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# The economic impact of the inoperability of the airport at a small-island tourism destination: The case of Madeira

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ABSTRACT

Climate change means that tourism on small islands is increasingly vulnerable to the disruptive effects of adverse weather conditions. Many small islands rely upon a single airport, so when weather conditions cause inbound flights to be delayed, diverted, or even cancelled, this will tend to reduce tourists' length of stay. There may also be longer-term damage to the destination's image in terms of transport reliability. This paper sets out to estimate the economic impact of weather-related flight delays and cancellations at a small-island tourism destination. Using Madeira as an example, a two-stage estimation approach was developed using both primary and secondary data. Based on the premise that around 1% of tourists are affected by delays that result in shorter stays, several scenarios were developed and estimates of their economic impacts computed. The results suggest that while the short-term economic impact may be relatively small, the longer-term effects may be more substantial.

## 1. Introduction

Adverse weather conditions, including heavy precipitation, air turbulence and wind shear, represent a major challenge to the tourism industry. This is because they can pose serious safety hazards for air traffic, requiring airports to delay, divert, or even cancel flights (Monioudi et al., 2018; Pagán-Trinidad et al., 2019; Najafi et al., 2021). While there are no statistics available on the number of disruptions to air traffic caused exclusively by adverse weather conditions, it is estimated that some 2.4 million flights across Europe are delayed or cancelled every year due to poor weather, air-traffic control disruptions, or delays caused by the airlines themselves (Wu et al., 2018; EUROCONTROL, 2022).

In addition to the reduction in revenue due to tourists arriving late and having less time to spend at the destination, travel disruptions have the potential to cause reputational damage to the destination. A favourable image is widely considered to be a key asset for any destination (Mair et al., 2016; Brown et al., 2021; Baños-Pino et al., 2023). Media coverage of passengers facing substantial travel delays, having their flights cancelled, or being diverted to other airports, can damage the destination's image (Day et al., 2013; León et al., 2021). Destination marketing organisations (DMOs) therefore often prioritise their public-relations expenditure on managing such events when they occur (León et a, 2021). Tourists affected by the travel disruptions may also receive a negative impression of the destination. Travel disruptions can detract from tourists' overall satisfaction with the stay, resulting in less-positive word of mouth recommendations and a reduction in revisit intentions. The result of these effects is likely to be a loss of competitiveness for the destination (Becken and Wilson, 2013; Štumpf et al., 2022).

Many tourism destinations are expected to experience an increased frequency and intensity of adverse weather conditions due to climate change (Bujosa and Rosseló, 2013; ACI, 2018; Burbidge et al., 2023). Small-island destinations can be especially vulnerable to such weather events because their economies tend to be highly dependent on international tourism (León et al., 2021). They also rely upon airports to provide the critical connectivity needed to facilitate tourism (Böcker et al., 2013). As such, adverse weather conditions are likely to have significant negative economic impacts on small-island tourism destinations (Burbidge et al., 2023). Knowledge of the effect of such events on patterns of tourism demand, and the economic impacts associated with these, would enable the relevant authorities to assess how much should be spent on mitigation measures, as well as the amounts of financial resources that need to be allocated to destination marketing and public relations (ICAO, 2021; ACI, 2018; Burbidge et al., 2023; Voskaki et al., 2023).

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While the literature provides many studies on the topics of airport efficiency (Ball et al., 2010; ACI, 2018; ICAO, 2021; Pagliara and Zingone, 2023) and operational recovery (Arreeras and Arimura, 2022; Lindbergh et al., 2022; Liu et al., 2022), there is a scarcity of research on both the short-term and long-term economic impacts of travel disruptions (Brown et al., 2021). Research on tourists' attitudes on transport disruptions and mitigation efforts on the part of tourism authorities is also scarce (Voltes-Dorta et al., 2017; Suau-Sanchez and Voltes-Dorta, 2019; Bangwayo-Skeete and Skeete, 2021). The purpose of this paper is to investigate the incidence and implications of weather-related travel disruptions. This will entail estimating the economic impact of disruptive weather on the tourism economy of Madeira, a small-island destination with a mature tourism industry that attracts around two million tourists per year (DRE, 2023).

The remainder of this paper is, therefore, organised as follows. The following section provides an overview of the challenges faced by Madeira as a weather-dependent tourism destination. The third section then reviews the literature, the aim being to shed light on the interrelationship of weather conditions, air travel, and passengers' attitudes. The fourth section describes the methodology and methods used to estimate the impacts of weather-based travel disruptions on Madeira's tourism economy, while the fifth presents a discussion of the results of the analysis conducted in this study. The closing section then presents the conclusions of the study and offers some recommendations for how destinations can best manage the effects of adverse weather. The conclusions are highly relevant to DMOs of destinations that are highly dependent on air travel and follow a tourism-led growth strategy, meaning that they are especially vulnerable to episodes of disruptive weather.

## 2. Context

The focus of this study is on Madeira, an autonomous region of Portugal comprising the main island of Madeira, where the region's principal international airport is situated, and various outlying islands such as Porto Santo and Desertas. Located in the mid-Atlantic, tourism has traditionally been a major engine of economic growth for Madeira, which has built its international reputation as an up-market destination on its warm climate throughout the year, pristine natural environment, opportunities for outdoor activities, high-quality accommodation, and ability to project an image of personal safety for tourists in a relatively exotic setting (Almeida and Garrod, 2018, 2021). Passenger numbers to Madeira are rising, the average annual rate of growth in the period 2010 to 2023 being 5.5%.

Madeira's airport has a relatively poor reputation regarding flight delays and cancellations, with negative incidents featuring in the news media on a regular basis. Despite the extension of the runway at the turn of the century, airport operations are still heavily constrained by weather conditions, especially high winds. Data show a sharp increase in the number of non-operational days related to high winds between 2014 and 2018. According to the Portuguese Institute of the Sea and the Atmosphere, no clear pattern emerges from the data, either on a daily or monthly basis (Belo-Pereira and Santos, 2020; Miranda et al., 2021).

With the aim of preventing accidents, the airport authority has issued special procedures and operational limitations in the event of high winds. Because of the unpredictability of adverse weather events, the airport monitors conditions in real time. Landing is prohibited when a windspeed of 18 knots is exceeded (Belo-Pereira and Santos, 2020; Miranda et al., 2021). Affected flights may be cancelled or, if they are already in transit, diverted to other airports (such as the Canary Islands or Lisbon). If it is not possible to divert any such flights, all aircraft approaching the airport are instructed to wait in a predictable circular flight path between Porto Santo and Madeira until there is a window of slower winds in which to achieve a safe landing (Stewart et al., 1995).

