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Climate and carbon risk of tourism in Europe

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ABSTRACT

Europe accounts for 51% of international tourist arrivals and the tourism industry provides about 10% of workplaces in Europe. Tourism will be impacted by climate change in a diverse number of ways. At the same time, tourism is also a significant contributor of greenhouse gas emissions. The aim of this article is, therefore, to provide an assessment of climate and carbon risks for the European tourism industry based on a systematic literature review. Climate risk is the dominant category with 313 papers (74%), while 110 papers (26%) were on carbon risks. The following gaps were identified: geographical gaps, especially in countries of the former Soviet Union and former Yugoslavia; a lack of coherent studies on national tourism's and its sub-sectors' emissions; research addressing how climate policies might affect tourism demand; assessments of the integrated carbon and climate risks; lack of evidence on the link between tourism climate indicators and tourism demand; lack of climate change and tourism studies addressing policy and institutional tools for adaptation and implementation of adaptation measures in destinations; and research on rising sea levels and coastal erosion and its impacts on tourism destinations and demand.

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Climate risk; carbon risk; tourism; Europe; systematic review; adaptation; mitigation

Introduction

Climate change is an immense challenge for society. More than a decade since the publication of the UNWTO/UNEP/WMO (2008) report on climate impacts on tourism, it is clear that tourism worldwide has to adapt to numerous climate-related changes and increase its efforts to reduce greenhouse gas (GHG) emissions. Due to the intensity of its economic development and because tourism is highly climate-sensitive—e.g. the appeal of a landscape, weather/climate as pull and push factors and natural resources required for outdoor activities (UNWTO, 2021)—tourism in Europe is confronted with numerous challenges related to climate change impacts, adaptation and mitigation (Scott, 2021). Together with a high economic relevance of tourism in many European countries, especially in the Mediterranean (World Bank, 2022), these challenges highlight the need for a comprehensive assessment of available research.

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The IPCC AR6 summary of the observed changes over the European continent since 1950 shows an increase in hot extremes in all regions (AR6 WG1 reference regions), an increase in heavy precipitation in all regions except the Mediterranean and an increase in drought in Western and Central Europe (Masson-Delmotte et al., 2021). For the future, projected warming (median of climate model results relative to 1850–1900) is 2.3 °C–2.5 °C for 2021–2040, 2.6 °C–3.7 °C for 2041–2060 and 2.6 °C–6.7 °C for 2081–2100 (Gutiérrez et al., 2021). There is high confidence that extreme heat events will increase throughout the 21st century across all areas extending from the Mediterranean (MED) to Eastern (EEU), Northern (NEU) and Western and Central European (WCE) regions—at a rate above that of the global average (Arias et al., 2021). In terms of precipitation, there is high confidence that there will be a future decrease in the MED, along with increases in aridity, droughts and fires, as well as increases in heavy precipitation and pluvial floods in the EEU, the NEU and the WCE. The entire continent will also face an increase in severe windstorms (medium confidence). The cryosphere (snow cover, glaciers) is also significantly affected: for example, snow cover in the Alps will decrease below 1500–2000 masl (high confidence) and periglacial processes in the Nordic countries are likely to disappear by the end of the century (medium confidence) regardless of the warming rate. Glaciers in the European Alps are projected to lose two thirds of today's ice mass in a low emission (RCP 2.6) late century or might be mostly ice-free in a high emission scenario (RCP 8.5) (Zekollari et al., 2019). Last but not least, the European coastline is open to increasing risks (high confidence) from rising sea levels, coastal floods and erosion, marine heatwaves and acidification (including lakes) (Arias et al., 2021). The consequences of such physical changes undoubtedly imply further impacts on the vulnerability of the European tourism market.

In addition to the effects of climate change on tourism, the urgent need to reduce greenhouse gas (GHG) emissions, endorsed by the Paris Agreement, implies the implementation of a carbon reduction policy that constitutes another challenge for the tourism industry and tourism-related transport sector (Scott & Gössling, 2022), which accounts for more than 8% of GHG emissions worldwide (Lenzen et al., 2018). As the latest UNEP report shows, current climate change mitigation policies are estimated to result in a warming by 2.8 °C by the end of this century (UNEP, 2022), notably still far off the Paris Agreement goal of limiting global warming to well below 2 °C. According to UNWTO and the International Transport Forum (ITF), the tourism sector is not at all on the path of reducing emissions but is predicted to even increase its CO_2 emissions by at least 25 percent by 2030 (UNWTO & ITF, 2019). Yet climate does not seem to be a priority for tourism policy makers (Becken et al., 2020), and it seems imperative to provide a clear view of the situation in the European tourism market.

