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Regional impact of climate change on European tourism demand

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Contents

Abstract

The tourism industry, a significant contributor to European GDP, may face considerable stress due to climate change. This study examines the potential impact of climate change on tourism demand in European regions in the 2100 time horizon. Using data from 269 European regions over a 20-year monthly timespan, we estimate the effect of current climatic conditions (rated with a Tourism Climatic Index, TCI), on tourism demand, considering various regional typologies. Our findings reveal that climate conditions significantly affect tourism demand, with coastal regions being the most impacted areas. Next, we simulate the impacts of future climate change on tourism demand for four warming levels (1.5°C, 2°C, 3°C, and 4°C) under two emissions pathways (RCP4.5 and RCP8.5). We find a clear north-south pattern in tourism demand changes, with northern regions benefitting from climate change and southern regions facing significant reductions in tourism demand; that pattern becomes more pronounced for higher warming scenarios. The seasonal distribution of tourism demand would also change, with relative reductions in summer and increases in the shoulder and winter seasons.

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1 Introduction

Tourism is one of Europe's largest economic sectors, acting as a significant generator of growth and employment in the EU, while contributing to development and economic and social integration. Europe stands as the most visited region in the world and accounts for 51% of all international arrivals (582 million tourists) and 41% of tourism receipts (UNWTO, 2020).

EU policy aims to maintain Europe's status as a leading touristic destination. In 2010, the European Commission adopted a new political framework for tourism (European Commission, 2010), setting out a new strategy and action plan for EU tourism based on stimulating competitiveness in the sector, promoting the development of sustainable tourism and consolidating Europe's image as a high-quality destination. More recently, the European Commission launched a roadmap to achieve a twin (green and digital) transition and to promote resilience in tourism (European Commission, 2022). The document contemplates a transition pathway that highlights the links inherent in making tourism more environmentally friendly and in implementing several ongoing legislative initiatives relating to environmental protection and climate neutrality.

Experts and stakeholders agree that for developing sustainable tourism, local and regional planners need to consider the impact of climate change and the surrounding natural environment when developing destinations. Thus, climate mitigation and adaptation measures should always be part of the smart and sustainable tourism strategies at national, regional, and local levels. The Council of the European Union (2022) reinforced the call for resilience and sustainability in tourism when shaping the 2030 EU Agenda for tourism.

The objective of this study is the analysis of how climate change will affect European tourism demand for various global warming levels. Climate is considered an important factor in explaining tourism demand, as climate and environment conditions influence, for example, the choice of tourist destinations and activities (Hu & Ritchie, 1993; Goh, 2012; Moreno, 2010). Scott and Gössling (2022) have made a call for more literature analysing the relationship between tourism and climate, as the last three decades of research have failed to prepare the sector for the net-zero transition and climate disruption that will transform tourism in the 2050 time horizon.

The present study builds on earlier work performed under the PESETA projects (Feyen, L., et al., 2020), namely the analysis done by Amelung and Moreno (2012) who assessed the effect of future climate change until 2080 on outdoor international tourism expenditure within Europe, and the work of Barrios and Ibáñez (2015) who analysed the potential impact of climate change on tourism demand in the European Union (EU) and provided long-term (2100) projections accounting for climate adaptation in terms of holiday duration and frequency.

We first run a historical assessment estimating the statistical relationship between bed nights (proxy for tourism demand) and, as explanatory variables, a climate-related index of human comfort (the Tourism Climate Index, TCI), and economic variables (price and income effects), while controlling for seasonal, spatial, and geographical time-invariant characteristics. The historical data related to tourism demand was collected from EUROSTAT, combining various datasets to obtain the number of bed nights from 269 regions monthly from 2000 until 2019.

We also consider a set of typologies or categorisation for regions to account for structural features that can be relevant for the differentiated regional response to climate change. For instance, at first one could argue that tourism demand in coastal regions can be more sensitive to changes in climate conditions than in rural regions. In particular, we employ a specific typology for Europe (Batista e Silva et al., 2021), based on the number of accommodation rooms and geographical criteria. Six different tourism categories representing the predominant use of tourism in each region are considered: 'Urban', 'Coastal', 'Nature', 'Snow Mountain' 'Rural', and 'Mixed'.

We find that a 1% increase in TCI increases the monthly regional number of bed nights by 0.57%, an impact that varies in magnitude based on the specific tourism typology considered. Thus, the estimated elasticity for coastal regions is much higher, around twice that figure (1.2%). The results reveal also significant variations in the response of tourism demand across seasons. On average, the flow of tourism increases by approximately 70% when moving from the coldest to the hottest season.

In the second half of the analysis, preliminary regional projections of bed nights are simulated for the goals of the Paris Agreement (1.5°C and 2°C) and for two higher global warming levels (3°C and 4°C). These projections were generated using an ensemble of 10 regional climate models, under both a moderate mitigation (RCP4.5) and high emissions (RCP8.5) scenarios.

We find a clear north-south pattern in tourism demand changes, with northern regions benefitting from climate change and southern regions facing significant reductions in tourism demand; that pattern is more acute for higher warming levels scenarios. For instance, for a 4°C warming scenario, compared to the present (2019), ranging from an average decrease of -9% in the Greek Ionian Islands to an average increase of +16% in West Wales, UK Coastal and island regions are expected to face the largest impacts on tourism demand for the highest warming scenario, denoting higher sensitivity to climate signals. Despite this, the overall climate impact on European tourism demand is positive under every warming scenario, with a projected demand increase of 0.35% to 1.58%, depending on the warming scenario considered.

Seasonality patterns are also expected to undergo substantial changes, with varying impacts across regions. For example, Northern European coastal regions are expected to see significant increases (>+5%) in demand during summer and early autumn months. Conversely, Southern coastal regions are projected to lose significant amounts of summer tourists (-10%) compared to the present, particularly in warmer climate scenarios (3°C and 4°C). In these regions, the decline in summer demand is partially offset by increases in spring, autumn, and winter. In aggregated terms, the month of April is expected to see the highest increase in tourist flows reaching a +8.89% compared to the present in a 4°C scenario. The largest decline in European tourism demand is projected for July, ranging from -0.06% in the 1.5°C scenario to -5.72% under the warmest climate scenario.

The report is divided into five sections, starting with Section 2 which provides an outline of the research methodology used to estimate current and future tourism demand. This is followed by an overview of the data employed in Section 3. Section 4 discusses the empirical results, including projections of regional tourism demand, while section 5 presents the main conclusions and steps for future research.

2 Methodology

2.1 Modelling tourism demand

The methodological approach presented in this study builds on a previous analysis performed under the PESETA project (Amelung and Moreno, 2012) that investigated the influence of climatic conditions on regional tourist flows, represented by the number of nights spent on tourist accommodations. We adopt a similar spatial focus, the EU NUTS 2 regions but we expand the time horizon considered from 12 months to 240 months. Furthermore, we apply a different statistical technique, panel data modelling, motivated by the several advantages that the use of panel data has over time series or cross-section approaches, including a greater degree of freedom, the mitigation of multicollinearity, and a reduction in omitted variable bias (Hsiao, 2003).

Recent studies have also used panel data techniques to examine the relationship between climate and tourism demand. Based on monthly tourism data, Bigano et al. (2005) explored the impact of temperature and precipitation on domestic tourism demand in Italy. Taylor and Ortiz (2009) used panel data techniques to study the effects of temperature, precipitation, and sunny conditions on domestic tourism demand in the United Kingdom. Based on an eight-year panel data set of 254 Italian municipalities, Cai et al. (2010) examined the responsiveness of tourist arrivals and the average length of stay to local weather conditions. Ridderstaat et al. (2014) presented evidence from Aruba in determining the Impacts of seasonal patterns of climate on recurrent fluctuations in tourism demand. Li and Li (2017) used the dynamic panel data technique, to focus on the demand of tourists from Hong Kong for 19 of the major tourism cities in Mainland China.

We build an enlarged standard tourist demand model linking the total number of tourists' bed nights to a climate suitability index represented by the Tourism Climate Index (TCI), and a set of economic determinants of tourism demand (Li and Li, 2017), in particular, economic activity (expressed through GDP) and the consumer price index in the destination regions. Specifically, we estimate the following fixed effects monthly model for 269 European regions over the 2000-2019 period:

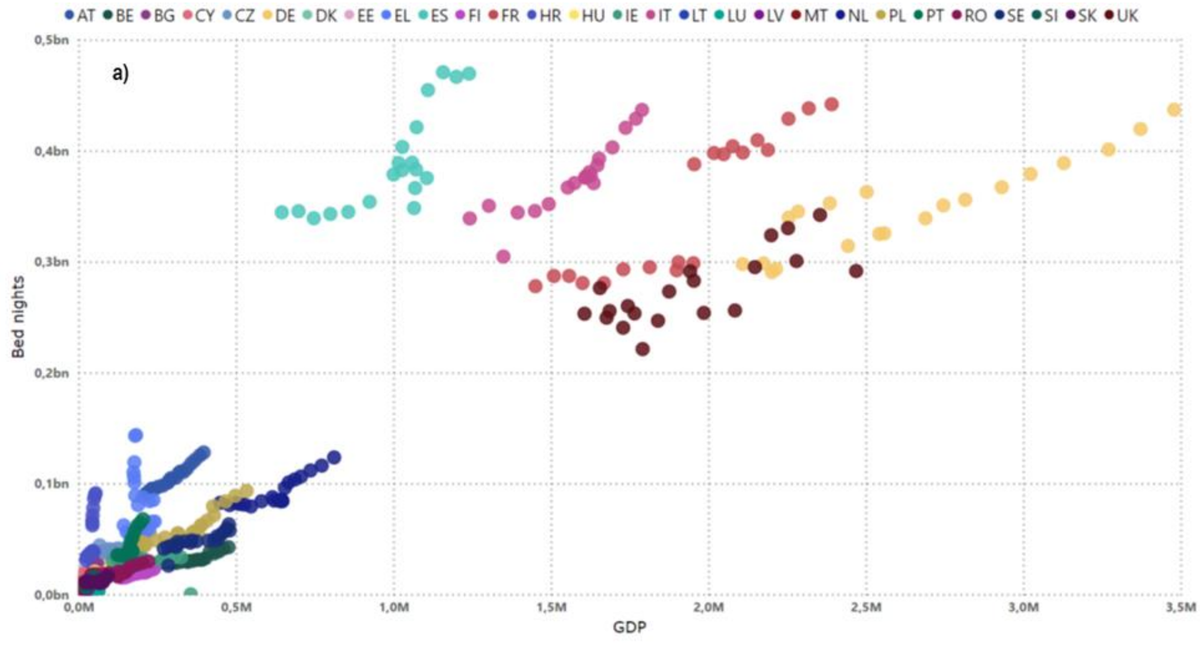
$$\ln BN_{itm} = \alpha_i + \beta_1 lnTCI_{itm} + \beta_2 lnGDP_{itm} + \beta_3 lnHICP_{itm} + \\ + \beta_4 TCI_{itm} * Tclass_i + + d_s M_s + \varepsilon_{itm} \tag{1}$$

The natural logarithm (ln) of the number of bed nights (BN) from a certain region i, in the year t and month m is regressed on regional fixed effects (α), the monthly Tourism Climate Index (TCI), the regional GDP and the regional harmonised index of consumer prices index HICP, all at the year-month tm. The TCI is further interacted with each region's tourism typology ($Tclass$) to capture the varying tourists' climatic preferences across the six major tourism segments and destination types. Finally, seasonal dummy variables (M) were included to capture the influences of specific seasonal characteristics s in determining the tourism demand.

In this study we measure tourism demand with the help of the number of bed nights spent at tourism accommodation establishments. Bed nights are the most populated variable at this level of regional and time detail available in EUROSTAT. The estimates and the projections of the model will refer only to overnight stays and do not cover same-day visitors.

Several economic factors have been accounted to affect the number of bed nights in a certain country. In this study we take into account the GDP, which has a strong significant relationship with the number of bed nights. Panel a) of Figure 1 shows the evolution of this relationship at country level across the 2000-2019 period. The elasticity between the two variables clearly depends on the country, a phenomenon that the econometric model employed in this study manages to capture. Panel b) of Figure 1 gives a closer look at the smaller economies in terms of tourist's flows and displays a zoomed-in version by excluding from the graph the largest 5 economies of the European Union in terms of bed nights to real GDP relationship (Spain, Italy, France, Germany and United Kingdom).

Figure 1. Number of tourist bed nights compared with total GDP for (a) all EU27+UK countries and (b) focus on smaller economies.



Source: JRC analysis based on EUROSTAT data.

2.2 Tourism Climate Index

For several decades, the climate suitability for tourists' activities has been assessed using tourism climate indices. The first composite index developed was the Tourism Climate Index (TCI) (Mieczkowski, 1985), designed to integrate seven climate variables considered relevant to tourism, and has become the most widely used to describe the attractiveness of certain tourists' destinations. The index consists of five sub-indices, describing daytime thermal comfort, daily thermal comfort, precipitation, hours of sunshine and wind speed (Table 1), where all sub-indices can reach a maximum value of 10.

Table 1. Components of the Tourism Climate Index.

