_t and x_t is one at all frequencies, the Error Correction Model (ECM), with quarterly data, can be written as follows (Engle *et al.*, 1993):

$$\Delta_4 y_t = \sum_{j=1}^q \partial_j \Delta_4 x_{t-j} + \sum_{i=1}^p \beta_i y_{t-i} + \gamma_{11}(y_{1,t-1} - \alpha_{12}x_{1,t-1}) + \gamma_{12}(y_{2,t-1} - \alpha_{22}x_{2,t-1}) - (\gamma_{13} + \gamma_{14}B)(y_{3,t-2} - \alpha_{32}x_{3,t-2} - \alpha_{41}y_{3,t-3} - \alpha_{42}x_{3,t-3}) + \varepsilon_t \quad (21)$$

where Δ_k is the difference operator ($\Delta_k y = y - y_{t-k}$).

In equation (21), the following components in equations (22), (23) and (24), must be integrated of order zero $I(0)$ at all frequencies:

$$z_{1t} = y_{1,t} - \alpha_{12}x_{1,t} \quad (22)$$

$$z_{2t} = y_{2,t} - \alpha_{22}x_{2,t} \quad (23)$$

$$z_{3t} = y_{3,t} - \alpha_{32}x_{3,t} - \alpha_{41}y_{3,t-1} - \alpha_{42}x_{3,t-1} \quad (24)$$

Engle *et al.* (1993) argue that, for the first two equations, the parameters can be estimated through the Engle-Granger two-step procedure, utilizing ordinary least squares. These parameter estimates can then serve directly in defining and estimating the Error Correction Model (ECM). To test cointegration at

the specified frequencies, the residuals from these cointegration regressions can be examined for remaining unit roots at the frequencies of 0 and $\frac{1}{2}$.

The two-step approach begins by estimating the following residuals in the first step:

- u_t residuals obtained from the regression of y_{1t} on x_{1t} .
- v_t residuals obtained from the regression of y_{2t} on x_{2t} .
- ω_t residuals obtained from the regression of y_{3t} on x_{3t} and $x_{3,t-1}$.

The second step consists of testing the stationarity of the residuals obtained in the first step. To test for noncointegration at a zero frequency, an auxiliary regression of Δu_t on u_{t-1} is performed, which may or may not include deterministic components and is supplemented with the necessary lagged values of Δu_t . The critical values are found in Engle and Granger (1987) and in Engle and Yoo (1987). A similar procedure is followed when testing for noncointegration at the biannual frequency $\frac{1}{2}$, but the auxiliary regression is of $(v_t + v_{t-1})$ on $-v_{t-1}$.

For frequencies $\frac{1}{4}$ and $\frac{3}{4}$, the noncointegration tests are defined in Engle *et al.* (1993), nevertheless for this paper, we will concentrate on frequencies 0 and $\frac{1}{2}$.

3.3.3. Seasonal Error Correction Model

If cointegration is detected at each frequency, a Seasonal Error Correction Model (SECM) can be estimated. The SECM specifically incorporates the cointegration constraint at both zero and seasonal frequencies. Since time series data may exhibit poles at various points on the unit circle, multiple cointegration scenarios can arise (Hylleberg *et al.*, 1990).

Seasonal error correction terms, obtained from the first stage, are lagged one-quarter period and substituted as explanatory variables in the SECM, as in equation (25).

$$\Delta_4 y_t = \sum_{j=1}^q \partial_j \Delta_4 x_{t-j} + \sum_{i=1}^p \beta_i \Delta_4 y_{t-i} + \gamma_{11} u_{t-1} + \gamma_{12} v_{t-1} + \gamma_{13} \omega_{t-1} \quad (25)$$

Where $\Delta_4 = (1 - B^4)$

We interpreted the coefficients of the seasonal error correction terms as the speed of adjustment at which the dependent variable corrects the short-term deviation. What makes SECM an interesting analysis framework is the separation between long- and short-term parameters, thereby facilitating a more precise evaluation of both the long-term and seasonal implications of a given theory and the dynamic processes involved.