Accordingly, the aim of this article is to provide an assessment of the climate and carbon risk (Scott & Gössling, 2022) with a specific focus on the tourism industry on the European continent. To this end, we conducted a systematic literature review with an emphasis in results presentation on contributions published since the IPCC's Fifth Assessment Report (IPCC, 2014). To our knowledge, this is the first review that includes both climate and carbon risks of the tourism industry on the European continent and that is not limited to specific forms of tourism. A research agenda is derived from the state of the art of research and highlights urgent knowledge gaps that need to be addressed to better inform the tourism industry on potential climate risks and the needs and options for adaptation and mitigation.

Methods

The literature search was conducted in the Web of Science database (Clarivate, 2022). The search terms 'climat* chang* AND touris*' were used in combination with all countries on the European continent (Figure 1). We also included countries (Azerbaijan, Armenia, Georgia, Kazakhstan, Russia and Turkey), where only parts lie on the continent according Ural mountains and river delineation.

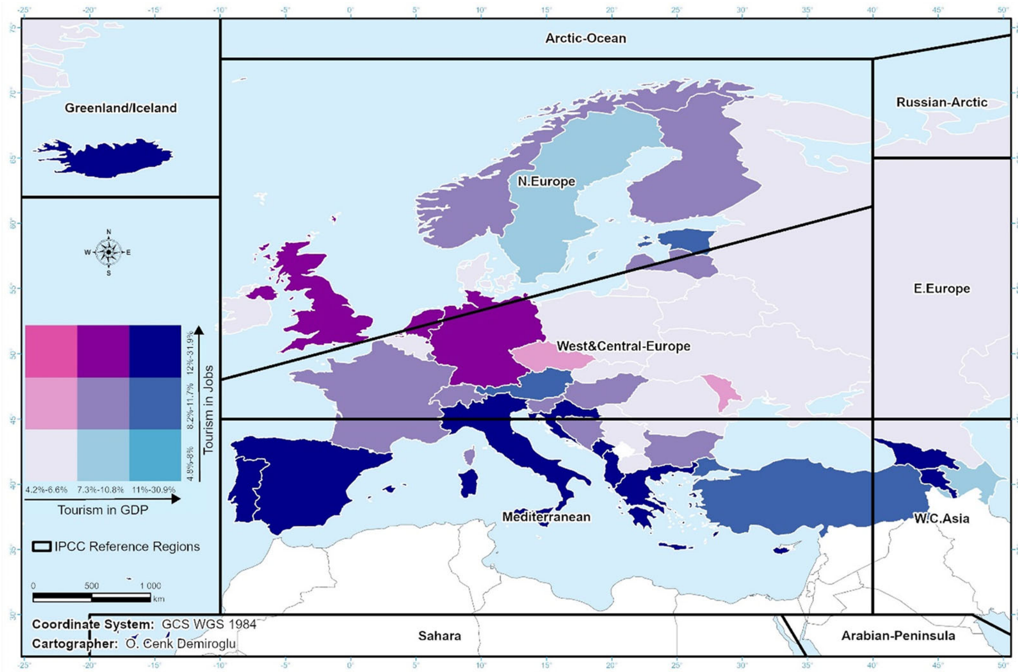

Figure 1. Total Contribution of Tourism to GDPs and Employment in Europe in 2019.
Data source: WTTC, 2021 (detailed data see Table A1 in the Appendix)

Furthermore, we also used the following search terms: Euro*, Mediterranean, Balear*, Scandinavia* and major mountain regions (Alp*, Apennin*, Carpath*, Caucaus*, Pyrenee*). As literature on tourism's contribution to climate change was underrepresented in this research, we conducted an additional search with 'CO2 AND touris*' in combination with the above-mentioned terms. The search was limited to publications in English language mainly because of two reasons: an initial review of a random sample of publications in French, German, Spanish and Turkish revealed only little additional value to English publications. Furthermore, as the author team could only cover a small fraction of languages in Europe, there is a risk of getting skewed results towards these countries, whereas English language is open for the international academic community.