Sub-index	Climate variables	Description	Weight
Daily Comfort Index (CIA)	Mean daily air temperature (°C) Mean daily relative humidity (%)	Thermal comfort over 24 hours period	50%
Precipitation (P)	Total daily precipitation (mm)		20%
Wind (W)	Mean wind speeds (km/hr)		10%
Aesthetic (A)	Cloud cover (%)		20%

Source: Adapted from Mieczkowski (1985).

The following equation is used for calculating the TCI:

$$TCI = 5CIA + 2P + 2A + W$$

In order to reflect that tourists are generally most active during daytime, the highest weight is given to the daytime comfort index (50%). The amount of precipitation and the percentage of cloud cover (CC) are given the second–highest weights (20%), followed by wind speed. TCI values range from 0 to 100, where 0 represents potentially dangerous and 100 ideal conditions for tourism activities. An ideal rating is obtained when all the five components are within the range of conditions most preferred by the majority of tourists, while TCI scores of less than 50 represent conditions that were deemed not suitable.

Table 2. Tourism Climate Index rating system.

Score	Descriptive Rating
90-100	Ideal
80-89	Excellent
70-79	Very good
60-69	Good
50-59	Acceptable
40-49	Marginal
30-39	Unfavourable
20-29	Very unfavourable
10-19	Extremely unfavourable
0-9	Impossible

Source: Adapted from Mieczkowski (1985).

The different rating schemes used for all the indices' components are shown in Table 3. We use a measure of perceived temperature or daily thermal comfort (CIA) represented by the Canadian Humidex (or humidity index), a combination of daily temperature and relative humidity, reflecting that when the atmospheric moisture content (i.e., relative humidity) is high, the rate of evaporation from the body decreases, making the human body to feel warmer. The Humidex is a nominally dimensionless quantity, though generally recognized by the public as equivalent to the degree Celsius.

Table 3. Tourism Climate Index rating system.

a)

Humidex (°C)	Rating
≥36.0	0
35.0-35.9	1
34.0-34.9	2
33.0-33.9	3
32.0-32.9	4
31.0-31.9	5
30.0-30.9	6
29.0-29.9	7
28.0-28.9	8
27.0-27.9	9
20.0-26.9	10
19.0-19.9	9
18.0-18.9	8
17.0-17.9	7
16.0-16.9	6
10.0-15.9	5
5.0-9.9	4
0.0-4.9	3
−5.9-−0.1	2
−10.9-−6.0	0
−15.9-−11.0	−1
−20.9-−16.0	−2
≤−21.0	−6

b)

Sun Hours	CC (%)	Rating
10	0.0-16.6	10
9	16.7-24.9	9
8	25.0-33.2	8
7	33.3-41.6	7
6	41.7-49.9	6
5	50.0-58.2	5
4	58.3-66.6	4
3	66.7-74.9	3
2	75.0-83.2	2
1	83.3-91.6	1
0	≥91.7	0

c)

Precipitation (mm)	Rating
0.00-0.49	10
0.50-0.99	9
1.00-1.49	8
1.50-1.99	7
2.00-2.49	6
2.50-2.99	5
3.00-3.49	4
3.50-3.99	3
4.00-4.49	2
4.50-4.99	1
≥5.00	0

d)

Wind (km/h)	Rating (<23.9°C)	Rating (24-32.9°C)	Rating (≥32.9°C)
≤2.88	10	4	4
2.89-5.75	9	5	3
5.76-9.03	8	6	2
9.04-12.23	7	8	1
12.24-19.79	6	10	0
19.80-24.29	5	8	0
24.30-28.79	4	6	0
28.80-38.51	3	4	0
≥38.52	0	0	0

Source: Adapted from Mieczkowski (1985).

3 Data

3.1 Historical data for tourism demand and climate

The 2000-2019 historical data related to tourism demand was collected from EUROSTAT, by combining various datasets in order to obtain the number of bed nights per NUTS 2 region, on a monthly basis. Mainly, the country-level data "Nights spent at tourist accommodation establishments"[1] available on a monthly basis from 2000 onwards was merged with "Nights spent at tourist accommodation establishments by NUTS 2 regions"[2], with an annual time frequency. The monthly distribution at the country level was assumed for all regions in the country. Therefore, the bed nights at monthly and regional level $BN_{m,r}$ were obtained by regionalizing the monthly, country m, C level data based on the weight that each region had in its corresponding country, in a given year.

$$BN_{m,r} = BN_{m,C} \times \frac{BN_{y,r}}{\sum_{r \in C} BN_{y,r}},$$

where $BN_{y,r}$ represent the bed nights in a given year y and region r.

The independent variables covering the economic data employed in estimating the tourism demand, namely GDP and HICP, were also obtained from EUROSTAT. The monthly GDP (expressed in 2015 euro) at NUTS 2 regional level comes from joining the annual Regional $GDP_{y,r}$ with the quarterly country-level $GDP_{q,C}$,[3] with the implicit assumption that the quarterly GDP distribution of the country applies to all regions within that country; moreover, within each quarter, the GDP is distributed equally for the 3 months of the quarter.

$$GDP_{q,r} = GDP_{q,C} \times \frac{GDP_{y,r}}{\sum_{r \in C} GDP_{y,r}}$$

On the other hand, the regional HICP was computed based on the monthly figures[4] by assuming the same overall consumer price inflation for all regions in a given country and month.

A series of operations were performed in order to harmonize the various datasets used, each with different spatial scale and temporal detail, into a single multi-region monthly panel dataset (i.e., 269 NUTS 2 regions over 240 time periods). Together with a linear interpolation methodology, other mechanisms were applied in order to fill in the missing observations, on a case-by-case basis, as there were no systematic gaps across regions, countries, or time periods. The seasonal characteristics of the variables (e.g., the evolution of the same month in the neighbouring years, the importance of a certain month in a given year and its development across time), the spatial weight (i.e., the evolution of each NUTS 2 region with respect to the corresponding country), evolution of the neighbouring values, were taken into account when supplementing the missing data.

The climate data required in order to build the historical values of the TCI (see Table 1 above) was computed on a monthly basis, at regional level, and was obtained from ERA5 hourly climate reanalysis data (Hersbach et al., 2023). Regional-level TCI historical values are available online at the JRC Data Catalogue[5].

Our approach also controls for the effect of different regional tourism typologies. We used a recently proposed regional (NUTS 3) tourism typology for Europe (Batista e Silva et al., 2021) based on the number of accommodation rooms (for both hotels and short-term rentals) and geographical criteria.

Regions were labelled according to six different tourism categories: 'Urban', 'Coastal', 'Nature', 'Snow Mountain' 'Rural', and 'Mixed'. These categories are meant to represent the predominant use of tourism in each region.

Table 4 shows the descriptive statistics for the variables used in this study across the regions and over time. The period 2000 M1–2019 M12 was chosen because it is the longest period available for both regional-monthly tourist, economic and climatic variables. Our sample contains around 64,560 observations and the

[1] Table code [tour_occ_nim]
[2] Table code [tour_occ_nin2]
[3] Specifically, the [nama_10r_2gdp] and [namq_10_gdp] underlying datasets were combined.
[4] HICP - monthly data (index) [prc_hicp_midx]
[5] http://data.jrc.ec.europa.eu/collection/id-00375.

data is quite symmetric for each of the variables considered because the values of mean and median are rather similar. Across variables, all regions have data for all time periods, generating in this way a strongly balanced panel data set.

Considerable variation is observed for most variables, except for the HICP where the name of variable itself already explains the similarity between the price levels across regions within the European Union. On the other hand, the TCI and number of bed nights present the highest variability, as expected considering that they differ substantially across regions and seasons.

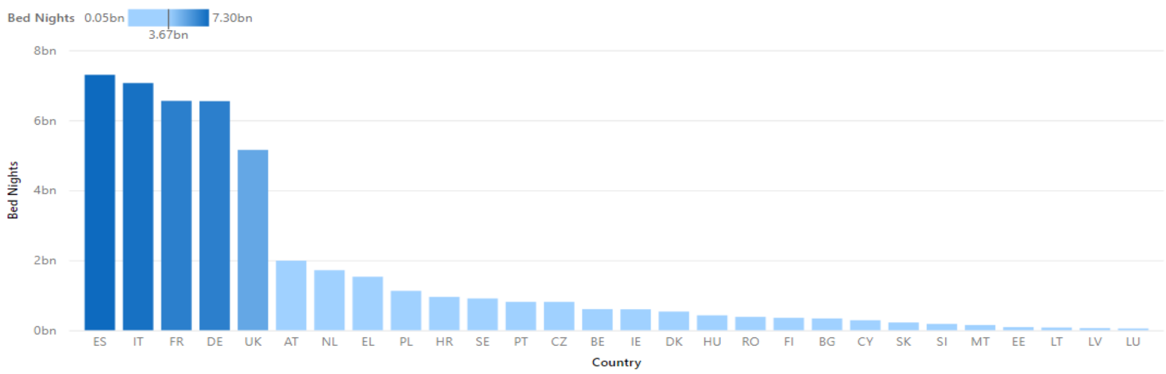
Table 4. Descriptive Statistics: Variation across regions and over time (2000 M1–2019 M12).

Variable	Mean	SD	Min	Max	Median
ln_BN	12.90	1.14	8.24	17.08	12.91
ln_TCI	3.88	0.30	1.96	4.52	3.89
ln_GDP	7.81	1.00	4.18	11.04	7.90
ln_HICP	4.50	0.14	3.18	4.72	4.53

Source: JRC analysis based on EUROSTAT data.

The most popular tourism destinations are Spain, Italy, France Germany, and United Kingdom recording the highest numbers of bed nights in 2019 (Figure 2) and across all years (Figure 3), countries internationally recognised to be among the world's top 10 destinations (UNWTO, 2020).

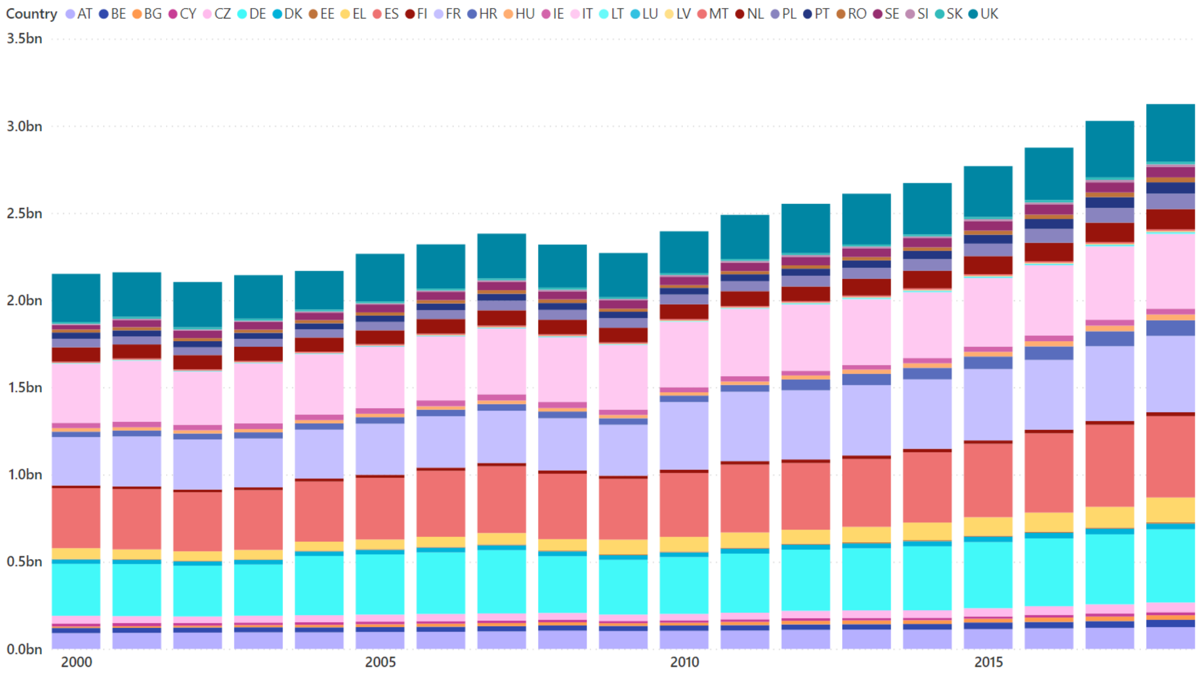
Figure 2. Number of bed nights by country in 2019.



Source: JRC analysis based on EUROSTAT data.