4. Results

The methodological approach adopted in this study involved gathering quantitative data on waste production (including municipal solid waste, paper, plastic, and glass) and tourism-related indicators (such as the number of guests and overnight stays) on São Miguel Island. This data was then subjected to an analysis of seasonal cointegration, as outlined in Section 3.3. The cointegration analysis was applied using the STATA program proposed by Depalo (2009), which is based on the method of Engle and Granger (1987), adapted to the case of seasonality by Engle *et al.* (1993). Before proceeding with the cointegration tests, the stationarity of the series was tested through the seasonal unit roots test. The *sroot* command for Stata proposed by Depalo (2009) produces results similar to the method proposed by Hylleberg *et al.* (1990), additionally allowing the performance of cointegration tests through the transformed variables.

Tables 1 and 2 illustrate the results of the seasonal unit root test for a significance level of 5%, concluding that, for all series, except the one for paper and plastic, the null hypothesis of unit root is not rejected. The paper and plastic series is only stationary at frequency 0 (non-seasonal). For the remaining series and according to the t-tests, the unit root hypothesis is not rejected at frequency 0 or at frequency 1/2 (seasonal frequency corresponding to 1 semester).

Table 1. Seasonal unit root test (*Sroot*) for waste related variables

	ln(MSW)		ln(paper and Plastic)		ln(Glass)		ln(Other MSW)	
	Test Statistics	Critical value 5%	Test Statistics	Critical value 5%	Test Statistics	Critical value 5%	Test Statistics	Critical value 5%
Z(t) Frequency 0	-0,112	-3.710	-1.432	-2.960	-1.481	-2.960	-2.009	-3.710
Z(t) Frequency 1/2	-0,431	-3.080	-1.996*	-1.950	-0.595	-1.950	0.940	-3.080
Z(t) Annual Lag	-0,809	-3.660	-3.427*	-1.900	-0.554	-1.900	-0.485	-3.660
Z(t) Annual	-0,432	-1.910	-1.736*	-1.720	-0.320	-1.720	-1.068	-1.910
Joint Annual Sig.	0,427	6.550	10.210*	3.040	0.208	3.040	0.695	6.550
Seasonal Frequencies Sig.	0,344	6.090	9.452*	2.630	0.251	2.630	0.809	6.090
Total Frequencies Sig.	0,258	6.530	10.998*	3.470	0.732	3.470	1.721	6.530

* The null hypothesis is rejected at a significance level of 5%.

Table 2. Seasonal unit root test (*Sroot*) for tourism-related variables

	ln(Guests)		ln(Overnight Stays)	
	Test Statistics	Critical value 5%	Test Statistics	Critical value 5%
Z(t) Frequency 0	-0.196	-2.960	-0.284	-2.960
Z(t) Frequency 1/2	-0.895	-1.950	-1.030	-1.950
Z(t) Annual Lag	-0.996	-1.900	-0.982	-1.900
Z(t) Annual	-0.689	-1.720	-0.450	-1.720
Joint Annual Sig.	0.735	3.040	0.584	3.040
Seasonal Frequencies Sig.	0.754	2.630	0.751	2.630
Total Frequencies Sig.	0.574	3.470	0.578	3.470

* The null hypothesis is rejected at a significance level of 5%.

As noted by Depalo (2009), the results are contingent upon the joint significance of the parameters. In this study, the joint significance supports the previously mentioned findings, with the null hypothesis of unit roots not being rejected for the annual, seasonal, and total frequencies (both seasonal and non-seasonal), except in the case of the paper and plastic series.

The cointegration test proposed by Depalo (2009) was carried and the results are included in Table 3 for the case of guests and in Table 4 for overnight stays. The method consists of transforming the non-stationary variables (removing the effect of unit roots) and studying the autoregressive vector of these components. Thus, and for the long-term frequency, the unitary roots relative to the various semesters are removed, through the semiannual differentiation, leaving only the one concerning the long-term trend. For the semester frequency, the long-term trend is removed, differentiating the initial values of the series, thus leaving only the effect of seasonal unit roots.

In the cointegration test outlined by Depalo (2009), the unit roots test is applied to the residuals obtained from regressions involving the transformed variables. When the null hypothesis is rejected, it is concluded that the residuals are stationary, indicating that the series are cointegrated. In this study, we conducted tests for seasonal cointegration between variables at the zero frequency (long-term) using u_t residuals, and 1/2 (semester) using v_t residuals.