The Madeira Airport Authority is currently attempting to acquire new radar technology to obtain more accurate weather forecasts. The regional government has also been trying to increase the 18-knot windspeed ceiling, based on more up-to-date data and analytical techniques (Diário de Notícias, 2023; Dinheiro Vivo, 2023). In the meantime, it falls upon the DMO to deal with any emerging problems through the application of public-relations and service-recovery initiatives (Mair et al., 2016).

Data provided by the Airport Authority for the period 2010 to 2023 suggests the average number of passengers affected by adverse weather to be around 5700 per month (i.e., 70,000 a year). This is a substantial number, even for a mature tourism destination such as Madeira. Of even greater concern, however, is that the data show a 13.6% annual growth rate in the number of passengers affected. The data also show periods with sharp increases both in the number of passengers affected (Fig. 1) and the number of hours of unserviceability (Fig. 2). A cyclical and volatile pattern can be seen. The number of passengers affected saw a fourfold increase, at certain points of time, in the period after 2016. The increase in the number of hours of unserviceability is less pronounced. The higher number of passengers involved nevertheless implies that even modest increases in the number of interruptions may have far-reaching effects. The monthly average of passengers affected was 2671 over the 2010–2015 period, while the corresponding figure for the 2016–2019 period is 8935. The Covid-19 period altered the dynamics of in terms of passengers, but not in terms of the number of episodes of disruptive weather. This period is characterised by a sharp decline in the number of landings (−53.6%), and passengers (−65.1%). While the number of hours of unserviceability is in line with the cyclic and random pattern observed for the whole period, the period from September 2020 to May 2021 shows an above-average number of disruptions. The number of passengers affected is reduced mainly due to the reduced number of flights.

The present study assumes that the impact of the number of cancellations and delays increases with the number of flights and passengers going through the airport. The study also assumes that flight disruption is primarily due to the incidence of strong wind (Belo-Pereira and Santos, 2020). Indeed, Belo-Pereira and Santos (2020), Mazon et al. (2018), Gultepe et al. (2019), Clark et al. (2000), Sharman et al. (2012) and Parker and Lane (2013) all highlight the critical importance of wind as the principal cause of flight disruptions worldwide.

Following a simple estimation based on the equation $\ln Pax = f(\ln Hours; \ln Arrivals)$, with lnPax standing for the log of the number of passengers affected, lnHours standing for the log hours of unserviceability and lnArrivals standing for the log number of Arrivals, it was concluded that a 1% increase in the number of passengers resulted in a 2.08% increase in the number of passengers affected. The corresponding figure for the impact of a 1% increase in the number of hours of flight disruption was 1.33%. However, the beta coefficients suggest that the effect of disruption (0.6229) is greater than that of growth in passenger numbers (0.3079). This implies that around two thirds of the growth in the number of passengers affected was the result of flight disruption while around one third resulted from the overall growth in passenger numbers.

## 3. Literature review

A substantial literature exists on the impact of the weather conditions at a destination on tourists' satisfaction (Becken and Wilson, 2013; Hewer et al., 2015; Jarvis et al., 2016; Steiger et al., 2016; Giddy et al., 2017; Jeuring, 2017; Lam-González et al., 2019; Vojtko et al., 2020). Tourists tend to prefer destinations with weather conditions that are predictable and comfortable from a physiological, physical, and psychological point of view (Martín, 2005; Kim et al., 2017). Tourists tend, of course, to book their travel some time in advance, so they will usually base their decisions on expected rather than actual weather conditions (Bujosa and Rosselló, 2013; Hewer et al., 2016; Falk and Lin, 2018; Muñoz et al., 2023). Such expectations are, of course, determined largely by climate records and long-range weather forecasts (Kim et al.,