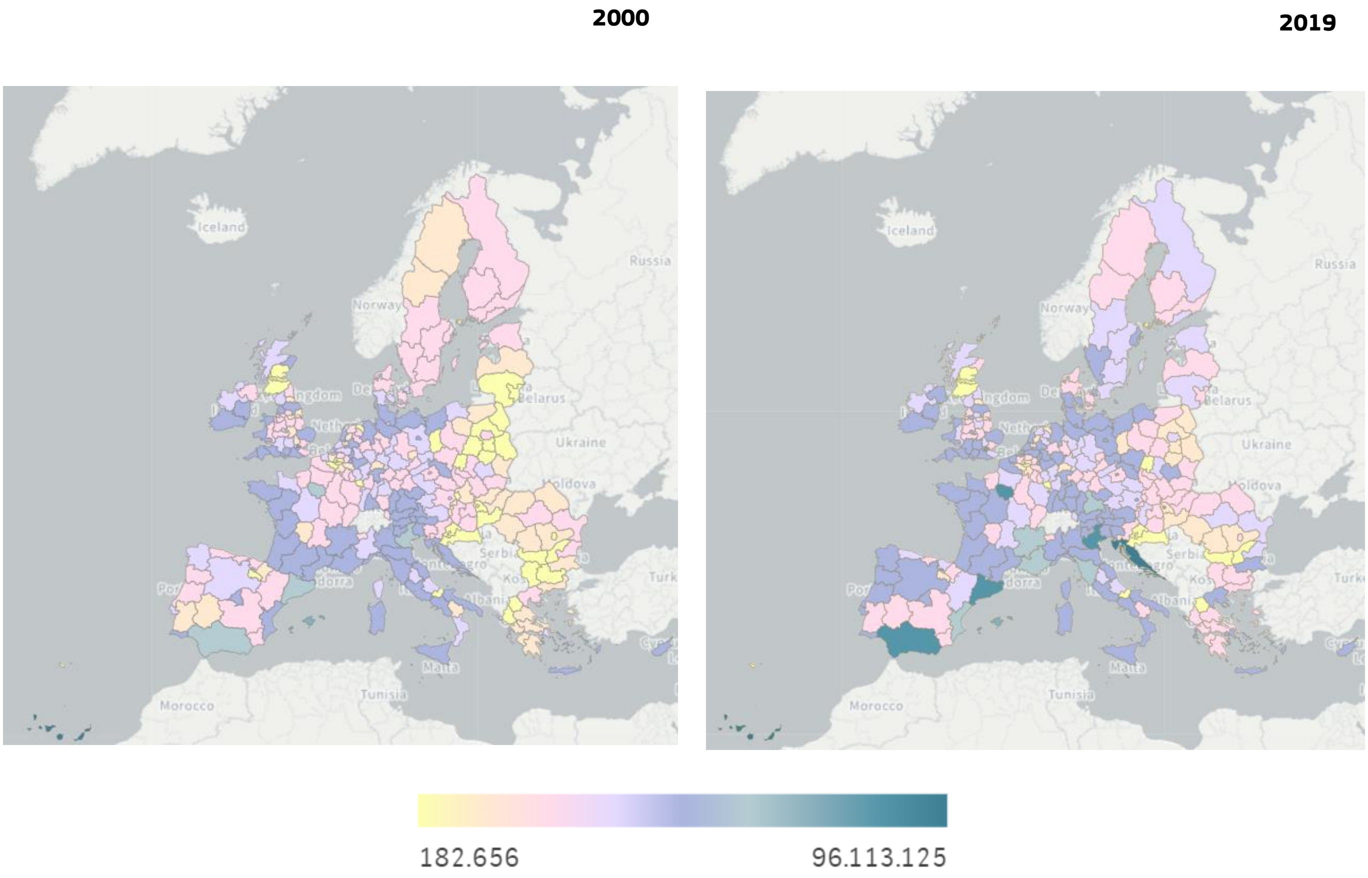
Tourism has seen a continued expansion over the last two decades, starting from 2.15 billion in 2000 and reaching almost 3.2 billion in 2019 (Figure 3). On average the profile of the most visited European nations has not really changed during this time, all top ten main players maintaining their importance in the total tourism demand in Europe, despite some small variations in their market share in the total number of bed nights. United Kingdom, Italy and Spain lost approximately two percentage points of their share (reaching 10.5% 13.7% and 15%, respectively in 2019) while France, Greece and Croatia destinations gained some power over the 20-year period (adding 1.2, 1.8 and 1.5 percentage points to reach a share of 14.2%, 4.6% and 3.7%, respectively).

Figure 3. Evolution of the annual number of bed nights over the 2000-2019 period.



Source: JRC analysis based on EUROSTAT data.

Figure 4. *Regional pattern of the number of bed nights in 2000 and 2019.*



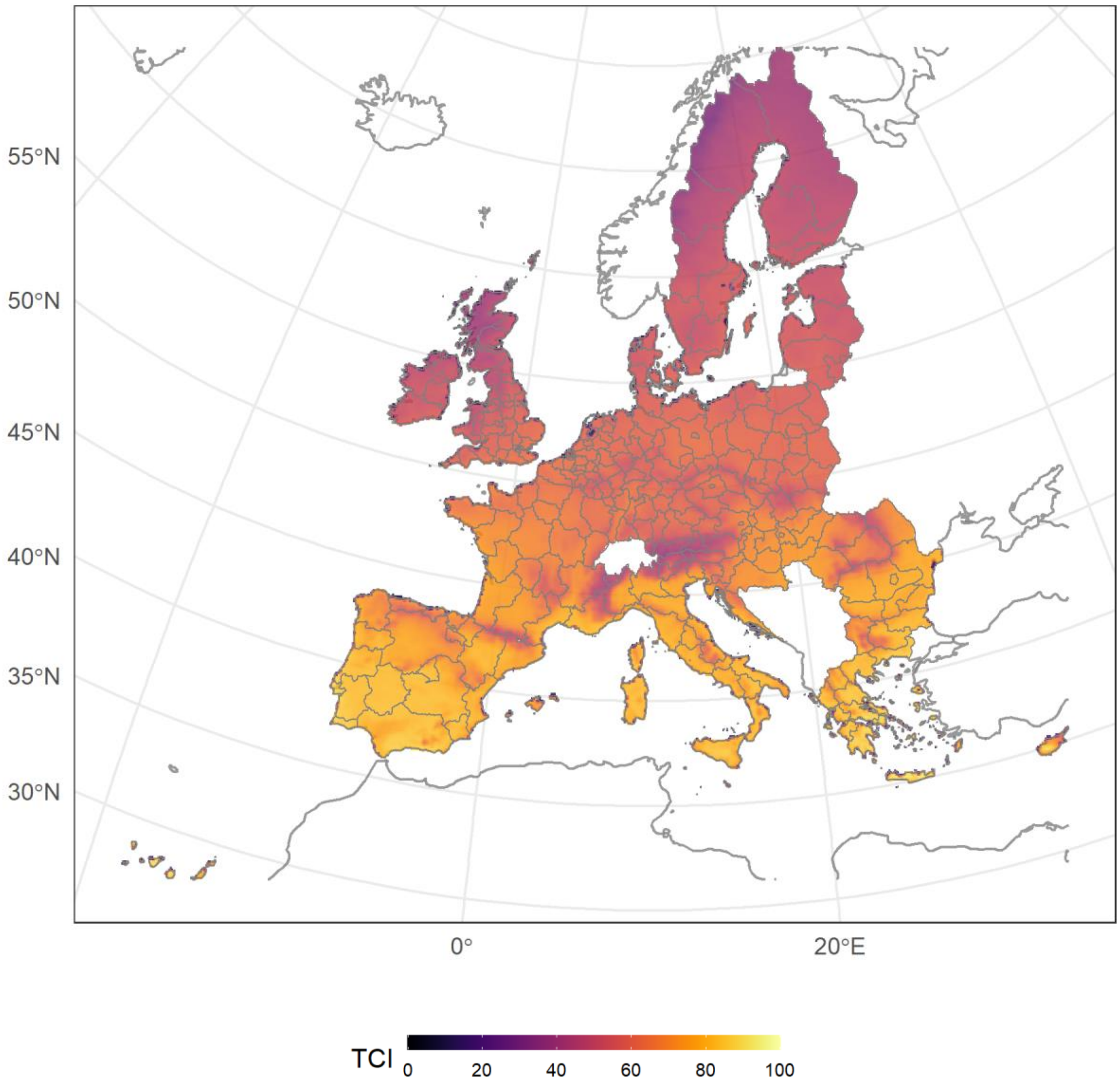
Source: JRC analysis based on EUROSTAT data.

Figure 5 shows the spatial pattern of TCI across the studied area. An evident north-south gradient can be observed, with lower latitude regions scoring higher TCI values. Additionally, mountainous areas can be clearly identified, and they are characterized by lower values in all the climatic facets considered (thermal comfort, physical, and aesthetic).

All regions show a clear seasonal pattern in their annual TCI profile, with the exception of some specific spots that systematically show high values, such as the Canary Islands. The peaks are observed during the summer season, moderate to high values during the shoulder seasons, and low values typically during winter months (Figure 6). This behaviour correlates well with the intensity of tourism demand, which is also highly seasonal and more intensive during the summer.

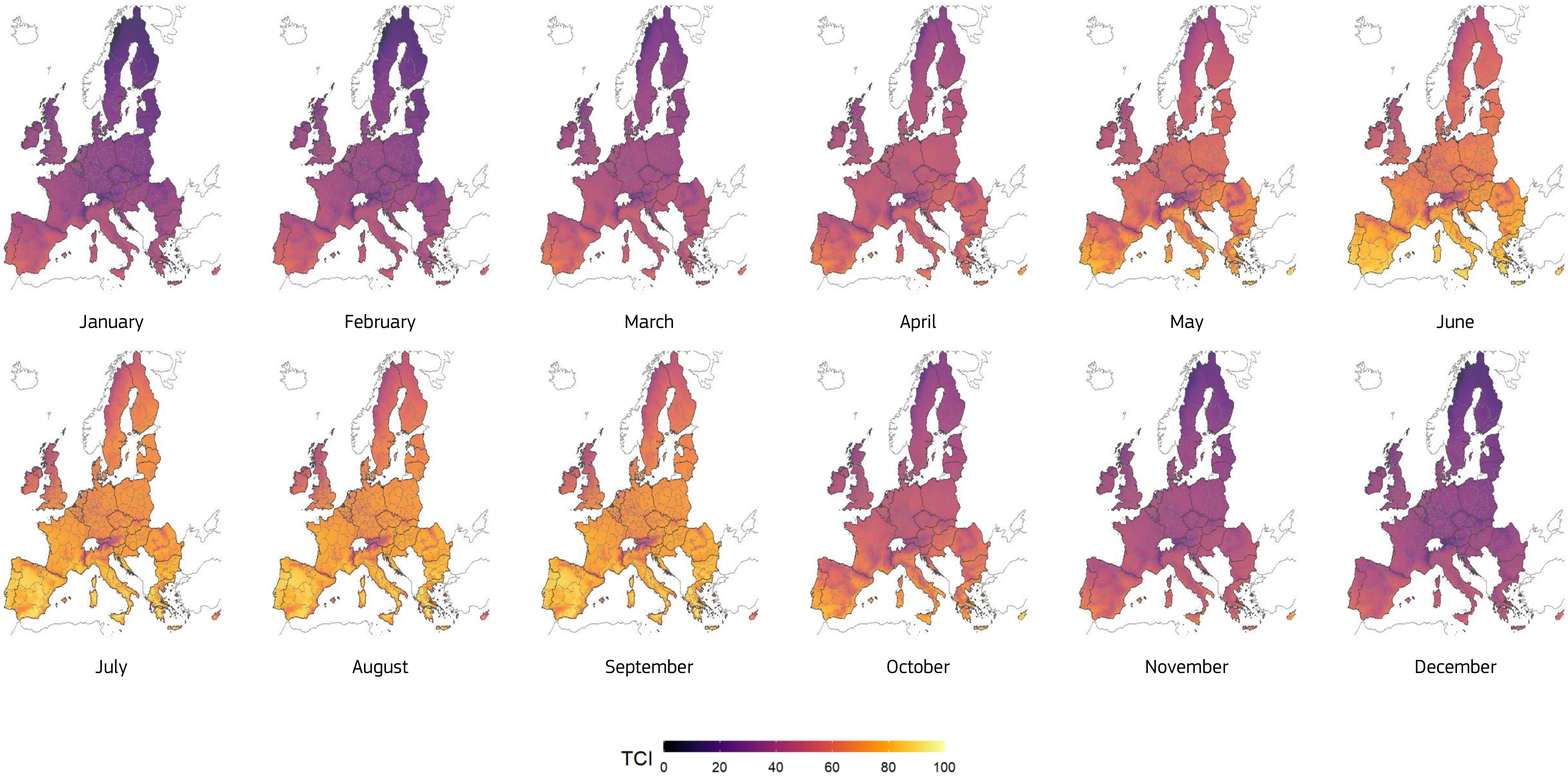
Interestingly, southern (warmer) regions experience declines in their overall TCI scores during summer months. This is penalized by lower thermal comfort scores resulting from daily average Humidex values well above 30.

Figure 5. Average TCI in September for the historical period 1981-2020.



Source: JRC analysis based on ERA5 data.

Figure 6. Spatial pattern and intra-annual variability of the TCI for the historical period 1981-20



Source: JRC analysis based on ERA5 data.