In Tables 3 and 4, we observe that, although it is not possible to conclude for the cointegration at frequency 0, as for the seasonal frequency (1/2), the series follow each other in the long run. This means that, in semesters with greater tourism, the production of MSW and glass will be greater. In the case of paper and plastic, no conclusions can be drawn, since the series does not have the same order of integration as the series related to tourism.

Cointegration at the long-term frequency suggests that the nonstationary series exhibit a consistent, parallel trend over time. Cointegration at the long-term frequency suggests that the nonstationary series exhibit a consistent, parallel trend over time. Cointegration at a specific seasonal frequency, on the other hand, indicates that the seasonal components of the two series move in a synchronized manner during the relevant seasonal periods.

Table 3. Cointegration test for the number of guests

ln(Guests)	ln(MSW)		ln(Glass)		ln(other MSW)		Critical Value 5%
	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	
Z(t) Frequency 0	-1.921	-0.870	-1.208	-1.615	-2.479	-1.803	-2.960
Z(t) Frequency 1/2	-2.071*	-0.905	-2.164*	-1.033	-3.099*	-1.201	-1.950
Z(t) Annual Lag	-3.002*	-3.362*	0.408	-2.323*	-3.106*	-2.852*	-1.900
Z(t) Annual	-3.082*	1.127	-3.386*	-1.867*	-2.393*	1.123	-1.720
Joint Annual Sig.	14.990*	6.839*	6.002*	5.855*	11.540*	5.300*	3.040
Seasonal Frequencies Sig.	24.002*	4.838*	8.956*	4.922*	30.865*	3.949*	2.630
Total Frequencies Sig.	19.811*	3.974*	8.655*	4.846*	28.737*	4.253*	3.470

* The null hypothesis is rejected at a significance level of 5%.

Table 4. Cointegration test for the number of overnight stays

ln(Overnight Stays)	ln(MSW)		ln(Glass)		ln(Other MSW)		Critical Value 5%
	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	Long Term Frequency Test Statistics	Semester Frequency Test Statistics	
Z(t) Frequency 0	-1.990	-0.954	-1.170	-1.623	-2.481	-1.771	-2.960
Z(t) Frequency 1/2	-2.047*	-0.689*	-2.181*	-1.085	-3.039*	-1.082	-1.950
Z(t) Annual Lag	-3.104*	-2.865*	0.408	-2.011*	-3.040*	-2.613*	-1.900
Z(t) Annual	-3.062*	1.141	-3.403*	-1.547	-2.445*	1.359	-1.720
Joint Annual Sig.	15.582*	5.221*	6.058*	3.900*	11.388*	4.972*	3.040
Seasonal Frequencies Sig.	24.403*	3.622*	9.186*	3.420*	29.927*	3.634*	2.630
Total Frequencies Sig.	20.103*	3.124	8.755*	3.618*	27.796*	4.086*	3.470*

* The null hypothesis is rejected at a significance level of 5%.

Table 5 shows the results of the four Seasonal Error Correction Models (SECM) related to MSW and glass with number of guests and overnight stays. The estimated models are of the general form:

$$\Delta_4 y_t = \Delta_4 x_{t-1} + \gamma_{11} u_{t-1} + \gamma_{12} v_{t-1}$$

Seasonal error correction terms, obtained from the first stage of the two step-procedures from Engle *et al.* (1993), are lagged one-quarter period and substituted as explanatory variables in the SECM.

Table 5. Seasonal error correction model (SECM)