Using the above-mentioned search strings, we found 1340 articles. The title and abstract of these articles were screened to identify whether the article investigated climate and/or carbon risk to the tourism industry. We excluded papers, if one of the following criteria were met:

Articles where tourism or climate change were not the focus: For example, where tourism is mentioned in the introduction or discussion section, e.g. that tourism is an important source of income in the studied region (introduction), but no further analysis of tourism is made; or that tourism could be affected by climate change (discussion) without specifying how it would be affected. The same applies to climate change: sometimes climate change is mentioned as one of the big challenges for tourism in the introduction; but, the actual paper is not about climate or carbon risks to the tourism industry.

We also excluded articles investigating the sensitivity of tourism indicators to weather variables. We acknowledge that this is important work to understand the type and magnitude of relationships between weather/climate and tourism. However, in this article, we focus on potential future impacts including research on the type and severity of expected impacts as well as the industry's contribution to climate change and options for adaptation and mitigation.

According to these criteria, we reviewed 423 articles. A data base with the following information for each article was created: research objectives, methodology, investigated region and key findings. Based on this data, the content structure of this article was jointly developed by all authors. Climate risk was the dominant category accounting for 313 papers (74%), while 103 papers (24%) were on carbon risks and seven papers (2%) illustrated both climate and carbon risk. For the sake of readability, we did not cite each and every one of these 423 papers. Especially in sub-fields with a high number of papers, e.g. change in the climatic suitability for tourism in Europe or climate change impacts on ski tourism, fewer studies are cited in the text than were reviewed. Where more papers were available than were citable in the text, the aim was to cite more recent work, especially work published after the IPCC's Fifth Assessment Report (IPCC, 2014) and from different geographical areas.

Tourism in the European region

According to data from the World Bank (World Bank, 2022), Europe accounted for 51% of international tourist arrivals in 2017. France, Spain and Italy top the list with a market share of 37% within Europe. However, the relative importance of the tourism industry for national economies, exemplified by the direct, indirect and induced contributions, shows a distinct pattern (Figure 1). According to this pattern, many of the Mediterranean and Caucasian countries, as well as Iceland, benefit from, but also depend upon the travel and tourism sector, in terms of GDP and employment. By contrast, many Eastern and Central European countries fall into the category where the relative total contributions of tourism to both GDP and employment are at the lowest. In special cases such as Andorra, where the direct and direct + indirect contributions of tourism to GDP are 40% and 61%, respectively, the national economy's dependency on the tourism sector can be very critical (Pons et al., 2013). This is also true from a labor perspective, as in the EU27, some 13 million people are employed in the tourism industry, representing a share of 9.4% of the workforce (Eurostat, 2018).

Data on the importance of specific tourism products or types of destinations are not available on the continental level. However, Eurostat 2022 data for the EU27 shows that the volume of overnight stays is considerably higher in the summer half (May–Oct.: 70%) than in the winter half (Nov.–Apr.: 30%) and that 47.4% of overnights occur in coastal municipalities (Eurostat, 2022). This suggests that there is higher demand for summer than for winter activities for the whole of Europe. Nevertheless, it needs to be acknowledged that at national or sub-national level the tourism industry can be highly specialized, e.g. for ski tourism in many mountain regions (e.g. Austria or Andorra) or for cultural tourism in historical cities e.g. in Italy or France.

The most important source market for tourism in the EU is the domestic market (52.7% of overnights), followed by other EU27 states (28.3%) and from outside the EU27 (19%) (Eurostat 2022). For non-domestic overnights, Germans represent the largest group (20.3% of total non-resident nights), followed by the British (13.5%) and Dutch (6.4%) (Eurostat, 2022, 2019 data). Europe accounts for 36% of tourist departures (World Bank, 2022, 2019 data) but represents only 11.5% of the global population. This underlines the disproportionately high responsibility resting on the shoulders of European tourists to reduce their GHG footprint when traveling.