3.2 Regional tourism typologies

The method to classify NUTS 2 regions according to the dominant tourism typology involved four main steps, employing Geographical Information Systems (GIS) and detailed geospatial data on (a) online tourism accommodation capacity (hotels and vacation rentals), (b) spatial delimitation of NUTS 3 and NUTS 2 regions and (c) key geographical characteristics/features. The overall workflow had already been tested and documented by (Batista e Silva, et al., 2018), consisting of the following main steps:

1. Spatial delineation of five distinct geographical areas within each NUTS 3 region;
2. Spatial intersection between the 'accommodation layer' and the geographical zoning mentioned in point 1;
3. Classification of each NUTS 3 region by typology using a rule-based approach applied to the relative presence of tourism accommodation capacity across the geographical zones;
4. Classification of each NUTS 2 region by typology based on a majority rule of nights spent across the respective NUTS 3 regions.

In the **first step**, we considered fives types of geographical zones: coastal zones, mountain and natural areas, snowy mountains, cities, rural areas. 'Coastal zones' were delineated by applying a 10 km-straight line buffer to the coastline (EuroBoundaryMap). 'Mountain and natural areas' included the areas above 800 m of altitude (EU-DEM v1.1) and a 2 km-straight line buffer from the protected areas listed in the Natura 2000.[3] 'Cities' comprised 683 'urban centres' across the EU-27 delineated by Eurostat. 'Snowy mountains' contained mountain areas characterized by a significant share of snow cover surface. This was achieved by selecting cells above 800 m and where snow cover was predominant for at least 60 consecutive days. Finally, all areas that do not belong to any of the latter were considered 'rural'. In case of overlapping areas, we applied the following order of priority: 1) snowy mountains, 2) cities, 3) coastal zones, 4) mountains and natural areas, 5) rural areas. This order was based on our judgment of the touristic function prevalence of the different geographical areas. Finally, the 5-class geographical zoning was intersected with the NUTS 3 boundaries in order to 'split' each NUTS 3 region per any of the occurring zones.

In the **second step**, the NUTS 3 zoning layer was overlaid with the 'accommodations layer' using a 'zonal statistics' function to obtain the tourism capacity (number of rooms) for each geographical zone within each NUTS 3. The 'accommodation layer' is a point dataset recording the number of rooms in tourism accommodation based on information available from the TripAdvisor online booking platform and scraped from the web in January 2021. For the 27 European Union countries, the number of hotels was slightly above 509,000 and vacation rentals over 436,000 on a total of 17 million rooms.

In the **third step**, each NUTS 3 was classified according to a tourism typology based on the split of accommodation capacity across the respective geographical zones, using a predefined rule set as follows: take Type A and Type B as the geographical zones with the highest and second highest tourism accommodation capacity within a NUTS 3 region, respectively. If Type A has a tourism capacity share twice as high as the accommodation capacity of Type B, then the corresponding NUTS 3 is classified as Type A. Else, if Type A has a share equal or above 50% and Type B is equal or below 40%, then the corresponding NUTS 3 is classified as Type A. Else, if Type A and Type B have both shares equal or above 33%, then the corresponding NUTS 3 is classified as a combination of those 2 geographical zones (Type AB). All other cases result in the NUTS 3 being classified as Mixed. The described rule-based approach led to a total of 15 classes, with 5 'pure classes', 9 combinations of two geographical zones, and 1 Mixed. The rules are expressed in the pseudocode below:

```
If ShareTypeA ≥ 2 * ShareTypeB:
Classify as Type A
If ShareTypeA ≥ 50% and ShareTypeB < 40%:
Classify as Type A
If ShareTypeA ≥ 33% and ShareTypeB ≥ 33%:
Classify as Type AB
Else:
Classify as Mixed
```

In order to simplify and reduce the final number of classes, an aggregation was applied to the 9 combinations described above, whereby classes Type AB become Type A whenever this has a higher share. Otherwise, the

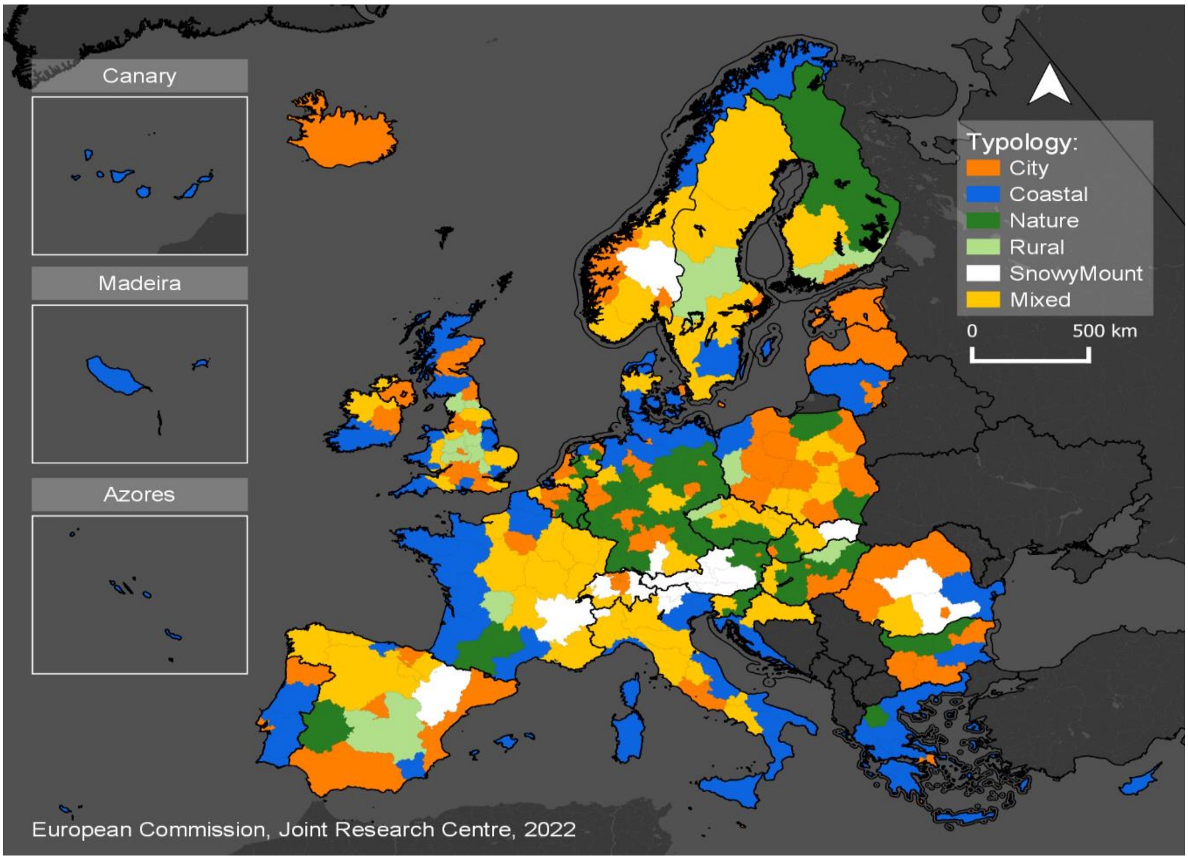
NUTS 3 is classified as 'Mixed' type. The simplified typology resulted in a total of 6 classes. Bellow the corresponding pseudocode:

```
In TypeAB if ShareTypeA > ShareTypeB:
Classify as Type A
Else:
Classify as Mixed
```

In the **fourth and final step**, starting from the above simplified typology, annual nights spent per NUTS 3 regions were aggregated per each of the 6 tourism classes per NUTS 2. The NUTS 2 was then classified according to the tourism class with more than 50% of the nights spent, to reflect the actual balance of tourism demand within the NUTS 2. For this criterion, the classes Nature and Rural were considered together. If Nature and Rural were above 50%, final label to the NUTS 2 was attributed to the class with the highest number of nights among the two. The final NUTS 2 classification can be inspected in Figure 7. The data on nights spent per NUTS 3 for 2019 were obtained from the Eurostat dataset on nights spent at accommodation offered via collaborative economy platforms (ESTAT).

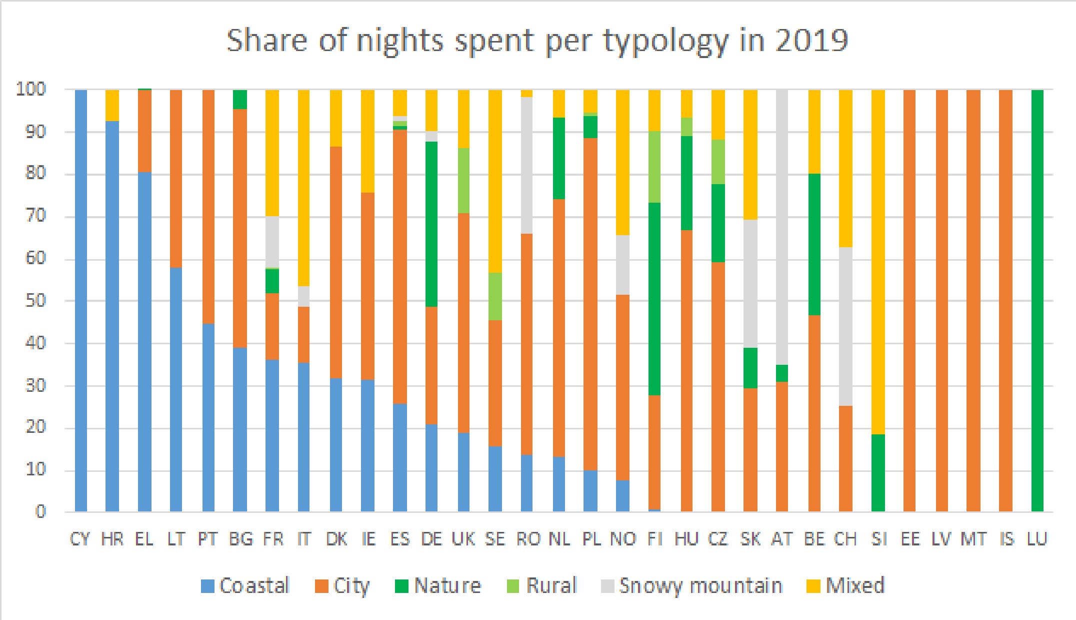
The NUTS 2 share of nights spent per typology was then calculated at country level. Countries were then sorted by descending order of their coastal share resulting in Figure 8. Smaller countries or those with one single NUTS 2, like Cyprus, Luxembourg, Latvia, Malta, and Iceland, have all their nights spent classified under one typology, while the remaining are characterized by a higher or lesser balance between two or more typologies.

Figure 7. Regional tourism typologies at NUTS 2 level.



Source: JRC analysis.

Figure 8. Share of nights spent per tourism typology class per country in 2019.



Source: JRC analysis.

3.3 Future climate data

The analysis uses climate variables projections through the year 2100 coming from an ensemble of 10 regional climate models (RCMs) and global circulation models (GCMs) produced by the Coordinated Regional-climate Downscaling Experiment over Europe (EURO-CORDEX) project. Four future global warming levels scenarios are computed (compared to pre-industrial): the Paris Agreement targets (1.5°C and 2°C) and two higher warming levels (3°C and 4°C), similar to what was considered in the JRC PESETA IV study (Feyen, L., et al., 2020)[6]. The climate models are run under two representation concentration pathways (RCPs): RCP4.5 and RCP8.5. Table 5 details the year when the specific warming levels are reached for each combination of RCM/GCM and the two RCPs considered.

[6] Canary Islands (NUTS 2: ES70) are not included in the assessment of future climate conditions due to this region lying outside EURO-CORDEX domain.

Table 5. Years when the warming levels are reached for the individual RCMs and GCMs, and the two RCPs considered.

RCM	GCM	1.5°C		2°C		3°C		4°C
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP8.5
CCLM4.8-17	CNRM-CERFACS-CNRM-CM5	2035	2029	2057	2044	NA	2067	2089
	ICHEC-EC-EARTH	2033	2026	2056	2041	NA	2066	2090
	MPI-M-MPI-ESM-LR	2034	2028	2064	2044	NA	2067	2089
HIRHAM5	ICHEC-EC-EARTH	2032	2028	2054	2043	NA	2065	2086
WRF331F	IPSL-IPSL-CM5A-MR	2023	2021	2042	2035	NA	2054	2073
RACMO22E	ICHEC-EC-EARTH	2032	2026	2056	2042	NA	2065	2087
RCA4	CNRM-CERFACS-CNRM-CM5	2035	2029	2057	2044	NA	2067	2089
	ICHEC-EC-EARTH	2033	2026	2056	2041	NA	2066	2090
	IPSL-IPSL-CM5A-MR	2023	2021	2042	2035	NA	2054	2073
	MOHC-HadGEM2-ES	2021	2018	2037	2030	2069	2051	2071

Source: JRC analysis. Note that under the RCP4.5 scenario only one model reaches 3°C while none reach the 4°C warming level.