Model	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	$\Delta_4 \ln(\text{MSW})_t$	$\Delta_4 \ln(\text{MSW})_t$	$\Delta_4 \ln(\text{Glass})_t$	$\Delta_4 \ln(\text{Glass})_t$	$\Delta_4 \ln(\text{other MSW})_t$	$\Delta_4 \ln(\text{other MSW})_t$
Constant	-0.00113059* (-4.37)	-0.0017647* (-3.99)	-0.0032298* (-4.11)	-0.0038132* (-3.92)	-0.0040928* (-4.62)	-0.0043231* (-3.99)
$\Delta_4 \ln(\text{Guests})_{t-1}$	-0.0094899* (-2.32)		-0.0174935 (-1.67)		-0.0317504* (-2.59)	
$\Delta_4 \ln(\text{Overnight Stays})_{t-1}$		-0.0113231* (-2.65)		-0.0197654* (-2.08)		-0.0310611* (-2.91)
$\Delta_4 \ln(\text{MSW})_{t-1}$	0.0086093 (1.19)	0.0104402 (0.99)				
$\Delta_4 \ln(\text{Glass})_{t-1}$			-0.0123901 (-1.57)	-0.0168549 (-1.68)		
$\Delta_4 \ln(\text{other MSW})_{t-1}$					0.0239624 (1.31)	0.0222366 (1.01)
$u1_{t-1}$	0.9806779* (117.73)					
$v1_{t-1}$	0.0033047 (0.75)					
$u2_{t-1}$		0.9769655* (80.59)				
$v2_{t-1}$		0.0035938 (0.64)				
$u3_{t-1}$			1.004987* (178.39)			
$v3_{t-1}$			0.0008455 (0.22)			
$u4_{t-1}$				1.004056* (146.03)		
$v4_{t-1}$				0.0015688 (0.35)		
$u5_{t-1}$					0.9573831* (54.89)	
$v5_{t-1}$					0.0122883 (1.01)	
$u6_{t-1}$						0.9637194* (45.04)
$v6_{t-1}$						.014659 (1.14)
N	33	33	33	33	39	39
F	5741.56	2608.10	9126.41	5967.67	1114.40	742.00
Prob > F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R Square	0.9988	0.9973	0.9992	0.9988	0.9924	0.9887

* The null hypothesis is rejected at a 5% significance level; ** The null hypothesis is rejected at a 10% significance level

In all models, the t-statistics for the error correction term associated with the first frequency were found to be statistically significant. The positive values of the adjustment speeds suggest that the system will progressively move away from equilibrium. Furthermore, the inclusion of lagged values of the explanatory variables was significant across all models, indicating that short-term dynamics are present in each case.

It is safe to conclude that tourism variation contributes to a significant variation in the production of waste in São Miguel Island for the third quarter of each year, because the greater tourism inflow during this time window increases the production of MSW and glass waste.

In practical terms, during the years under study, local municipalities did not adopt a strategy to update waste collection teams or adjust the frequency of waste disposal, despite the increase in tourist numbers and the demonstrated connection between tourism and waste generation. Nevertheless, in 2015, the municipalities of Ribeira Grande, Vila Franca do Campo, and Lagoa revised their operational strategies for waste collection with the goal of increasing recycling by implementing selective collection circuits and, simultaneously, by decreasing the weekly MSW collection. The municipality of Ponta Delgada as well as the municipality of Nordeste had already implemented this work method in 2010.

Moreover, the Strategic Program of Prevention and Management Waste from the Azores (PEPGRA), promoted by MUSAMI, presents practical solutions to the issue concerning treatment of the waste produced on São Miguel Island. These treatments take place in the sorting center, energetic recovery plant, and organic recovery center by compost, facilitating the continuous treatment of long-term residues. However, amongst these three infrastructures, only the sorting center and the organic recovery center by compost of garden and green residues are operating. The waste including glass, paper, and plastic are forwarded for recovery (recycling) to mainland Portugal. Contribution to the energetic recovery plant and organic recovery center by compost are still not an option for MSW and organic residues treatment, respectively (the organic residues correspond to the organic fraction that will be selectively collected and that is presently included in the MSW). Once implemented, these infrastructures will allow São Miguel Island to accommodate MSW continuously. Nowadays, MSW is sent to landfill. This method is presented as a short-term solution, bearing in mind the limited area available on an island and the impossibility of starting new landfills.

Given that the MUSAMI energy recovery plant has no established construction timeline, coupled with the fact that the currently used landfill, designed with a 20-year lifespan, is nearing capacity (yet has not yet reached 50% of its projected operational life), and recognizing that waste production is closely tied to tourism during the peak season, it is crucial to monitor and forecast the future trajectory of tourism on São Miguel Island. It is equally important to implement short- and medium-term strategies that effectively minimize the impacts of waste generation, particularly municipal solid waste (MSW).