In an outlook for future development published in 2019, a growth of arrivals between 2% and 4% was expected for the period from 2019 to 2022 (Weston et al., 2019). However, the COVID-19 pandemic caused a dramatic 70% drop in international arrivals in 2020 (CCSA, 2021). The recovery after the pandemic has started, reaching 71,5% of international arrivals (and 64% of overnight stays) between Jan-Aug 2022 compared to 2019 (Tourmis, 2022).

Climate risk

The majority (74%) of reviewed papers (423) aim to assess the climate change risk for tourism. The following studies address the concept of vulnerability whereas the remaining papers in the climate risk section focus on the impacts of temperature and precipitation changes; extreme weather and natural hazards; sea level rise and coastal erosions; ecosystem and biodiversity change; and the implementation of climate change adaptation strategies.

Santos-Lacueva et al. (2019) revealed five socio-political factors that influence the vulnerability of destinations to climate change: past evolution of destinations, evolution of tourism policy, occurrence of extreme meteorological events, dependence on tourism activity and the characteristics of the tourism offering.

Some studies apply the vulnerability concept and use indicators to assess the destinations' exposure, sensitivity and adaptive capacity to climate change. Perch-Nielsen (2010) used 12 indicators to assess the vulnerability of beach tourism. Most European beach destinations have a comparably low vulnerability, with Cyprus and Ireland ranked as least vulnerable globally. Within Europe, Turkey and France rate as most vulnerable to climate change. Koutroulis et al. (2018) used 16 indicators and show that southern European destinations despite high and increasing exposure might be able to reduce their vulnerability due to their high adaptive capacity in two shared socioeconomic pathways (SSP 1—sustainable pathway and SSP 5—fossil-fueled development). However, vulnerability would increase in SSP3, a scenario of regional rivalry. In the to-date most comprehensive assessment of tourism's vulnerability to climate change, a Climate Change Vulnerability Index for Tourism (CVIT) was developed consisting of 27 indicators (Scott et al., 2019). Here, Mediterranean countries have a low vulnerability, except for Turkey, Cyprus and Montenegro, while the rest of Europe has very low vulnerability scores.

Temperature and precipitation changes

Thermal comfort for outdoor activities

Increasing temperature and altered precipitation patterns are expected to affect tourism throughout Europe. Studies investigating thermal comfort of the human body find that cold stress will decrease while conditions with heat stress and sultriness will increase (Endler & Matzarakis, 2011; Matzarakis et al., 2013; Katavoutas et al., 2021). Consequently, tourism in cooler regions and/or seasons might benefit from climate change (Matzarakis et al., 2012; Pröbstl-Haider et al., 2021), while in hot regions/seasons, declining thermal comfort might have negative impacts on tourism (Matzarakis et al., 2007; Nastos & Matzarakis, 2019).

A frequently applied method to analyze impacts on tourism is indices, where different weather variables are weighted/fuzzified and combined to represent the climatic suitability of a location for tourism. The indices differ in the number of weather variables that are included, weighting/combination of the individual variables and incorporation of potential overriding effects (e.g. of rain) thus providing an inconsistent picture. An application of the Tourism Climate Index (TCI) shows a northward shift of good climate conditions (Perch-Nielsen et al., 2010b) until the end of the 21st century in a high emission scenario. A line approximately spanning Brittany (France), the Southern Alps and Czechia demarcates northern regions with an improving climate index (including the above-mentioned regions) from southern regions where more frequent hot conditions lead to deteriorating conditions in the summer months. In spring and autumn, TCI values improve across Europe revealing a potential to reduce tourism seasonality (Grillakis et al., 2016; Köberl et al., 2016; Prettenthaler et al., 2016; Suto & Fejes, 2019).

Other tourism climate indices have been developed to address limitations of the TCI (see e.g. Scott et al., 2016), such as that different forms of tourism have different climatic requirements that climate indices need to account for. Using the climate index for tourism (CIT), Amengual et al. (2014) note the split between climate winners and losers for beach tourism in northern and southern Europe. Other studies most often find that the effects of near future climatic conditions on the summer seasons of coastal destinations remain positive (e.g. Moreno & Amelung, 2009; Lemesios et al., 2016; Scott et al., 2016; Čavlek et al., 2019; Demiroglu et al., 2020b). For a high emission late 21st century scenario, Demiroglu et al. (2020b) projected unfavorable conditions with great climatic discomfort and potential health risks for southern Spain, Italy and large parts of southeastern Europe.