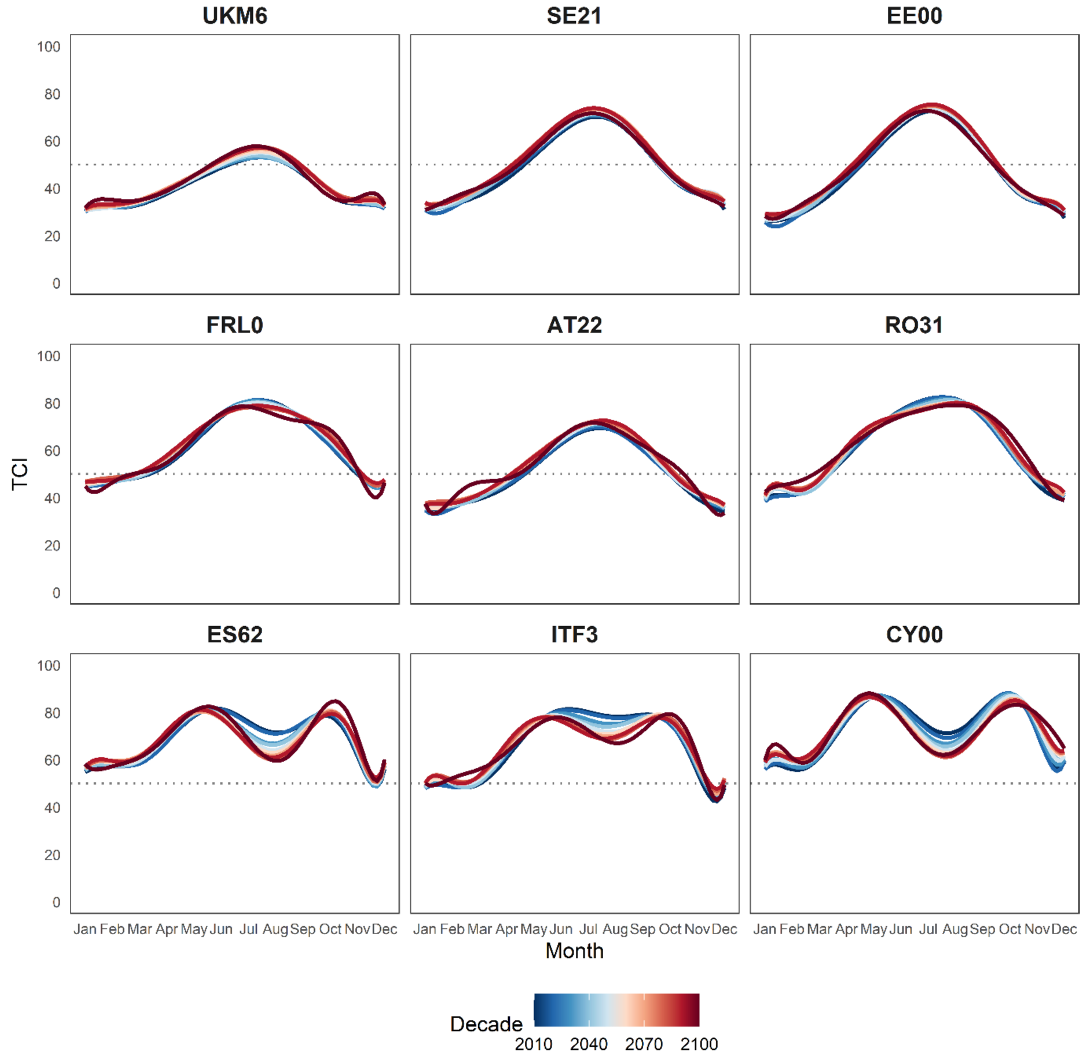
The following climate variables for the period 2000-2100 have been used in the study: maximum and mean daily temperature, minimum and mean daily relative humidity, total precipitation, average wind speeds and cloud cover. All RCMs were run over the same numerical domain covering the European continent at a resolution of 0.11°. (Dosio A. , 2016) and (Dosio & FIscher, 2018) offer a detailed technical description on how the high-resolution RCMs are produced and bias-adjusted, and on how the global warming levels are defined. We use these climate variables to derive both future TCI scenarios (2020-2100) as well as a historic baseline (2000-2019), which we then aggregate to monthly and NUTS 2 regions level.

The projected evolution of TCI for the 21st century decades spanned by an ensemble of the climate models described in Table 5 for some representative European regions is shown in Figure 9 (under emission scenario RCP4.5) and Figure 10 (scenario RCP8.5), organised according to latitude (rows) and longitude (columns). In general, Northern regions will show higher TCI values than presently over the entire century. This trend becomes more pronounced over time and with increased warming, with some top northern regions becoming suitable for summer tourism by end of century under high-emissions (high warming) scenarios.

In mid-latitudes, we observe a mixed response depending on the scenario and region considered. There are some regions showing a behaviour similar to what is observed in northern areas, i.e., generalised better conditions reflected in a gradual parallel upward shift of the curve over time. Other regions will experience a clear decline in TCI values during summer months. A decrease that, in some cases, could be potentially offset by the presence of better conditions during shoulder seasons.

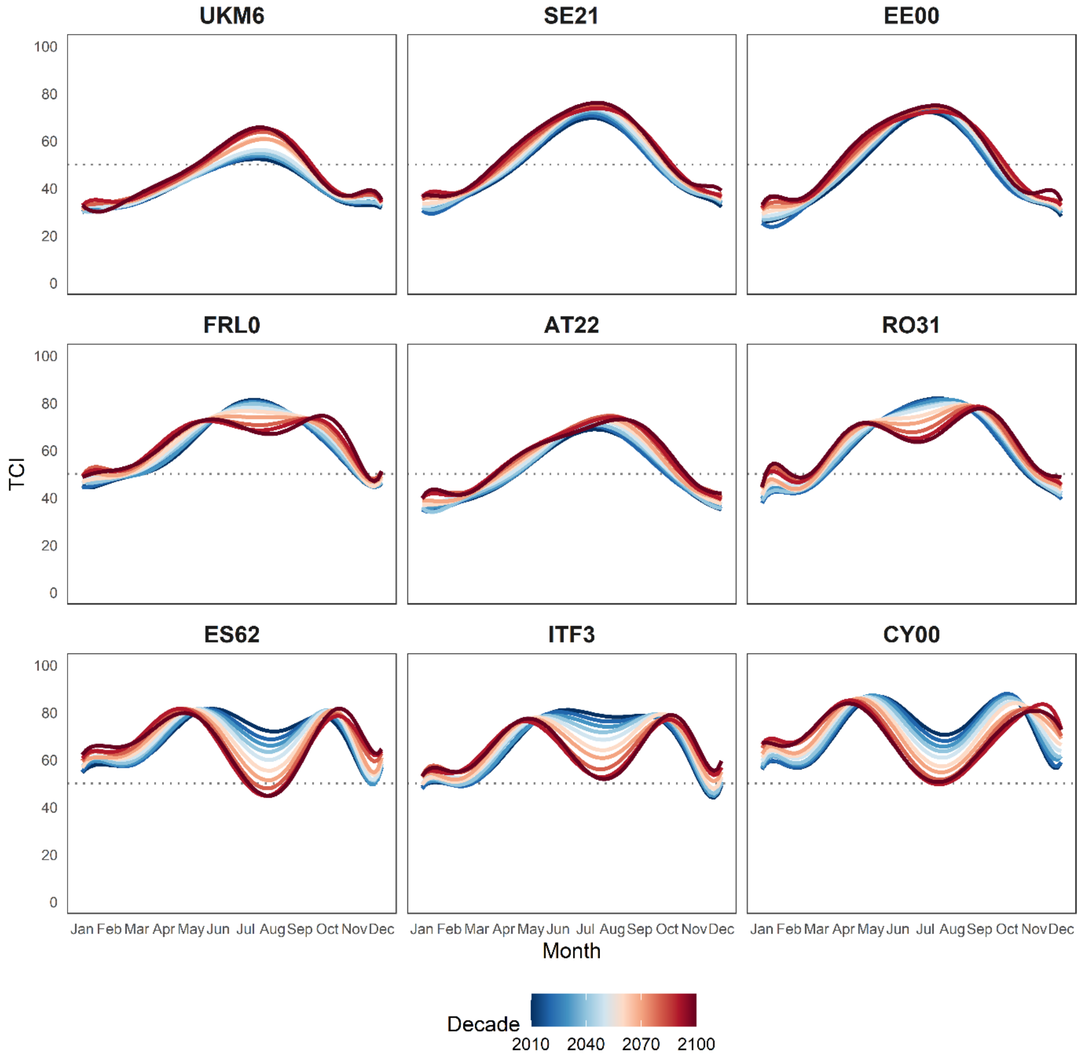
Southern European regions show an unequivocal signal towards worse conditions for tourism during summer. This decrease can be substantial in many areas, potentially becoming unsuitable for tourism under stringent warming. A displacement of the two shoulder seasons is also expected, taking place spring earlier and fall later in the year, respectively. Figure 11 compares the TCI curve for Andalusia (Spain) between the years 2020 and 2100, illustrating both the displacement of the two shoulder seasons and the unequivocal signal towards worse conditions for tourism during summer in southern European regions.

Figure 9. Projected mean evolution of the TCI at different NUTS 2 regions under emission scenario RCP4.5. Rows and columns are representative of different latitudes and longitudes, respectively.



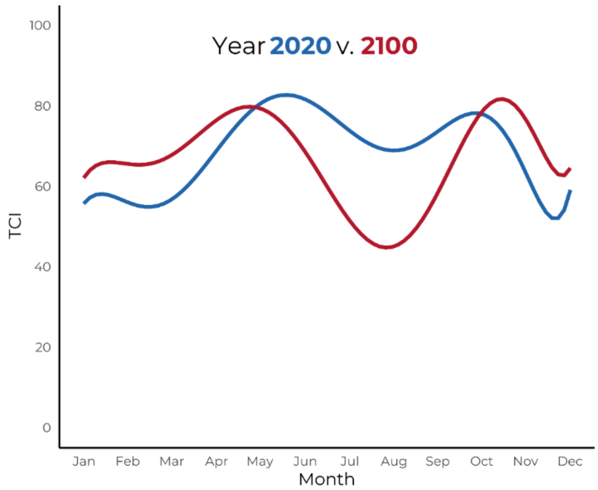
Source: JRC analysis. TCI values below 50 denote unfavourable conditions for tourism.

Figure 10. Projected mean evolution of the TCI at different NUTS 2 regions under emission scenario RCP8.5. Rows and columns are representative of different latitudes and longitudes, respectively.



Source: JRC analysis. TCI values below 50 denote unfavourable conditions for tourism.

Figure 11. Current versus year 2100 TCI annual profile in Andalusia (Spain) under the emission scenario RCP8.5.



Source: JRC analysis.

4 Results

4.1 Empirical results

By estimating equation (1) we found a statistically significant relationship between the evolution of bed nights and the climate suitability index TCI, for the extensive panel data modelled. Table 6 presents the parameter estimates and their significance obtained by using a fixed effects panel analysis with regional clusters.

Table 6. Years when the warming levels are reached for the individual RCMs and GCMs, and the two RCPs considered.

lnBN	Estimate	Drisc/Kraay std. err.
Constant	5.415	
lnTCI	0.569	(0.045)***
lnGDP	0.318	(0.079)***
lnHICP	0.519	(0.167)***
lnTCI*Urban	-0.009	(0.033)
lnTCI*Coast	0.651	(0.031)***
lnTCI*Nature	-0.186	(0.029)***
lnTCI*SnowMount	-0.439	(0.031)***
lnTCI*Rural	-0.071	(0.025)***
lnTCI*Mixed	0	(empty)
Winter	-0.176	(0.02)***
Spring	0.036	(0.023)
Summer	0.542	(0.026)***
Autumn	0	(empty)
Observations	64524	
R^2 -within	0.632	
F-statistics	564.32***	

*Source: JRC analysis. The asterisks indicate that the coefficient is significant at the *10%, **5%, and *** 1% level.*

The results of the 20-year monthly panel data model of the 269 European regions show that all determinants considered have statistically significant influence in explaining tourism demand, except the interaction term between the TCI and the 'Urban' regional typology.

A higher climate comfort level is estimated to have a positive effect on the monthly evolution of tourism flow (coefficient = 0.569), an impact that varies in magnitude according to the tourism segment considered. The tourism demand model developed confirms what other studies have anticipated (Gössling & Hall, 2005; Scott, Hall, & Gössling, 2012; IPCC, 2022), namely that coastal destinations are considered particularly sensitive to climate-induced environmental change. Thus, an additional positive effect is estimated when controlling for the Coastal regions (+0.651, with a total effect of 1.2), whereas Snow Mountain, Nature and Rural regions create an additional negative effect of the TCI on the total number of bed nights (-0.439, -0.186 and -0.071, respectively). Note that the fifth category (the "Mixed") was excluded from the interaction to avoid multicollinearity.

Moreover, the two economic control variables (GDP and the level of prices) show a positive and statistically significant effect on the number of bed nights, estimating that a 1% increase in GDP leads to around a 0.31% increase in tourism demand. The estimated sign of the price effect is somehow counterintuitive as one would expect a negative elasticity. Furthermore, seasonality patterns of the tourism demand are also accounted for, confirming that the summer period has a strong positive effect on the number of bed nights, while the winter months negatively affect the tourism demand when considering the entire European panel dataset. Of course, the impact of each season varies when estimating the model individually for each Member State, the winter season having a significant positive impact in countries like Austria and France where winter sports regions are driving the tourism demand in that specific season.