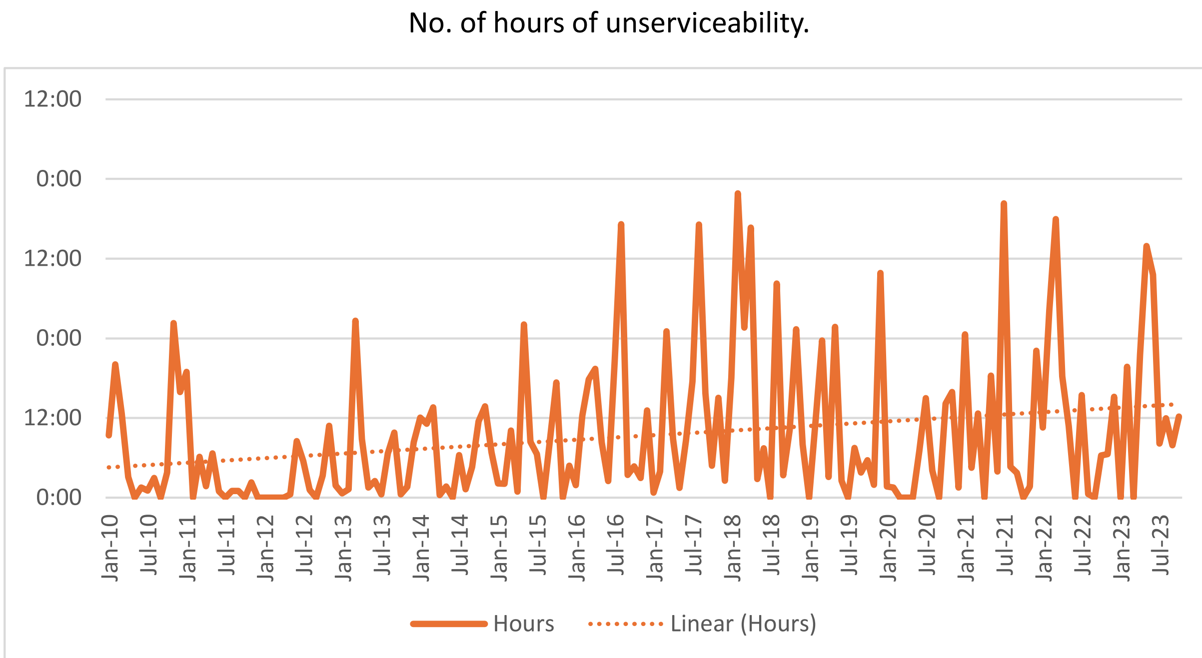


**Fig. 1.** No. of hours of unserviceability.

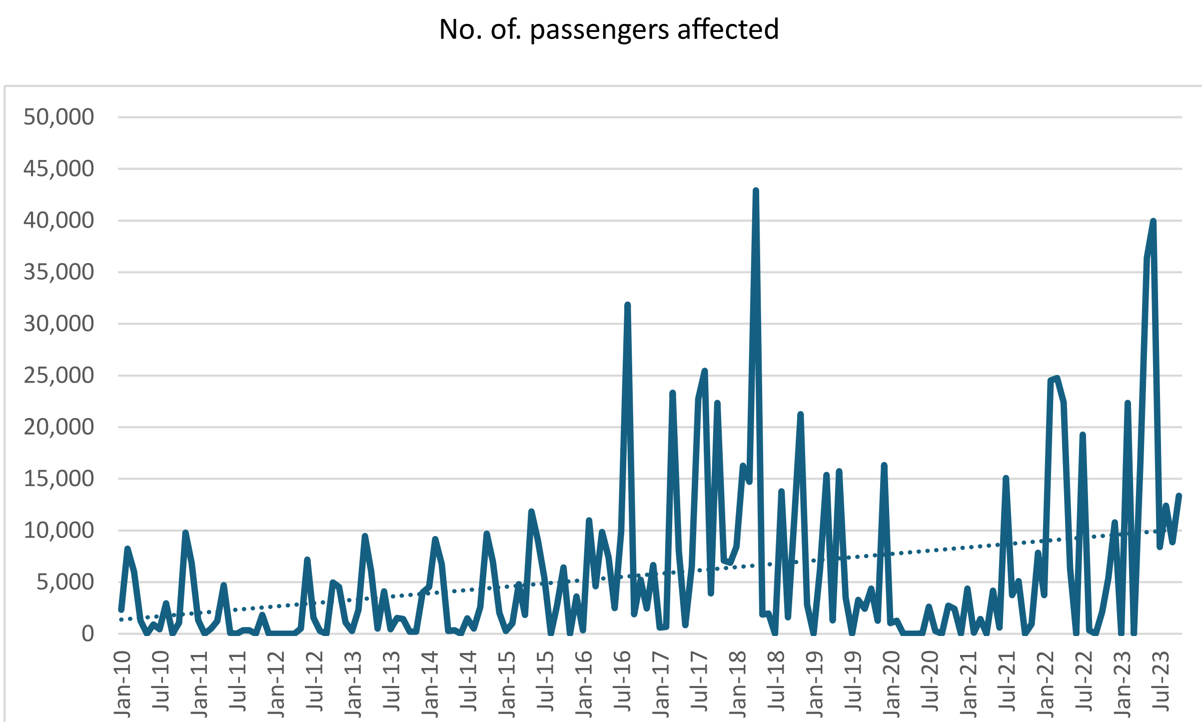


**Fig. 2.** No. of passengers affected.

2017).

Weather patterns are expected to be increasingly affected by climate change, and the literature makes it clear that the effects will vary by location. Some are expected to see a significant increase in the frequency and/or intensity of wind, while others are expected to see a decrease (IPCC et al., 2021). Some locations will see increased and less predictable precipitation, while others will see the opposite (Rocha et al., 2020). Meanwhile, it is expected than some regions will see a greater incidence of more powerful convective storms (Burbidge et al., 2023). Such weather events will can be expected to translate not only into physical damage to airport infrastructure but also into more travel disruption due to delayed, diverted, and cancelled flights (Pejovic et al., 2009; Lopez, 2016; Monioudi et al., 2018; Vogiatzis et al., 2021). As mentioned by Kim et al. (2017, p.898), in most instances "tourists can address or avoid adverse actual weather conditions by making schedule adjustments and changing activities or itineraries". Such adjustment and changes will, however, have implications for the economic impact of the tourism activity that results. For example, a shortened length of stay is likely to result in lower tourist spending in the destination.

Kim et al. (2017) argue that DMOs must pay close attention to the effect of disruptive weather on tourists' perceptions of the destination image. This is because tourists tend to base their decision making on their holistic perceptions of the quality of the destination compared to the conditions they actually experience (Mair et al., 2016), the extent of changes imposed by adverse weather on their planned itineraries, and any initiatives implemented by the DMO to try to mitigate such impacts (Denstadli et al., 2011; Becken and Wilson, 2013; McKercher et al., 2014). Any such initiatives will need to be adaptive of they are to be effective, particularly in the face of continued climate change (León et al., 2021). Climate change implies that cancellations will become the new normal, and changed travel plans routine experiences (Scott et al., 2004; Amelung and Viner, 2006; Dubois and Ceron, 2006; Moreno and Amelung, 2009; Weaver, 2011).

While the literature notes the possibility of negative economic impacts related to weather-related travel disruption, there has thus far been no study which attempts to identify the scale of such impacts in either the short-run (related to reduced time in the destination) or the long-run (due to reputational damage to the destination image). The purpose of this study is to undertake such an exercise in the case of Madeira.

## 4. Methodology

This study aims to estimate the short- and longer-term economic impacts of disruptive weather through flight delays, diversions, and cancellations. As no agreed methodology exists to determine the economic impact of episodes of adverse weather on an entire destination, and data protection regulations restrict public access to key documents and datasets, an indirect methodology was employed. The method comprised three stages and was based on the use of both primary and secondary data.

Table 1 summarises the main assumptions retained in this study with a view of highlighting the plausibility and soundness of the main line of reasoning and the necessity of a relatively complex and time-consuming approach.