In a study for Mallorca (Spain), the CIT was adapted and specified for seven different activities to identify which activities become suitable/unsuitable in the future (Bafaluy et al., 2014). In summer, CIT values increase for motor boating and sailing and decrease for cycling, football, golf, hiking and cultural activities. Until the end of the century, sailing becomes climatically suitable in spring and autumn and hiking in autumn. Thus, these activities hold future potential for tourism in the shoulder seasons. However, it is important to note that weather perceptions and evaluation can differ between seasons, as shown in a study in Hungary (Kovacs et al., 2016) and perceptions are heterogeneous between individuals, which, in turn, is likely to alter climate attractiveness of locations for specific activities and target groups.

Tourism in mountain regions during the summer season might benefit from warmer and more stable weather conditions, as the Alps are currently perceived as rainy and cold (Pröbstl-Haider et al., 2015). For South Tyrol (Italy) for example, demand is predicted to increase by 10% by the 2050s (Cavallaro et al., 2017a). Mountain tourism might also benefit from increasing heat stress in urban areas, by providing heat escapes at higher altitude (Juschten et al., 2019).

For Nordic countries, studies reveal some unique climate risks related to the cold climate and high latitude. Outdoor tourism in the summer season at the low and the high Arctic (see also Polar Regions article in this issue) is less dependent on weather and climate conditions from both supplier and consumer perspectives, yet a clear sky is still critical especially for attractions such as the Midnight Sun. Other perception studies with tourist actors show that positive aspects of climate change are emphasized (Kietavainen & Tuulentie, 2013) and potential benefits (e.g. more favorable weather) are expected to exceed the costs (Tervo-Kankare et al., 2018).

Cultural heritage and urban tourism is also projected to be negatively affected by increasing temperatures in the summer months (Rutty & Scott, 2010; Matzarakis et al., 2014). In a study on the medieval city of Gubbio (Italy), indoor temperatures are projected to increase from 29 °C to 32 °C, while outdoor temperatures could increase by up to 10 °C due to the microclimatic conditions, posing a serious threat to human health and potentially negatively affecting heritage tourism (Pioppi et al., 2020). This is supported by Cellini and Cuccia (2019) who show that museum visits are negatively influenced by increases in temperatures during the summer months (Jun to Sep). However, they also find that visits are positively influenced by rain in the summer months and by increasing temperatures during the non-summer months (Oct to May). By surveying visitors and tracking their activity behavior via GPS devices in Lisbon (Portugal), it was found that higher maximum air temperature leads to fewer visited attractions per day. Furthermore, overall satisfaction decreases in higher air temperatures (Caldeira & Kastenholz, 2018). Lopes et al. (2021) analyzed the perceptions of human thermal comfort in the urban destination of Porto (Portugal) showing that tourists prefer warmer conditions than they are used to experiencing at home even in often-hot summer months.

Sottini et al. (2021) studied the comfortable climatic conditions for wine tourists and show that climate change could lead to an increase in tourist presence and a deseasonalization of wine tourism in the five regions studied. Conversely, a projected decline of quality wine areas in Tuscany (Italy) is projected to reduce tourism revenues by up to 20 million euros per year until the 2050s (Nunes & Loureiro, 2016).

Snow and ice

Longer autumns and delayed snow cover are reported to have a negative impact on people's mood, as less light is available due to the missing reflection of the snow surface. Access to the wilderness is negatively affected due to shorter winters and less reliable snow conditions (Kajan, 2014). Cross-country skiing, deemed a national sport in Nordic countries, is affected by deteriorating snow conditions as well (Landauer et al., 2012). Pouta et al. (2009) projected a 39% decline in demand in a high emission late-century scenario for Finland. Adaptation behavior (e.g. switching to other destinations and/or activities) and acceptance of potential adaptation measures (e.g. ski tunnels, snowmaking) were found to be heterogeneous among cross-country skiers (Landauer et al., 2009; Landauer et al., 2014). More frequent days with temperatures near freezing point have led to an increase in injuries caused by slippery conditions due to more freeze/thaw processes (Lepy et al., 2014) and an increase in the number of such days is projected for high latitudes (Lepy et al., 2016). A very special topic is Santa Claus that some places use for place branding (e.g. Rovaniemi in Finland). If snow conditions continue to become less reliable during the Christmas period, place authenticity and consequently attractiveness may be affected (Hall, 2014). Tervo-Kankare et al. (2013) find that a snow landscape is very important for tourists in Rovaniemi and the majority would not visit the place in the absence of snow. Therefore, a repositioning of the destination may be necessary in the future.