We estimated the Hausman test to discriminate between fixed and random effects and the p-value of 0.002 clearly indicates that the proper model to use is the fixed effects one. We have performed various post estimation diagnosis tests for cross-sectional dependence (using Breusch-Pagan LM test of independence), heteroscedasticity and auto-correlation, and to avoid and control for all these disturbances, we have used Driscoll-Kraay standard errors. Besides being heteroskedasticity consistent, these standard error estimates are robust to general forms of cross-sectional ("spatial") and temporal dependence, when the time dimension is sufficiently large. Although Driscoll and Kraay standard errors tend also to be slightly optimistic, their small-sample properties are considerably better than those of the alternative covariance estimators when cross-sectional dependence is present (Hoechle, 2007). Moreover, we have also performed a variety of tests for unit roots (Augmented Dickey Fuller), all rejecting the null hypothesis and confirming that all variables in the panel dataset are stationary, including the dependent one, meaning that their statistical properties do not change over time.

4.2 Tourism demand projections

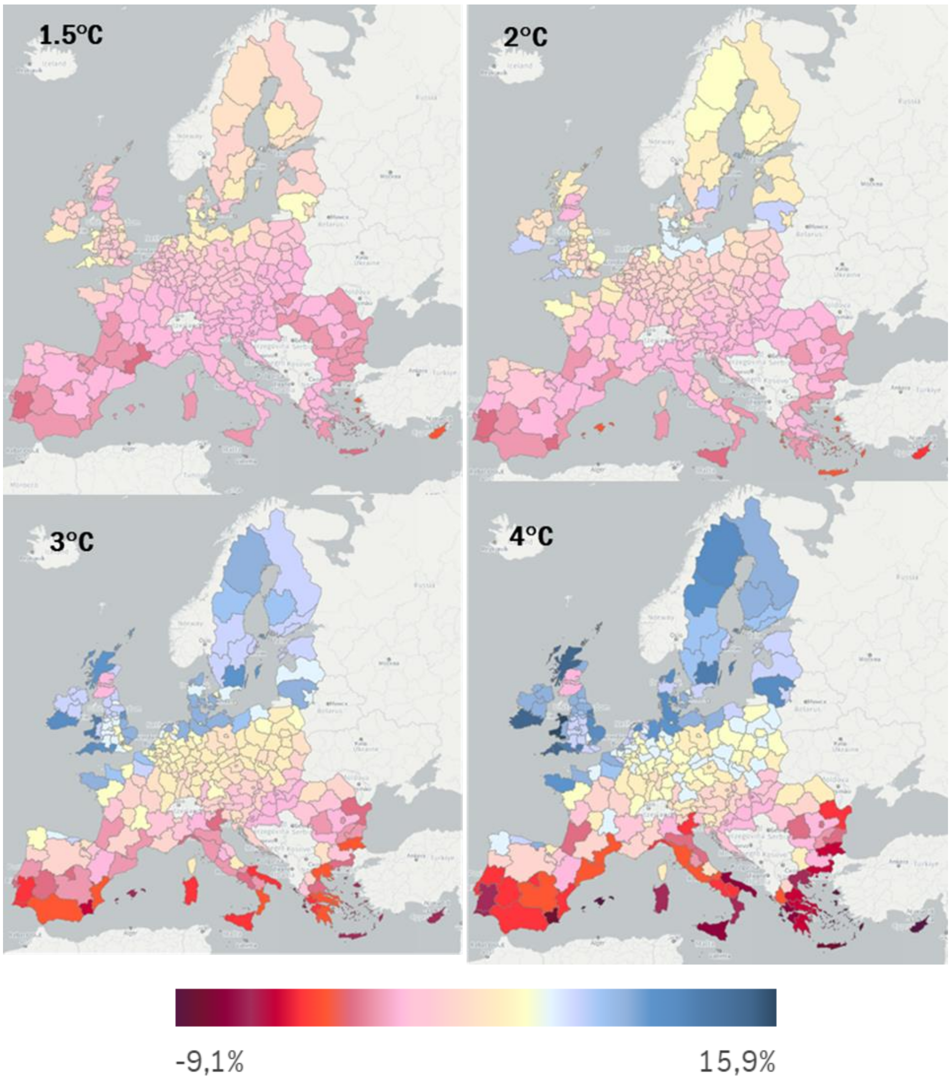
We simulate how the European regional demand will be altered under future climate change using the climate variables data from 10 regional climate models (RCMs). The impacts are estimated for the global warming targets set out in the Paris Agreement targets (1.5°C and 2°C) as well as two higher warming levels (3°C and 4°C). They are compared with the 2019 historical base year, built using the EURO-CORDEX climate variables dataset.

The main assumption underlying the model is that the econometric model coefficients (representing the input that the impact variables have on tourism demand) will remain stable over the projection period (2020–2100). Moreover, the economic determinant of the tourism demand will also be held constant to the base year 2019.

The projected changes from the base year 2019 in regional tourism demand under the 10-model-ensemble-average, for the four global warming levels are represented in Figure 12. The climate change impact varies considerably across the various regions of the EU, and we can clearly observe a north-south pattern. Whereas Mediterranean and Southern European regions are projected to see a considerable drop in the tourists' volumes (i.e., total number of bed nights) due to climate change, regions in higher latitudes are projected to experience an overall increase in tourism demand.

In a 1.5°C warming climate, the majority (80%) of the European regions are projected to be affected by climate change only in a rather small proportion, the flow of tourists visiting those regions fluctuating between -1% and +1%. The highest decline is estimated to occur in Cyprus (-1.86%) while the maximum increase could happen in a Finish coastal region (+3.25%). The results are rather similar for the 2°C warming scenario.

Figure 12. Projected evolution of the European regional tourism demand for all the global warming scenarios, compared to the present (2019) in percentage terms.



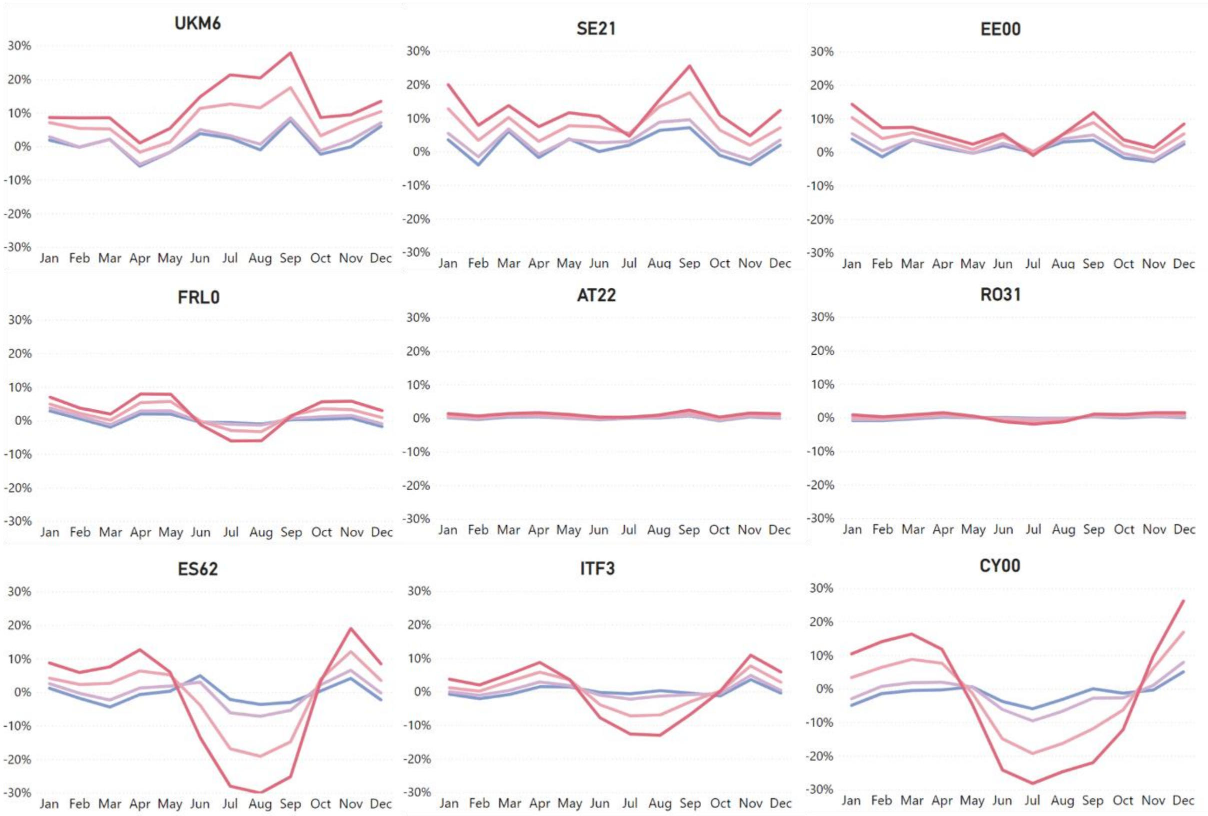
Source: JRC analysis. The values shown refer to the RCP8.5 emission scenario.

Under the 3°C and 4°C warming scenarios, significant shifts in the demand patterns are projected for Europe, with a clear north-south pattern arising. The Central and Northern Europe regions are projected to become more attractive for tourisms activities year-round, to the detriment of the Southern and Mediterranean areas. In a 4°C global warming scenario, 80 percent of the regions are projected to increase their tourism demand with respect to 2019. Growth rates higher than 3% in the number of bed nights are foreseen for a total of 106 regions (light to dark blue shaded regions in the map above). On the other hand, 52 European regions across Bulgaria, Greece, Cyprus, Spain, France, Italy, Portugal, and Romania are projected to lose tourist flows with respect to the present.

Coastal and islands regions are known to be highly vulnerable to impacts of climate change and this is also confirmed by our analysis, where the coastal regions are projected to face the highest impacts in tourism demand for the higher warming scenarios. Thus, when looking at variations larger than +/- 5% in the number of bed nights with respect to the base year, 63% of the affected European regions are coastal areas, destinations that are also simulated to experience the maximum disruptions in tourism demand (i.e., +16% in West Wales and -9% in Greek Ionian Islands) under an extreme global warming scenario. Additionally, the largest losses (<-5%) are projected across Cyprus, Greece, Spain, Italy, and Portugal regions, while the highest gains (>+5%) are distributed across Germany, Denmark, Finland, France, Ireland, Netherlands, Sweden and United Kingdom.

Other than the geographical redistribution, the seasonal patterns of the European tourism are also projected to be altered considerably, with summer months becoming less attractive while shoulder and winter seasons will be more appealing as climate conditions will improve. Figure 13 presents the projected seasonal shift across various regions in Europe, while Figure 14 shows the changes in the overall European monthly pattern for the different global warming scenarios.

Figure 13. Projected evolution of the monthly tourism demand in different regions (compared to the present, in percentage terms) across the various global warming levels scenarios.

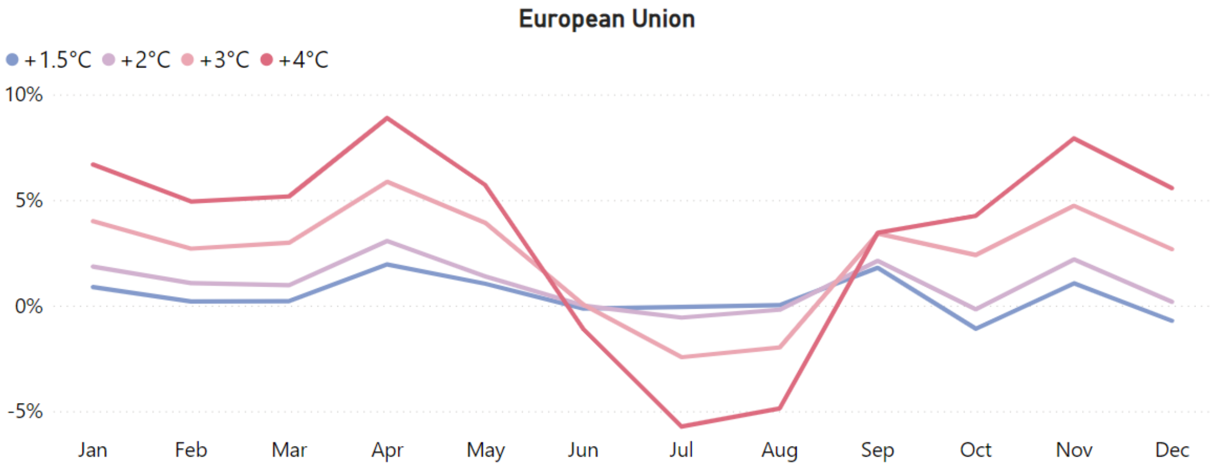


Source: JRC analysis. The values shown refer to the RCP8.5 emission scenario.

There is substantial heterogeneity across regions regarding the projected seasonal shifts in tourism demand patterns. The coastal regions in Northern Europe for example (UKM6 and SE21) are projected to register substantial increase (>+5%) in demand during summer and early autumn months, while at the opposite side, the Southern coastal regions (e.g., ES62 and CY00), strongly lose (<-10%) their summer tourist flows with respect to today, especially in the warmer climate scenarios (3°C and 4°C). In these latter regions, the drop in summer demand is somewhat compensated, even if not entirely, by the increases registered during spring, autumn and winter. Regarding the other types of regions, the Urban ones (e.g., EE00 and FRL0) are projected to have different demand shifts across the warming levels considered, depending also on the geographical position they are situated, while the Snow Mountain regions in Central Europe (e.g., AT22 and RO31) are projected to experience minimal increase in the number of bed nights during shoulder seasons and winter, ranging between +0.19% and +2%, depending again on the warming scenario.