The first stage involved the estimation of the relationship between the monthly number of days and passengers affected by disruptive weather conditions (measured in hours), with the latter in turn explained by meteorology-related variables (maximum speed of gust of winds). A system of three structural equations, where two contain endogenous variables among their explanatory variables, was estimated using three-stage least squares regression. The variables 'total number of passengers', 'time' (in linear, quadratic and cubic formats), and 'average wind speed' (at the airport) were classified as exogenous, while the variables number of passengers affected by cancelations and delays, the total number of hours of unserviceability at the airport and maximum windspeed of gusts were defined as endogenous. The first two endogenous variables play a key role in defining the overall impact of the episodes of disruptive weather. The number of passengers impacted is defined by the number of hours with records of cancelled or delayed flights. The degree of correlation measured by the Spearman coefficient was high ($\chi = 0.8233$; sig $= 0.000$), which suggests, in line with expectations, that a statistically significant relationship exists between the number of passengers affected and the degree of disruption experienced in terms of air traffic control operations. The data used in this exercise cover the period from January 2010 to October 2023.

The purpose of the second stage was to determine the short-term impact on GDP and employment through the loss of overnight stays. A simple cointegration analysis was used, involving the estimation of the spending generated by each additional overnight stay. This was then used to estimate the economic loss to the destination related to each reservation cancelled. In line with previous studies (Comerio and Strozzi, 2019; Kumar et al., 2022), other relevant covariates were included to enhance the econometric model. The data used for this purpose covered the period 1978 to 2019 and were obtained from Madeira's statistical office. The functional form for the OLS estimation was:

**Table 1**
Main hypothesis by table.

| Hypothesis | References employed to sustain the hypothesis |
|---|---|
| Table 2 makes the (technical) assumption that the number of passengers affected by disruptive weather is defined by the number of hours of unserviceability; disruptive weather is linked (technically and legally) to strong winds, as landings are prohibited for wind speed over 18 knots. Consequently, based on the available data on meteorologic indicators, the number of hours of unserviceability is linked to the maximum figures for wind speed recorded in each month; it sounds logical and plausible that the higher the figures for the wind speed, the higher the probability of 'disruptive weather'. Moreover, a visual inspection of the data indicates a growing trend, which suggests the inclusion of time trend, to take account of the most recent research of climate change | Belo-Pereira and Santos (2020); Voskaki et al. (2023); Mazon et al. (2018); Gultepe et al. (2019); Clark et al. (2000); Sharman et al. (2012); Parker and Lane (2013). |
| Table 3 displays official data and correlated figures from the Tourism Satellite Account (TSA) for Madeira. This, in conjunction with published data on GDP figures and number of guests and overnights, allows for the estimation of accurate figures on expenditures per guest and other indicators. Table 2 is based on official and internationally comparable data and subsequent calculations of simple indicators. | |
| Table 4 depicts the results of a simple econometric model, based on the Migration, Remittance, Aid, Bureaucracy (MIRAB) model, which assumes a 'special relationship' between the economy of an island (either an independent state or a sub-national island jurisdictions, e.g. Madeira, Azores, Canary Islands, American Samoa, Anguilla, Aruba, Bermuda, the British Virgin Islands) and the metropolitan patron (the former colonial power or the country of which the island is a territory). Most studies on small islands economies highlight the impact of the level of government expenditures fueled by access to official development aid (proxied by the variable government expenditure) and tourism development (proxied by the variables 'guest' and 'overnights.' The dynamics of the private sector are expressed in terms of the number of hotel establishments in operation. This basic macroeconomic model forms a sound the basis for the subsequent calculation of the impact of the losses in the number tourists and overnights on the GDP figures. | Bertram (2004); Garrod et al. (2023). |
| Table 5 is based on official data on the number of direct jobs in the tourism sector. Based on these figures and official figures on the taxation rates, it is possible to compute (albeit in a direct and linear fashion) the losses of jobs following a reduction in the number of overnights following disruptive weather. | |
| Table 6 combines inputs from the previous tables with some additional assumptions. The key assumption employed in this table concerns the figure of 1% for the passengers affected | Oliveira et al. (2023); Stone (2015) |

(continued on next page)

**Table 1** (*continued*)

| Hypothesis | References employed to sustain the hypothesis |
|---|---|
| by disruptive weather, which is close to the real number of passengers affected by disruptive weather (these figures have been made available by the airport but cannot be disclosed because of confidentiality reasons). The figure of 4.4% is based on a survey of 976 tourists undertaken in Madeira. This sample is large enough to offer a reliable measure of the passengers' preferences and likely behavior. Another plausible assumption relates to the loss of one day's duration of stay. In the case of Madeira, disruptive weather means circling around for one or 2 h, or redirecting the flight to an alternative airport, before landing the following day. The other calculations follow from these two assumptions. | |

$$GDPt = \alpha 0 + \alpha 1 GDPPt + \alpha 2 CEt + \alpha 3 Tt + \alpha 4 It\ \varepsilon t$$

where GDPt stands for the region's GDP at 2019 prices, GDPPt is the level of GDP in Portugal, CEt the level of public expenditure at 2019 prices, Tt the number of overnights stays, and It the volume of private investment (proxied by the number of new hotels), all at moment t. Meanwhile, εt represents the stochastic error.

Data relating to total GDP at constant prices and tourism sector dynamics (arrivals, overnights, expenditure, and direct employment) were provided by the Madeira statistical office. Once the coefficient of overnight stays (α3) was computed, the marginal impact on GDP of a 'standard' flight cancellation could be disaggregated by activities based in data provided by the Tourism Satellite Account (TSA) for the year 2019. The TSA provided data on the total amount of tourism expenditure, which was then used to calculate the average expenditure per tourist, the average spending by category of expenditure, and an estimate of the impact of the tourism sector on GDP. It also provided figures on the total number of employees in the tourism sector, which were used to estimate the impact of flight cancellations on direct employment.

The third stage covered the longer-term effect of the loss of competitiveness of the destination due to flight cancellations. Data were available from Madeira's Tourism Observatory (TO) on the number of repeat visits made by tourists to the island and on the number of passengers affected by disruptive weather, as well as their attitudes and likely behavior when faced with exceptional weather conditions leading to delays and cancellations. Simple extrapolation of these figures to the entire pool of tourists would be problematic for two main reasons. First, there is no guarantee that the sample used by the TO is representative of all tourists to Madeira because the data-collection process focused specifically on event attendees (and not all tourists attend events). Second, and perhaps more importantly, assumptions had to be made about the percentage of passengers affected, as well as the consequent impact on the average length of stay. While a general rising trend in the number of days adversely affected is clearly evident, the high level of monthly and annual variability suggests that episodes with significant increases in the number of cancelled flights tend to be followed by periods of calm.