During the winter half-year, tourism in mountain regions is expected to be negatively affected due to less snow and declining snow reliability affecting snow-dependent winter sports (Tervo, 2008; Spandre et al., 2019a). Snowmaking will be able to offset deteriorating natural snow conditions for alpine and Nordic skiing in many regions in the upcoming decades (Spandre et al., 2019b; Steiger et al., 2021). However, climatic conditions (Steiger & Mayer, 2008; Demiroglu et al., 2016a; Willibald et al., 2020), available water resources (Vanham et al., 2009; Soboll & Schmude, 2011; Soboll & Dingeldey, 2012; Gerbaux et al., 2020) and costs (Damm et al., 2014; Steiger & Scott, 2020) may limit the long-term suitability of this technique. Studies for the European Alps show that snow reliability of ski areas will decline despite snowmaking (Steiger & Abegg, 2018). Lower altitude ski areas often located at the fringe of the Alps will be the affected first, while after 2050 also higher elevated ski areas might be affected depending on the emission scenario (Steiger & Abegg, 2013; Steiger & Stötter, 2013). For the Pyrenees, a warming of 2 °C could be compensated by snowmaking, while a warming of 4 °C in the second half of the century exceeds the capacities of snowmaking (Pons et al., 2015). A study for a low mountain range Germany shows that the upper part of the ski area could still be considered snow reliable in a low emission late century, whereas in a high emission scenario projected ski season is too short to be considered as reliable (Schmidt et al., 2012). Two studies assessed the combined effects of climatic and demographic change. While for Tyrol (Austria) the effects of demographic change were found to have a higher (negative) impact until the middle of the century, accelerating climate change in the second half of the century is projected to have a higher negative impact than demographic change (Steiger, 2012). For a ski area in Southern Germany, demographic change could lead to a small increase of demand in the 2030s and 2040s in an optimistic demographic scenario (Witting & Schmude, 2019).

Studies on ski tourism in the Nordic countries reveal a competitive advantage in terms of snow reliability over the European Alps (Scott et al., 2020; Dannevig et al., 2021; Rice et al., 2022). However, this potential advantage might be impaired by accessibility and limited daylight (Demiroglu et al., 2020a). For ski tourism in Turkey, Demiroglu et al. (2016a) find deteriorating snow and temperature conditions, but fewer days with strong winds which could lead to fewer closure days. In a recently developed Ski Climate Index, other factors besides snow reliability like aesthetics and thermal comfort are included to better represent the variety of factors relevant for tourism demand (Demiroglu et al., 2021).

Tourists still consider natural snow as the most important factor for destination choice (Steiger et al., 2020) even for snow-independent winter activities (Bausch et al., 2021). If expectations are not met this can lead to dissatisfaction (Bausch et al., 2019). Nevertheless, the perceived importance was also found to decrease with increasing age (Bischof et al., 2017). Tourism demand has been found to be highly adaptable with tourists changing travel plans (Pröbstl-Haider & Haider, 2013; Landauer et al., 2014; Schwirplies & Ziegler, 2017). In a case study approach in alpine and low mountain range destinations, overnight guests were more likely to switch to alternative activities than day guests. However, substitution behavior was also found to differ between presumed similar case studies suggesting that yet unknown factors also influence substitution behavior (Witting et al., 2021).