When concentrating on the overall European Union, the tourism demand is projected to increase in the spring (March to May) and fall (September to November) shoulder seasons, and this increase is accentuated with the degree of warming level considered. For example, the month of April is projected to record the highest increase in tourist flows in Europe, growing by 1.96% in the 1.5°C warming scenario, with an increase of 8.89% in the 4°C scenario. On the other hand, the sharpest fall in the European tourism demand is projected in July, starting from a decrease of -0.06% in 1.5°C scenario and reaching -5.72% under the warmest climate scenario.

Figure 14. Projected evolution of the overall European monthly tourism demand (compared to the present, in percentage terms) for the various global warming levels scenarios.

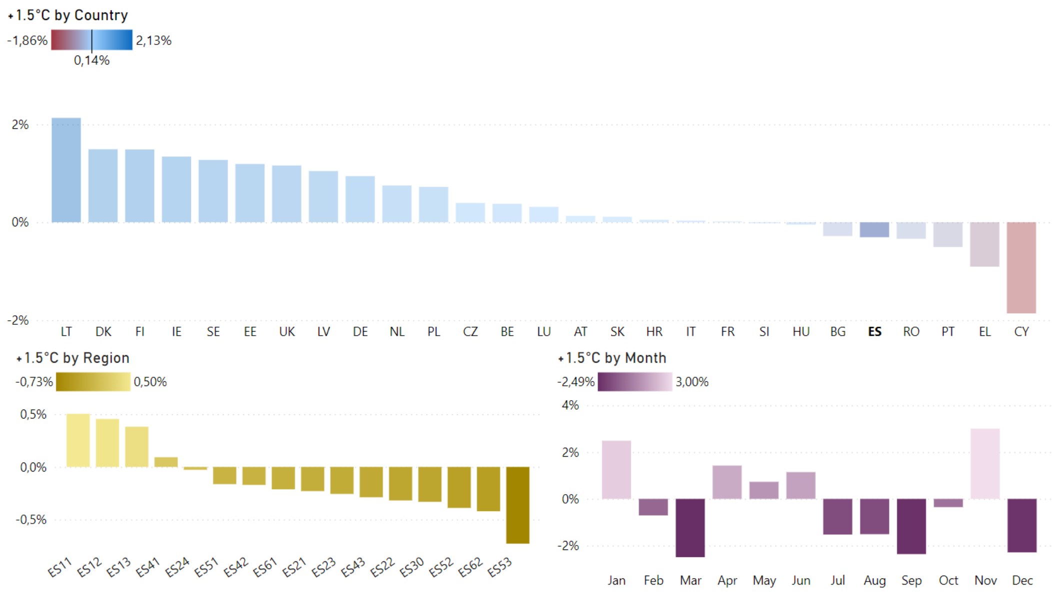


Source: JRC analysis. The projected European monthly tourism demand was obtained by summing up across the regions and countries the projected evolution of the regional tourism demand, in a given month. The values shown refer to the RCP8.5 emissions scenario.

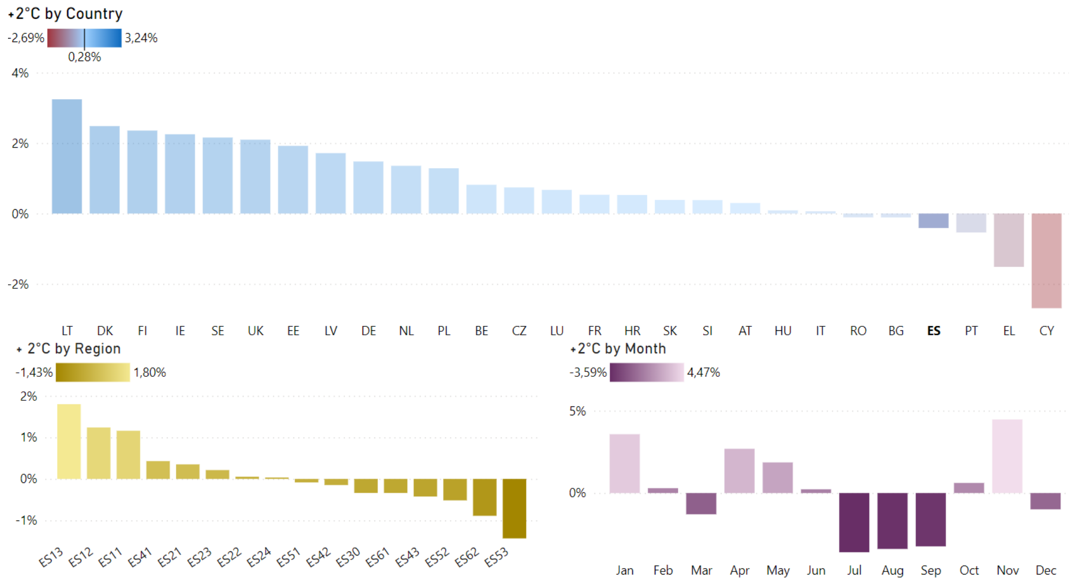
A closer look to the geographic and seasonal pattern shifts projected across the four global warming scenarios for Spain and Sweden is offered in Figure 15 and Figure 16, respectively. Each figure is divided into four parts, representing the four warming scenarios (A, B, C, and D for 1.5°C, 2°C, 3°C and 4°C, respectively). Each part contains three small figures: the one on the top represents the tourism demand changes for all European countries, the figure on the bottom left represents the tourism demand changes for each region in the selected country, and the figure on the bottom right represents the country demand changes for each month of the year.

Figure 15 A-D. Projected impact of tourism demand for Spain, by region and month, presented as a percentage change compared to 2019, for the four global warming levels considered.

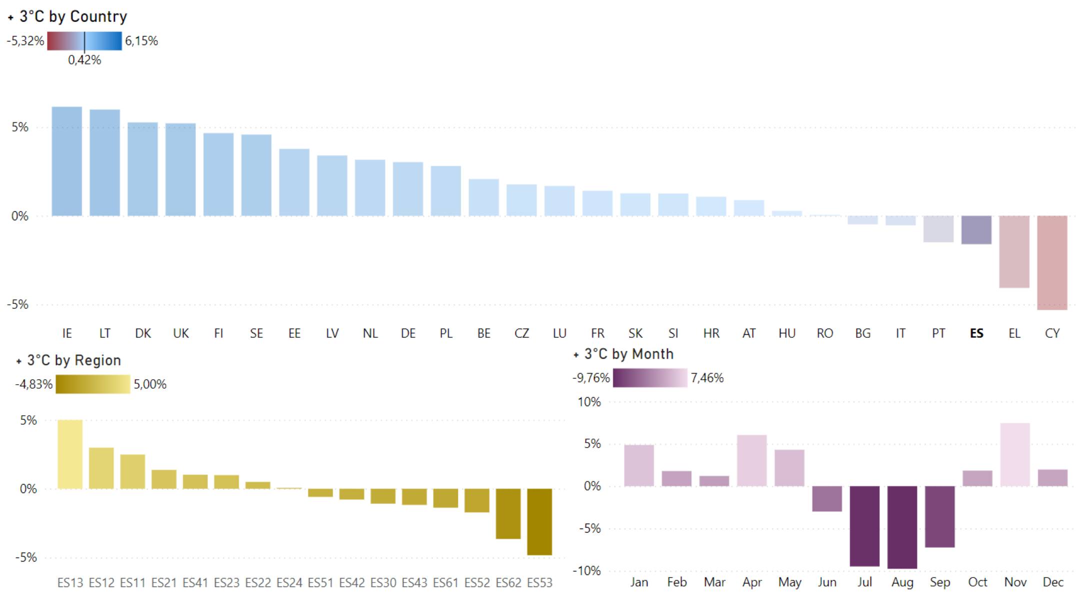
A.



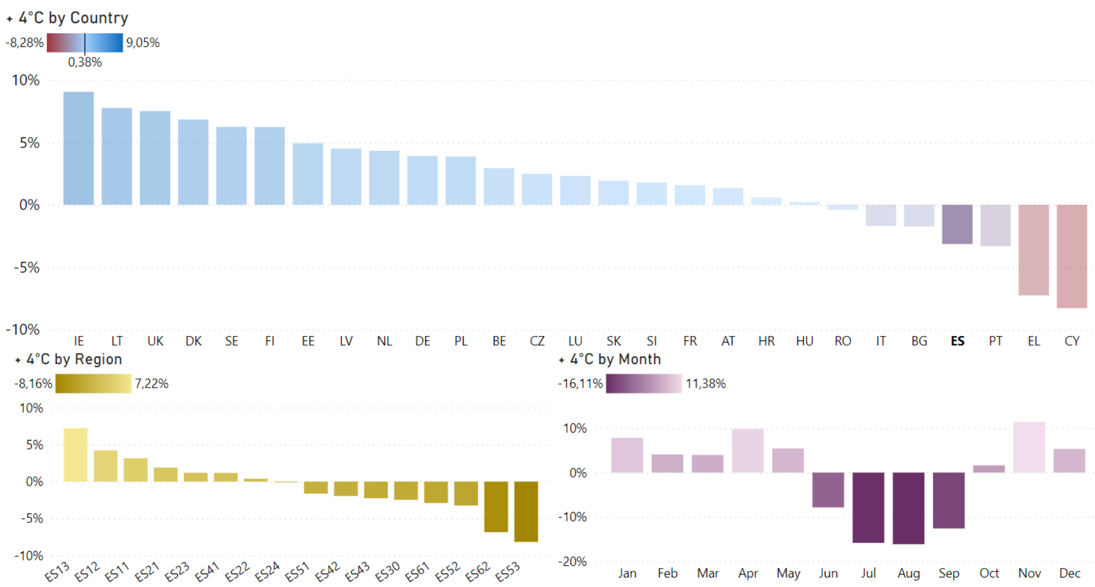
B.



C.

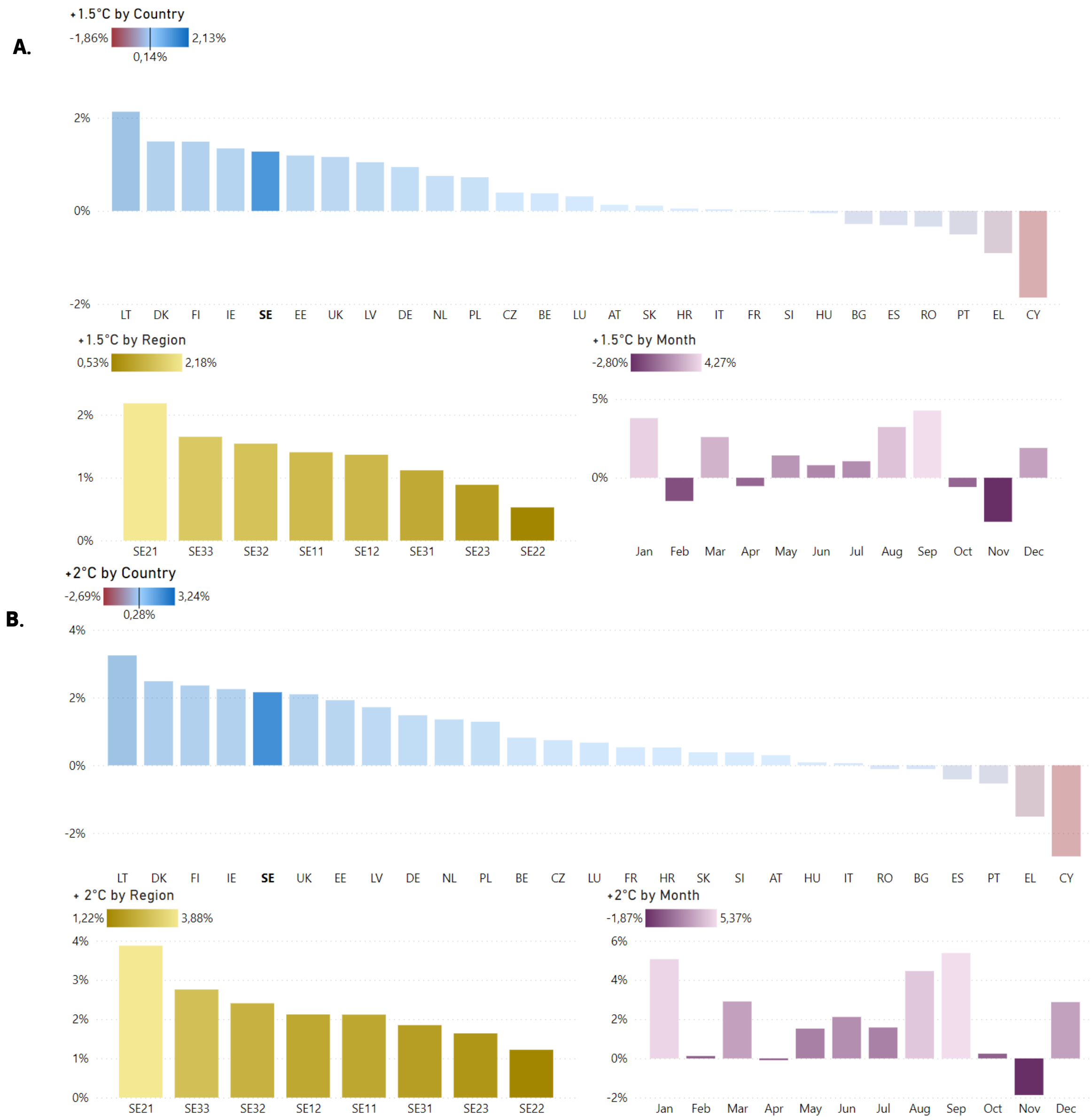


D.