5. Discussion

This study reinforces the existing evidence on the persistent relationship between tourism activity and waste generation, particularly in ecologically sensitive island contexts. In São Miguel, the observed seasonal cointegration between tourist inflows and the production of municipal solid waste and glass waste is consistent with findings from comparable regions such as Menorca (Mateu-Sbert *et al.*, 2013) and Tenerife (Díaz-Fariña *et al.*, 2020). These results further support the argument that seasonal tourism intensifies environmental pressures, in line with the conclusions drawn by Caponi (2022). Beyond reinforcing empirical evidence, our study contributes methodologically to literature by applying a seasonal cointegration framework.

The results further frame the Environmental Kuznets Curve (EKC) hypothesis, as the persistent positive association between tourism inflows and waste generation suggests that São Miguel Island remains in the initial “scale effect” phase, where economic growth contributes to environmental degradation. Although the findings do not explicitly fit a non-linear EKC model, the evidence highlights the urgent need to promote a transition toward the ‘technique effect’ phase, characterized by the adoption of cleaner technologies and more sustainable practices.

From a policy perspective, the findings emphasize the need for waste management strategies that are responsive to tourism seasonality. The development of forecasting tools could assist local authorities in anticipating peak periods, adjusting collection frequencies, allocating resources more efficiently, and preventing system overloads. Furthermore, economic instruments such as eco-taxes or environmental levies — as successfully implemented in Madeira and the Balearic Islands — could provide sustainable funding mechanisms without significantly discouraging tourist arrivals.

From the perspective of the private sector, enterprises such as hotels, restaurants, and tour operators are encouraged to place greater emphasis on strengthening recycling systems, reducing the use of disposable materials, and encouraging more sustainable behaviors among tourists, particularly during peak seasons. Moreover, the development of collaborative awareness campaigns, involving partnerships

between municipalities, businesses, and tourism boards, could help reinforce these efforts and contribute to the promotion of a culture of environmental responsibility.

Summing up, the empirical analysis, methodological innovation, and practical recommendations, of this study provides evidence of the relationship between tourism activity and waste generation and outlines strategic approaches to promote sustainability in destinations marked by significant tourism seasonality.

6. Conclusions

This study examined the relationship between tourism inflows and waste generation on São Miguel Island using a seasonal cointegration approach. The results reveal a sustained seasonal connection between tourism indicators (number of guests and overnight stays) and the production of municipal solid waste (MSW) and glass. This suggests that tourism seasonality is a key driver of fluctuations in specific waste streams. However, no long-term relationship was found between tourism activity and the production of paper and plastic waste, possibly due to the absence of consistent waste separation practices and the differing integration orders of the respective time series.

Seasonal cointegration models, by estimating both long-term relationships and short-term dynamics, provide important advantages for assessing the environmental impacts of tourism in sensitive regions. This approach proves to be particularly valuable for small island destinations, where ecological vulnerabilities amplify the pressures associated with seasonal tourism peaks.

Based on these findings, several practical recommendations can be made. For instance, municipal waste management authorities should adopt seasonal forecasting tools to anticipate waste peaks and adjust collection frequency, manpower allocation, and infrastructure needs accordingly. Local governments can promote short-term behavioral changes among tourists by providing clear and accessible information on waste separation practices.

Moreover, public tourism agencies and tourism industry associations should collaborate with all types of tourism service providers to encourage environmentally responsible practices and behaviors, particularly during the high season. Seasonal cointegration models, such as the one applied in this study, can serve as valuable tools for anticipating pressure on waste systems and for improving the sustainability of tourism planning in environmentally sensitive insular regions.

7. Limitations

This study presents some limitations at different levels. Firstly, the geographical context is limited to São Miguel Island where the tourism industry plays a significant role. This specificity may limit the generalization of the findings to other contexts, particularly mainland or urban environments. Secondly, the analysis depends on the availability of aggregated municipal data, which does not allow for disaggregation by specific waste generators (e.g., hotels vs. households). Thirdly, the cointegration models used in the study included only two indicators of tourism activity: number of guests and overnight stays. Although widely used in the literature, the inclusion of additional variables such as tourist expenditure could improve the robustness of the findings. Finally, the absence of data beyond 2019, due to COVID-related disruptions, prevented the inclusion of more recent observations that might influence the current dynamics of waste generation.

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