Economic impacts

Potential economic impacts have been assessed using regression models in combination with tourism climate indices or single weather variables. Amelung and Moreno (2012) estimate a positive net effect on annual overnight stays for the EU28 and Norway of up to 8% for a high emission late century compared to 2005. Conversely, Barrios and Ibanez (2015) found a very low net impact on GDP in the EU until the end of the century. For the summer months and a temperature increase of 2 °C, Jacob et al. (2018) projected a change of overnight stays from −8% (Cyprus) to 20% (Sweden). Conversely, Hein (2007) projected a 20% loss in tourists for Spain in a high-emission late-century future. Using a gravity model (Priego et al., 2015) and a discrete choice model (Bujosa & Rossello, 2013), results are more nuanced for Spain, with a decreasing number of domestic tourists in southern regions and an increase in (mostly coastal) regions in the North-West. For Portugal, a gravity model projects tourist arrivals to decline by 2.5%–5.2% by the 2080s, compared to 2008 (Pintassilgo et al., 2016).

Deteriorating snow conditions might change the geographical distribution of winter tourists (Pons et al., 2014). For South Tyrol (Italy), Cavallaro et al. (2017a) projected a decline of 13%–18% in overnight stays in a low and high emission scenario for the 2050s. Regression results for a ski area in Slovakia show a decline of 6% (+1 °C) to 19% (+3.2 °C) (Demiroglu et al., 2015). However, when also accounting for climate risk relative to competing markets, economic impacts could also be positive even if snow reliability is on the decline, as shown for Switzerland (Gonseth & Vielle, 2019). Despite these predominately negative impacts on winter tourism, studies for Croatia (Grdic & Nihe, 2016; Nizic & Grdic, 2018) and Romania (Surugiu et al., 2011) also show some potential for increasing tourist numbers due to improving conditions for non-snow activities. Conducting a cost-benefit analysis of climate change adaptation measures, Cupac et al. (2020) find that an investment of 1 euro could lead to a benefit of 14.15 euros for tourism in Bosnia-Herzegovina. For summer tourism in Switzerland a moderate welfare gain (+0.21%) is modeled using a general equilibrium model (Vohringer et al., 2019).

Extreme weather and natural hazards

Longer and more frequent dry spells, as projected for the subtropical part of Europe with a steppe climate (BSh and BSk in Köppen-Geiger classification), increases the risk of water shortages according to research on Spain (Rico-Amoros et al., 2013; Sauri et al., 2013; Martin-Arias et al., 2020), Greece (Klein et al., 2015; Michailidou et al., 2016; Katirtzidou & Latinopoulos, 2018; Skrimizea & Parra, 2019; Alamanos, 2021), Cyprus (Zachariadis, 2010) and Turkey (Demiroglu et al., 2018). Activities might be negatively affected such as mountain biking by more frequent heat waves and water sports by droughts with lower water levels and water flows (Auvergne-Rhône-Alpes Tourisme, 2021).

As the temporal population in tourist regions can increase by a multiple in the high season, water demand can also vary substantially between high and low season. In a study covering several regions in Belgium and the Netherlands, peak water demand was modeled to increase by 6. 5% by 2050, while net model water demand would only increase slightly by 0.8% (Vonk et al., 2019). A study for the tourism-intense region of Costa del Sol (Spain) shows that, due to future population growth and climate change, water pumping capacity will become insufficient as soon as the early 2030s (Martin-Arias et al., 2020). Potential adaptation measures to cope with future water shortages include an exchange of water of differing qualities, e.g. the use of treated wastewater in agriculture, or improved demand management in the tourism sector (Rico-Amoros et al., 2013; Dinares & Sauri, 2015). Investigating the potential for water-saving practices among tourists, Torres-Bagur et al. (2020) find that travel motivation of tourists (especially nature motivation) explains the visitors' efforts to save water. The results of their case study also stress the need to increase knowledge and awareness of the impact of climate change on water supply among accommodation managers and visitors. This is supported by Kennedy et al. (2022) who stress the need to raise awareness of natural hazards and to develop hazard management plans for tourism in Malta where floods, drought and storms represent the most important hazards.

Fire risk is also likely to increase, potentially affecting tourism regions, particularly in the Mediterranean (Varela et al., 2020). For Portugal, declines in tourist arrivals are projected to be between 1.2%–2.2% in the 2030s and 4.4%–21% in the 2050s, based on an econometric model considering past fires and effects on tourist arrivals (Otrachshenko & Nunes, 2022). Tourist actors expect an increase in production costs related to a higher incidence of forest fires (Gonçalves et al., 2022).