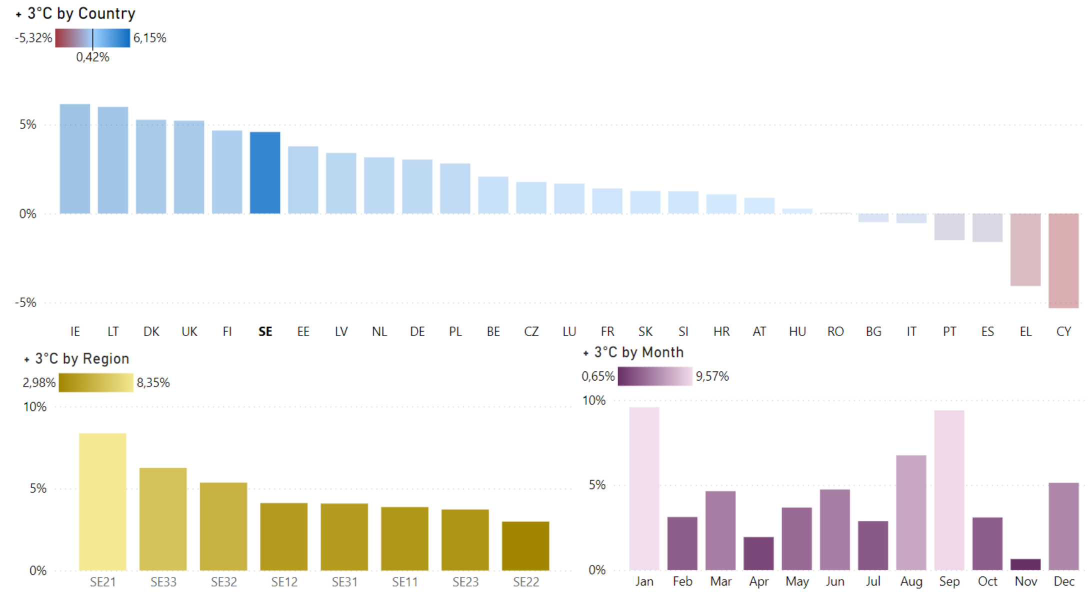


Source: JRC analysis.

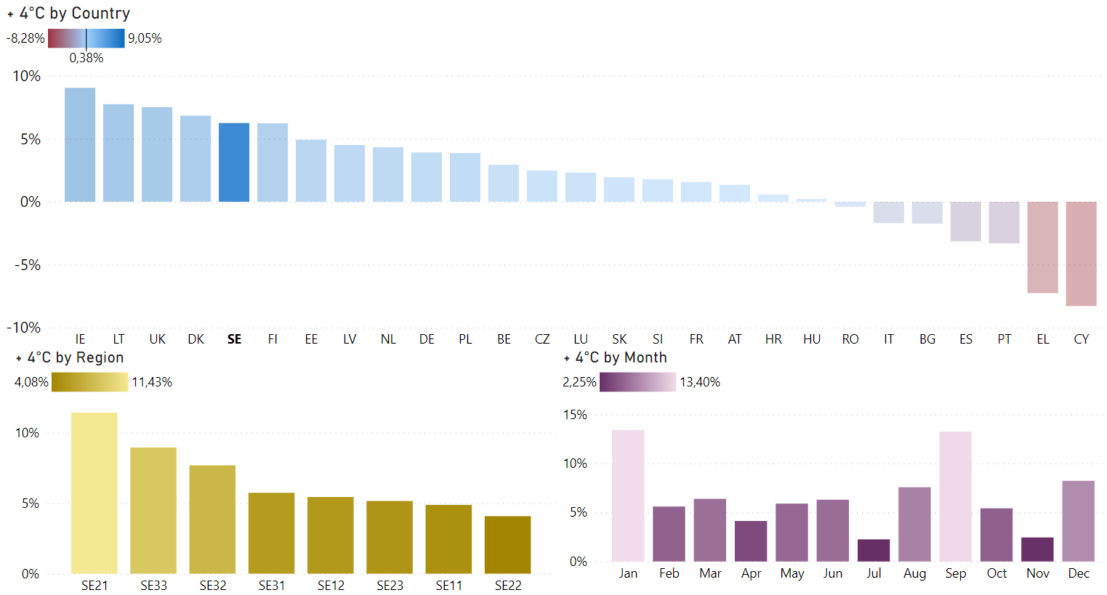
Figure 16 A-D. Projected impact of tourism demand for Sweden, by region and month, presented as a percentage change compared to 2019, for the four global warming levels considered.



C.



D.



Source: JRC analysis.

The country-level simulated evolution of the tourism demand with respect to the present (2019) is reported in Table 7, where the figures are obtained by summing up the projected number of bed nights by month and region for each global warming level scenario, and then taking the difference with respect to the 2019 country specific number of bed nights. The overall effect on the European Union's tourism demand is positive in each of the warming scenarios considered, the demand being projected to increase by 1.58% under the 4°C scenario. From this country perspective, the noted north-south pattern is also apparent. Southern countries face tourism demand reductions in all global warming scenarios, with considerable drops in Cyprus, Greece, Spain, and Portugal. Despite these losses, the relatively large positive effects of climate change projected in Northern and Central European countries fully compensate for the drops in number of bed nights.

It is also interesting to note that the changes in tourism demand are in general non-linear with respect to the change in warming levels. For example, moving from the 2°C warming scenario to the 4°C warming scenario (i.e., doubling the warming levels) would mean much more than doubling the relative demand reduction in Spain (from –0.4% in the 2°C scenario to -3.1% under the 4°C scenario). Similar non-linear effects would occur in Portugal and Greece. In the case of positive changes, that non-linearity also occurs in many countries. For example, moving from the 2°C warming scenario to the 4°C warming scenario (i.e., doubling the warming levels) would mean much more than doubling the relative demand reduction in UK (from +2.1% in the 2°C scenario to +7.5% under the 4°C scenario).

Table 7. Projected evolution of the tourism demand at country level compared to the present (2019), in percentage terms, for the different global warming scenarios.

	+1.5°C	+ 2°C	+3°C	+ 4°C
AT	0.13%	0.30%	0.88%	1.35%
BE	0.38%	0.82%	2.07%	2.93%
BG	-0.28%	-0.11%	-0.48%	-1.74%
CY	-1.86%	-2.69%	-5.32%	-8.28%
CZ	0.39%	0.74%	1.77%	2.49%
DE	0.94%	1.48%	3.03%	3.91%
DK	1.49%	2.48%	5.27%	6.83%
EE	1.19%	1.92%	3.78%	4.93%
EL	-0.91%	-1.51%	-4.07%	-7.26%
ES	-0.31%	-0.41%	-1.60%	-3.14%
FI	1.49%	2.36%	4.66%	6.23%
FR	0.01%	0.53%	1.41%	1.57%
HR	0.05%	0.53%	1.08%	0.58%
HU	-0.05%	0.09%	0.28%	0.22%
IE	1.34%	2.25%	6.15%	9.05%
IT	0.03%	0.06%	-0.54%	-1.69%
LT	2.13%	3.24%	5.99%	7.75%
LU	0.31%	0.67%	1.68%	2.31%
LV	1.05%	1.71%	3.40%	4.50%
NL	0.75%	1.35%	3.16%	4.33%
PL	0.72%	1.29%	2.81%	3.87%
PT	-0.50%	-0.54%	-1.49%	-3.31%
RO	-0.34%	-0.11%	0.03%	-0.40%
SE	1.27%	2.16%	4.58%	6.25%
SI	-0.01%	0.38%	1.26%	1.80%
SK	0.11%	0.39%	1.27%	1.94%
UK	1.16%	2.10%	5.22%	7.51%
EU	**0.35%**	**0.71%**	**1.45%**	**1.58%**

Source: JRC analysis. The values shown refer to the RCP8.5 emissions scenario.

5 Conclusions

This study estimates the historical role of climate on the European tourism demand and assesses the possible effects of future climate change for various warming levels. We find a consistent and robust historical influence of climate on tourism demand across EU regions, while accounting for seasonality and geographical patterns, and considering various regional typologies (e.g., coastal and urban). Using an extensive panel dataset of 269 NUTS 2 European regions tourism over the 2000-2019 period, we developed a fixed effects econometric model linking the total number of tourists' bed nights to a climate-related index of human comfort (the Tourism Climate Index, TCI) and economic control variables (price and income). Our analysis shows that a 1% increase in TCI leads to a 0.57% increase in the monthly regional number of bed nights, with the magnitude of the impact differing according to the specific tourism typology; we find the highest response in the coastal regions, with an elasticity of 1.2%. The tourism demand model developed confirms previous findings, that coastal destinations are more susceptible to climate conditions.

At a second stage, we assess climate change risk on future tourism demand, by generating monthly and regional tourism demand projections for four climatic futures: the Paris Agreement targets (1.5°C and 2°C) and two higher warming levels (3°C and 4°C), considering an ensemble of 10 regional climate models, under a moderate mitigation (RCP4.5) and a high emission (RCP8.5) scenarios. Under a 4°C scenario, significant changes are projected in tourism demand. The projected overall impact on European tourism demand is expected to be positive, with a projected rise of 1.58% for the highest warming scenario, but the aggregated results hide a high degree of heterogeneity across regions. We find a clear north-south pattern, with tourism demand gains in Central and Northern areas and demand reductions in southern zones. The most significant effect of climate change on tourism demand is projected for coastal regions, e.g., a decrease of -9.12% in the Greek Ionian Islands and an increase of +15.93% in West Wales (UK) under the highest emission scenario.

The tourism seasonality patterns are also expected to change with varying impacts across regions. Northern European coastal regions are projected to register a significant increase in demand during the summer and early autumn months, whereas southern coastal regions are expected to lose tourists during the summer, particularly in the warmer climate scenarios. The greatest increase in tourist activity throughout Europe is projected in the month of April, with an estimated rise of +8.89% compared to the current situation in a 4°C scenario. On the other hand, the greatest decrease in European tourism demand is expected in the month of July, varying from -0.06% in the 1.5°C scenario to -5.72% under the warmest climate scenario.

The present study is preliminary and subject to some limitations that should be acknowledged, some of which also represent opportunities for future research. For example, the analysis does not account for changes in tourists' preferences or awareness of climate change and its potential environmental consequences, which could impact travel patterns and modes. Additionally, our estimation results are subject to the inherent limitations of the TCI (Scott et al., 2016). These include: (1) the subjective rating and weighting system of climatic variables not empirically tested against the preferences of tourists or any other tourism performance metrics; (2) the TCI neglects the possibility of an overriding influence of physical climatic parameters (e.g., rain, wind) with a specific over-emphasis on thermal comfort, which comprises half of the index's weight; (3) the low temporal resolution of climate data (i.e., monthly data) has limited relevance for tourist decision-making; and (4) it ignores the varying climatic requirements of major tourism segments and destination types (i.e., beach, urban, winter sports tourism). The Holiday Climate Index (HCI, Scott et al., 2016), based on tourist's stated climate preferences was developed to address the key limitations of the TCI and can be used in future revisions of the present work.

This initial study serves as a foundation for various extensions and future research developments. Firstly, considering the importance of coastal regions in Europe and the fact that these areas are considered particularly sensitive to climate-induced environmental change, we plan to focus on this specific tourism segment and analyse the impacts and implications of climate change on costal-beach tourism. To do this, we intend to employ the newly designed climate index—the Holiday Climate Index HCI:Beach as to account for tourists' stated preferences and the climate suitability of the coastal regions, together with other sector specific control variables.

Secondly, we will turn our attention to winter tourism destinations and utilize the Mountain Tourism Meteorological and Snow Indicator (Morin et al., 2021) to assess the historical and future climate impact on winter tourism demand, a sector with major socio-economic role in the snowy and mountainous regions of Europe.

Thirdly, to gain a deeper insight into the regional variation of factors affecting demand and to identify any disparities in the effects of climate change on tourism demand, we aim to analyse the intricate relationship between tourism demand and climate change at the NUTS 3 sub-regional level in certain countries or tourism segments where this level of geographical disaggregation could make a significant difference.

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List of abbreviations and definitions

CC	Cloud Cover
CIA	Daily Comfort Index
TCI	Tourism Climate Index
UNWTO	World Tourism Organization

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