Statistics regarding the numbers of flights cancelled and passengers affected were provided by the local airport authority. Based on these, a reduction in the total number of tourists overnights of 1% (which amounts to 15,909 passengers out of a total of 1,590,882 passengers in 2019) was used to parameterise the study. This estimate was corroborated by qualitative information on the incidence of cancellations experienced by local operators (such as travel agents and hotels) collected from the local news media. Moreover, this estimate is in the same order as the actual figures on the average number of the affected passengers. Such material also assisted the researchers in contextualising the study's main conclusions and recommendations.

## 5. Results and discussion

The model was estimated both in levels and in logarithm form. This involved a series of estimations, grounded on the literature, to try to identify the most workable model in terms of the econometric approach and available data.

A three-stage estimation for systems of simultaneous equations was employed. The reason for the inclusion of a cubic time trend lies is that a cubic format was identified through graphical inspection of the data. The system of three equations, which contained two endogenous variables among the explanatory variables, can be written as follows:

$$Pa = \alpha 0 + \alpha 1 {*} H + \alpha 2 {*} Pa + \varepsilon 1 \quad (1)$$

$$H = \alpha 3 + \alpha 4 {*} maxW + \varepsilon 2 \quad (2)$$

$$maxW = \alpha 5 + \alpha 6 {*} T + \alpha 7 {*} T2 + \alpha 8 {*} T3 + \alpha 9 {*} aveW + \varepsilon 3 \quad (3)$$

Based on the available literature, the number of hours of unserviceability tends to be related to the incidence of strong gusts of wind. The data series on the maximum speed of gusts of wind is related to the average speed of the wind and to a trend factor.

The results suggest that each extra hour of cancelled or disrupted activity at the airport affects 455 passengers (Table 2). The impact of the increasing trend of tourism activity on the island, proxied by the total number of passengers, suggests that each additional passenger results in an increase of 0.021 passengers being affected. The variable 'hours', meanwhile, is impacted the by the windspeed recorded in the airport area. This, in turn, is determined by the variable 'average wind speed' and by a general rising trend measured by the variable 'time'. The impact of gusts of wind on the disruption of airport activity is evident in the data: an increase of 1% in the maximum speed of gusts of wind leads to a 4.17% increase in volume of disrupted activity.

The next step was to examine the impact on GDP and employment. As shown in Table 3, data from the TSA suggest that each inbound tourist contributed 790€ per visit (or 155€ per night) in 2019. These figures take into consideration the number of tourists, number of overnights, average length of stay and GDP, and the total level of expenditure and GDP of the tourism sector. Each day lost away from the destination due to flight delays, diversions and cancellations can thus be expected to result in an economic loss (i.e. expenditure reduction) of around 155€ per tourist. These figures take only the direct and indirect rounds of expenditure into account. To get an overview of the total impact of each day lost (including the induced effect), further analysis would be required.

**Table 2**
Relationship between passenger flows and wind conditions.

| PAX | Level format | | Logarithm format | |
|---|---|---|---|---|
| | Coefficient | P > z | Coefficient | P > z |
| Hours | 455.027 | 0.000 | 1.478 | 0.000 |
| PassengersAirportMadeira | 0.021 | 0.000 | 1.311 | 0.000 |
| _cons | −3369.049 | 0.002 | −11.579 | 0.000 |
| Hours | | | | |
| Maxspeedgustwinds | 0.380 | 0.000 | 4.169 | 0.000 |
| _cons | −22,165 | 0.000 | −16.657 | 0.000 |
| Maxspeedgustwinds | | | | |
| Time | 1.875 | 0.001 | −5.224 | 0.000 |
| Time2 | −0.019 | 0.007 | 0.336 | 0.000 |
| Time3 | 0.000 | 0.023 | 0.000 | |
| Averagewindspeed | 2.219 | 0.000 | 0.415 | 0.000 |
| _cons | −1133.775 | 0.002 | 34.385 | 0.000 |
| Obs | RMSE | R-squared | RMSE | R-squared |
| lpax | 4116.023 | 0.696 | 2.352 | 0.448 |
| lHours_01 | 8.572 | 0.367 | 1.357 | 0.225 |
| lnmaxspeed ~ s | 12.904 | 0.456 | 0.146 | 0.508 |

**Table 3**
Data from the TSA 2019.

| Variable | | Unit | Year |
|---|---|---|---|
| Expenditure | 1257 | $10^6$ € | 2019 |
| GDP | 5126.4 | $10^6$ € | 2019 |
| GVA | 723.1 | $10^6$ € | 2019 |
| Guests | 1,590,882 | | 2019 |
| Overnights | 8,123,309 | | 2019 |
| Expenditure/GDP | 24.51 | % | 2019 |
| Expenditure per guest | 790.13 | € | 2019 |
| Expenditure per night | 154.74 | € | 2019 |
| Expenditure per guest per night | 154.62 | € | 2019 |
| GVA per guest | 454.53 | € | 2019 |
| GVA per night | 89.01 | € | 2019 |

Source: DREM (2019)

### *5.1. Short-term impact on GDP and employment*

The relationship between the tourism dynamics (proxied by the number of guests and overnights) and economic growth in Madeira was estimated using an OLS model with the functional form described above. While variables in such models are often transformed into natural logarithm format, as the coefficient on the natural-log specification is interpretable as an elasticity, this can hinder the interpretation of the results. The model used in this study was thus estimated in levels, which allowed a more understandable measure of the impact of each guest and overnight stay on the level of GDP to be presented in euros.

The empirical strategy proceeded as follows. In the first step, a unit root test was carried out to verify the stationarity of the various series under analysis. Three complementary unit root tests were conducted: the Augmented Dickey-Fuller test with a null hypothesis of non-stationarity, the PP test, and the KPSS test with a null hypothesis of stationarity. According to the results of the tests (results not shown in this paper) the time series are integrated processes of first order I(1) – the tests carried out point to stationary series with I(0) in their first differences – which confirms the appropriateness of the research methodology implemented in this study. In the second stage, the 'basic' model was estimated (shown in Table 4), This involved several iterations, with different variables and proxies, in order reach a 'cointegrated' solution.

The estimated model indicates that each extra guest increases the GDP by 1082€ (inclusive of all impacts), which compares well with the computed figure of 790€ based on the TSA. Each additional overnight stay, meanwhile, generates an increase in GDP of 169€, which is again in line with the estimate based on the TSA. Note that these figures need to be multiplied by a factor of $10^6$ so that they can be read in euro terms. The coefficients of the variables "financial transfers" and "GDP Portuguese economy" can be interpreted at face value, while the coefficient of the variable "private investment" implies that each new hotel establishment increases the local GDP by 6.15 million euros.

Table 5 provides the results for direct employment. Based the Statistical Office data for 2019, it can be concluded that the sector employs one staff member for every 204,979 guests, taking into account the figures of 7223 employees in hotel establishments payroll and the total of 1,590,882 guests. Each extra guest generates 0.002248 jobs in hotel establishments, i.e., 2.48 jobs for every 1000 additional guests. The values for overnight stays are 0.000509 (per overnight) and 0.51 (per 1000 overnights). Therefore, in the long term, every loss of 1000 overnights means an 'average' loss of around 0.5 jobs in hotel establishments.

The TSA (2019) however points to a total of 23,836 jobs related to tourism characteristics activities, which contrasts with the far lower figure of 7223 jobs directly associated with hotel establishments. Each job directly linked to the hotel establishment's payroll thus generates 3.3 jobs across the tourism sector. In total, then, each additional direct job (in the hotel establishments) corresponds to 2.3 additional indirect jobs across the tourism sector as a whole.

**Table 4**
Basic model of Madeira's tourism economy.

| Dependent variable: GDP at 2019 constant prices | Guests | | Overnights | |
|---|---|---|---|---|
| | Coef. | P > t | Coef. | P > t |
| It (Private Investment: Number of Hotel Establishments) | 6.152022 | 0.000 | 6.531622 | 0.000 |
| GDPP (GDP Portuguese Economy at constant prices) | 0.018037 | 0.000 | 0.000019 | 0.000 |
| Financial Transfers (Current Public Expenditure) | 0.547315 | 0.037 | 0.674849 | 0.013 |
| Touristic Demand (Number of Guests) | 0.001082 | 0.002 | | |
| Touristic Demand (Number of Overnights) | | | 0.000169 | 0.020 |
| _cons | −1759.63 | 0.000 | −1968.13 | 0.000 |

$R^2$ = 0.9889; F(4,37) = 826,93; Nobs = 42; Johansen test for co-integration: rank = 1; trace statistic:34,8370 (5% critical value 47.21).
$R^2$ = 0.9877; F(4,37) = 743.38; Nobs = 42; Johansen test for co-integration: rank = 1; trace statistic:38.8956 (5% critical value 47.21.

### *5.2. Longer-term impact associated with repeat visits*

Based on data obtained from a survey of 976 tourists undertaken by Madeira's TO, it is possible to make an estimate of the longer-term effects of flight delays, diversions, and cancellations. When asked about their reaction to a hypothetical scenario of a delay/diverged flight, 75.4% of respondents stated that they would still go through with their journey, while 20.2% said that they would probably consider other options, and 4.4% said they would definitively reverse their decision to travel to Madeira. In total, therefore, 24.6% of the respondents would consider different options, ranging from certainly not travelling to a 'wait-and-see' stance.

Table 6 summarises the results of the study. On the assumption that 1% of all passengers are impacted by disruptive weather in a typical year, the following conclusions can be drawn regarding the extension of the impacts of disruptive weather:

(1) Assuming that 4.4% of all those affected change their travel plans and do not complete their inbound journey (representing a lower limit of those who will not arrive), a loss of 0.757 million euros of GDP (4.4%*15,909*1082€) will occur. If 24.6% of the total number of tourists affected by the disruption change their travel plans and do not travel to Madeira, then a loss incurred in terms of GDP rises to 6352 million euros. This is, however, a highly unlikely figure, so further restrictive assumptions can be made as follows.
(2) Assuming those passengers affected by flight disruption who do complete their journey to the destination have their length of stay shortened by one day, GDP will be reduced by 2689 million euros (15,909*1*169€). If their length of stay is reduced by a further day, which is more likely, GDP would fall by twice this amount, i.e., a loss of 5377 million euros.
(3) The losses computed above are consistent with a reduction in the volume of employees in the hotel establishments payroll as follows: 5.2 jobs for a 4.4% dropout rate and 35.8 jobs for a 24.6% dropout rate, based on the previous assumptions and on the coefficients estimated above.

**Table 5**
Employment in the tourism sector.

| | |
|---|---|
| Employment Hotel Establishments = 3302.68 + 0.002248*Guests; | R2 = 0.8017; F = 174.23; Sig = 0.000 (2) |
| Employment Hotel Establishments = 2838.91 + 0.000509*Overnights | R2 = 0.7784; F = 170.05; Sig = 0.000 (3) |

**Table 6**
Basic calculations and estimates.

| | Indicator | Value 2019 | Value 2029 | Source |
|---|---|---|---|---|
| 1 | GDP (RAM; 2019) | 5,126,382,000 € | 6,662,113,671 | DREM |
| 2 | GVA (RAM; 2019) | 4,475,338,000 € | 5,800,189,444 | DREM |
| 3 | GVA (Tourism Sector; RAM; 2019) | 723,096,000 € | 982,399,348 | DREM |
| 4 | Total expenditure (Tourism; RAM; 2019) | 1,021,915,000 € | 1,713,313,276 | DREM |
| (4)/(1) | Total expenditure/ GDP | 19.9% | 25.7% | DREM |
| (3)/(2) | GVA (Tourism)/GVA | 16.2% | 16.9% | DREM |
| 5 | Arrivals (Guests) (RAM; 2019) | 1,590,882 | 2,468,228 | DREM |
| 6 | Overnights (RAM; 2019) | 8,123,309 | 11,494,207 | DREM |
| 7 | Average length of stay (RAM; 2019) | 5 | 5 | FREM |
| (3)/(5) | GVA (Tourism) per guest | 455 € | 398 € | * DREM |
| 8 | Estimate (%) passengers Impacted | 1.0% | 3.6% | ** |
| 9=(5)* (8) | Estimated (Quant.) passenger Impacted | 15,909 | 88,342 | * DREM |
| 10 | Average expenditure by guest - Econometric model | 1082 € | 1692 | * |
| 11 | Average daily expenditure - Econometric model | 169 € | 264 | * |
| 12 | Jobs by guest - Econometric model | 0.0022480 | 0.0022480 | * DREM |
| 13 | Jobs by overnight guest - Econometric model | 0.0022480 | 0.0022480 | * DREM |
| 14 | Ratio total jobs/direct jobs | 3.3 | 3.3 | TSA |
| 15 | Average social unemployment benefit, per unemployed | 2882 € | 3512 € | DREM |
| 16 | Average ratio of repeat visits | 45% | 45% | TO |
| 17 | Likely average number of passengers cancelling | 4.40% | 4.40% | TO |
| 18 | Likely number of passengers do not make a return visit | 24.60% | 24.60% | TO |
| 19 | Likely number of vacation days lost | 1 | 1 | ** |
| (20)= (9)* (10)* (17) | Decline in GDP linked to cancellations/ disruptive weather | 757,387 € | 6,578,820 € | * |
| (21)= (11)* (9) | Total loss of expenditure (vacation shortened by one day) | 2,688,591 € | 23,353,650 € | * |
| (22)= (3)/ (5)* (9)*17 | Decline in GVA linked to cancellations/ disruptive weather | 318,162 € | 1,547,120 € | * |
| (23)= (12)* (14)* (9)* (17) | Jobs lost linked to cancellations/ disruptive weather (G) | 5.19 | 28,84 | * |
| (24)= ((13)* (9)* (19) | Jobs lost linked to cancellations/ disruptive weather (O) | 35,763 | 198,593 | * |
| (25)= (12)* (4)* (15) | Extra unemployment benefits with jobs lost (O) | 14,965 € | 101,296 € | * |
| (26)= (21)/ (4) | % of expenditure lost (with 4.4% of cancellations) | 0.26% | 1.36% | * |
| (27)= (18)* (16)* (9) | Loss of revenue owing to fewer repeat visits in the future | 1,905,517 € | 16,551,713 € | * |
| 28 | Loss of fiscal revenue per day | 30,14 € | 30.14 € | * |
| 29= (28)* (19)* (9) | Loss of fiscal revenue owing to disruptive weather | 479,505 € | 2,662,708 € | * |
| | **10-year timeframe** | | | |
| (20)-10 years | Decline in GDP linked to cancellations/ disruptive weather | 7,573,871 € | 65,788,201 € | * |
| (21)-10 years | Total loss of expenditure (vacation shorten by one day) | 26,885,909 € | 233,536,504 € | * |

Key: DREM = Madeira Statistical Office; TSA = Tourism Satellite Account; TO = Tourism Observatory; * Own calculations based on econometric methods or simple calculations based on DREM, TSA and TO; ** Most plausible working hypothesis.

(4) Jobs lost as a direct consequence of disruptive weather will also lead to an increase in government spending on social benefits.
(5) Based on the disaggregation of total expenditure per day (169€), by product category, and the corresponding VAT rates, the amount of VAT lost will be in the region of 14.66€ per day. Given the GDP losses estimated in (2), the loss of VAT receipts amounts to 479,000 euros. As the share of the VAT in the total amount of taxes and levies (excluding social insurance contributions paid by employers and employees) is 48.64%, the total impact in terms of lost tax revenue is estimated to be 986,000 euros.
(6) Based on data indicating that around 45% of tourists will return in the medium term as repeat tourists, and the assumption that the 24.6% of visitors affected by delays, diversions and cancellations will not be willing to return, a total of 2642 fewer visits can be expected. This corresponds to a loss of 2.8 million euros.
(7) The accumulated loss of GDP over a 10-year period due to tourists not travelling because of flight disruptions amounts to around 7.5 million euros, while the loss associated with those delayed by one day amounts to approximately 26.9 million euros. The accumulated loss of government tax revenue is estimated to be around 4.8 million euros.

It is now possible to develop a future scenario for 2029, based on the estimated annual growth of the number of passengers affected by the weather-based flight cancellations. This will, however, require some further working hypothesis.

First, the assumption is that the GDP of Madeira will grow at 2.66% annually. This is based on the economic record for the period 1995 to 2022. For purposes of comparison, the same dataset suggests that GVA in general will grow by 2.63% per annum, while GVA in the accommodation/restaurant sector (the best proxy for the tourism sector) will growth at 3.11% per annum. Based on data from the TSA for 2015 and 2019, it is estimated that the total expenditure linked to the tourism sector will grow at an annual rate of 4.58%.

In the basic model, the assumption was made that 1% of the passengers are currently affected. This can be considered a conservative estimate. First, while the average number of passengers affected on an annual basis is approximately three-to-five times higher than this (based on a different dataset for the 2000–2018 period), the average delay time is only one or 2 h. This will not appreciably affect the time they have to spend in the destination. Second, the figure includes both arrivals and departures, while only the former is relevant to this analysis. The model nevertheless assumes that the typical passenger affected by disruptive weather will have their vacation shortened by one day. Passengers who have been delayed are likely to be tired and choose to rest up in their accommodation. They may also arrive too late in the day to undertake any activities (such as shopping or riding the cable car, which may well be closed for the night).

For later years in the model, figures on the number of repeat visits and cancelations are maintained. The rationale for making this assumption is that while the number of episodes of disruptive weather will increase, passenger's tolerance and willingness to cope with adverse events will also be reinforced (Rittichainuwat et al., 2018), which suggests that the two effects may ultimately cancel each other out. This may be due to tourists adjusting their expectations to the new realities of flying to Madeira.

The results of the calculations, along with the estimate values of loss of expenditure for 2029 are shown in Table 6, which shows that, for the year 2029, disruptive weather is responsible for a loss of around 23.4 million euros due to cancellations and delays, a further 16.5 million euros due to loss of reputation, and a loss of 2.5 million euros in tax revenues. This is a considerable increase on the estimate for 2019 and demonstrates the importance of not only disruptive weather but also climate change to Madeira's economy.

## 6. Conclusions and recommendations

Madeira is impacted by several periods of adverse weather every year, leading to substantial flight disruption. While most tourists will eventually reach the destination, some are likely to abandon their trip. Those who do travel are likely to have less time to spend in the destination. They may also choose not to make a return visit to the destination if they believe that their future visits will also be disrupted by adverse weather. This study has developed and applied a methodology for estimating the losses to the economy associated with flight disruptions and has identified significant losses to the economy in terms of GDP and employment. This figure will only increase over time with the impacts of climate change on local weather patterns. The disruptions are also likely to vary greatly from year to year as the effect of climate change is to make weather patterns more variable and less predictable. In the longer-term, Madeira may acquire a bad reputation for flight delays, which may discourage future visits.

The importance of this issue for Madeira, and other small-island tourism destinations, cannot be overstated. Evidence suggests that frequent flight disruptions can lead to significant dissatisfaction from passengers (Mair et al., 2016; Baños-Pino et al., 2023). Such incidents can add significant amounts of physical and psychological discomfort, inconvenience, and financial losses to tourists, who are sometimes forced to stay overnight unexpectedly at intermediate airports. They may also face limited rebooking options. In such circumstances, there is a strong probability of a widespread lack of confidence among potential visitors. In the fullness of time, below-expected passenger seat occupancy will lead to airlines deciding for themselves to withdraw from unprofitable commercial routes (Stone, 2015). A reduction in the number of flights will negatively impact on tourism development, resulting in knock-on effects throughout the tourism economy, including lower occupancy rates for accommodation providers and a wider loss of revenue in ancillary businesses. It will also result in reduced tax revenue.

Destinations must take care to avoid suffering this vicious circle of decline. In this regard, the DMO must manage the media carefully to avoid sensationalism and negativity. According to Mair et al. (2016), media coverage may have a devastating effect on travel for years to come after an adverse weather event. Unfortunately, the world media often fails to report on efforts to build up confidence in a destination, so this role is left to the DMO.

DMOs would also be well advised to study their tourism market to identify segments that may respond differently to flight disruption (Mair et al., 2016). A key segment to target may be those who are the first to come back following a crisis event, as they will be least sensitive to any disruption they may experience (Baños-Pino et al., 2023). The most risk-adverse segments, meanwhile, will need to be given special attention. Mair et al. (2016) advocate strategies based on 'value-added' offers, rather than price discounts, thus maintaining the price structure. An aggressive discounting strategy could serve to give the destination the reputation of being a low-cost, 'bargain basement' holiday choice (Insch and Avraham, 2014). Best practices to help airports become more climate resilient can also be investigated. Damage-control measures, such as improving restaurants and ensuring that hotel accommodation remains affordable, can be tested and implemented (Becken and Wilson, 2013; Voskaki et al., 2023).

Unexpectedly extended waiting times at the airport and worries about the reimbursement of extra expenses leads to uncertainty, anger, frustration, and dissatisfaction (Becken and Wilson, 2013; Shaw et al., 2021; Vos et al., 2023). The airport authority must therefore think creatively about solutions that can have a positive effect on stranded passengers' mood at the airport. Advance notice on the nature of the measures the airport intends to take, and real-time passenger information may help (Vos et al., 2023).

Several authors mention that past weather conditions may have a permanent effect on demand, as potential tourists adjust their expectations of the climate of the destination downward (Martín, 2005; Falk, 2014; Muñoz et al., 2023). Climate-risk mitigation based on initiatives aiming at speeding the recovery period and reducing the exposure or vulnerability to climate hazards must therefore to be seen as a matter of urgency (Voskaki et al., 2023).

### 6.1. Critique and limitations

An argument could be made that the model presented in this paper is overly complex for the task to which it is being put, and that there is little benefit to the approach in comparison to a simple 'back-of-the envelope' estimate. This would not be a correct view of this paper for at least two reasons. First, while it can be pointed out that the economic losses are likely to be relatively small as a share of GVA, this would be to misunderstand the objective of the paper. The paper's purpose was to develop a model for estimating the magnitude of such losses, not to prove that they might be of a particular magnitude or have a particular incidence. They happen to be smaller than some reports in the Madeiran media might suggest but this does not devalue the approach. Nor, indeed, would the estimates turning out to be as large as predicted in the media have proven the model's worth.

It should be noted, moreover, that the model suggests that the economic losses associated with airport disruptions will rise from 5 million euros in 2019 to 42 million euros in 2029. This represents a roughly eight-fold increase in just a decade. It should further be borne in mind that these figures are based on very conservative estimates of the amount of disruption that will be faced and the sensitivity of travellers to such disruption. Given also that climate scientists predict that the effects of climate change will not only continue but intensify in the foreseeable future, it is likely that such losses will reach a more concerning magnitude before too long.

The results of the model thus have significant implications for policy makers and industry leaders, and, given the nature of these implications, there is a significant danger they may not be heeded. While 5 million euros may seem to represent a small economic loss in terms of Madeira's GVA – one so small that it is not worth investing funds into climate-change adaptation measures – the size of the losses will only mount if action is not promptly taken. Adaptation measures might include, for example, investing in weather-prediction technologies and investing in airport infrastructure. Importantly, marketing and public-relations work will be needed to try to avoid demand being adversely affected by any reputational damage in the long term. Simpler models would not have included this longer-term effect, which may even come to outweigh the former with time. It is also a fact of life when it comes to taking climate action that the longer such action is delayed, the higher will be the price that is ultimately to be paid.

Second, it must be remembered that the purpose of this paper was to develop a model that could be used to estimate the economic losses associated with weather-related airport inoperability that was less complex and costly than state-of-the-art econometric approaches, yet more transparent and manageable than more simplistic approaches. A multi-dimensional approach was therefore adopted, based on the analysis of various extant data sources, with calculations made in sequential stages. This approach could be of interest for other regions struggling with either a lack of data or established methodologies to compute preliminary results on the impact of disruptive weather.

It is also important to note that there is no established methodology to estimate, in one system, both the short- and longer-term reputational impacts of adverse weather on a small-island tourism destination. The study has adopted a pragmatic approach to attempt to fill this gap.

Weaknesses regarding lack of access to data must also be acknowledged. The use of a range of data sources and working hypothesis does, nevertheless, lead to estimates that are of the same order of magnitude, which lends some confidence to the estimates presented in this paper. Concerted efforts between researchers, government, and commercial interests are therefore required to generate and provide access to high-quality empirical data. This will allow researchers to produce more accurate estimates and make more precise policy recommendations.

## CRediT authorship contribution statement

**António Almeida:** Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Luiz Pinto Machado:** Methodology, Investigation, Conceptualization. **Brian Garrod:** Writing – review & editing, Methodology, Investigation, Conceptualization.

## Generative AI or AI-assisted

The authors declare that no generative AI or AI-assisted technologies were used in this study.

## Competing interest statement

The authors have no competing interests to declare.

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