In mountain regions, melting permafrost and retreating glaciers increase the risk of natural hazards, such as rock falls, debris flow, ice collapse and glacier lake outburst floods (Mourey et al., 2019). Such hazards have already affected access to mountain huts in the French, Italian and Swiss Alps (Mourey & Ravanel, 2017; Mourey et al., 2019) and also access to glacier tourism sites (Welling et al., 2020; Welling & Abegg, 2021). This has already led to a decrease in tourism numbers on glaciers in Norway (Furunes & Mykletun, 2012).

The degree of difficulty posed by high alpine routes (Mourey et al., 2020) increases and alpine routes sometimes disappear because of deglaciation or rock collapse (Mourey et al., 2019). Experienced mountaineers were found to be more exposed to an increased risk of natural hazards as higher risks are accepted in this group (Pröbstl-Haider et al., 2016). These impacts have consequences for mountain guides who need to adapt, principally by focusing on spatial and temporal substitution (change of itineraries, deseasonalization) (Salim et al., 2021a), but also by diversifying their activities (mountain biking, sports climbing and not just alpinism) (Salim et al., 2019) or by expanding their winter activities (Salim et al., 2019; Mourey et al., 2020).

Sea level rise and coastal erosion

Rising sea levels increase beach erosion and can lead to a decrease or complete loss of beach areas reducing attractiveness for tourism purposes (Rizzo et al., 2020; Mooser et al., 2020) and thus reducing the capacity for recreational activities and coastal protection (Jimenez et al., 2017; Sousa et al., 2018). This also has the potential to affect primary resources for tourism such as wetlands (Lefebvre et al., 2019), generally increasing the erosion of coastal zones (Royo et al., 2016; López-Dóriga et al., 2019) or more specifically, the Ebro Delta River in Catalonia (Spain) where current event tourism facilities would be affected (Garriga Sala, 2008).

Coastal erosion can be managed with engineering methods. Studies have been conducted for Croatia (Peric & Grdic, 2015), Greece (Tzoraki et al., 2018; Andreadis et al., 2021; Vandarakis et al., 2021), Turkey (Karaca & Nicholls, 2008), Lithuania (Bagdanavičiūtė et al., 2019), Estonia (Tonisson et al., 2019) and Sweden (Ebert et al., 2016). These studies aim to identify the most affected coastal stretches and show that in all of these cases, tourism beaches would be affected by sea level rise. However, no information on potential impacts on tourism is given. Using the hedonic price method, Hamilton (2007) revealed that dikes have a negative impact on accommodation prices. In a review of approaches to beach erosion in Portugal, Spain and Italy (Semeoshenkova & Newton, 2015), the implementation of hard structures (e.g. groynes, seawalls, artificial headlands) is considered insufficient from a tourism point of view, due to decreasing beach quality and human welfare. Soft methods, such as beach nourishment, dune stabilization or bioengineering, are deemed more suitable for preserving the natural value and tourism quality of beaches.

It is important to understand how beach users evaluate measures to adapt to rising sea levels in order to anticipate potential impacts of such measures on landscape attractiveness and recreational value. In a choice experiment with tourists in Mallorca (Spain), their willingness to pay for the implementation of adaptation policies to mitigate three different impacts of climate change was investigated, namely beach retreat, beach closure due to jellyfish outbreak and seagrass loss. Results show that adaptation to beach retreat is rated highest (Enriquez & Bestard, 2020). Likewise, Lam-Gonzalez et al. (2020) highlighted how certain market segments would avoid travel in cases such as beach loss and extreme events. In a study in Cyprus, Leon et al. (2021) found that tourists tend to prioritize solutions to issues such as beach protection, heat waves, water supply and prevention of infectious diseases. More integrated impact assessment models going beyond only considering temperature and precipitation changes (like in the tourism climate indices) are, therefore, needed to present the overall future climate risks of coastal tourism destinations.

In a study on the Atlantic Coast in France, residents and tourists sometimes did not understand the adaptation strategies (e.g. sand recharging, seawall construction and relocation of property), developed to counteract to rising sea levels (Rey-Valette et al., 2015; Rey-Valette et al., 2019). A survey among property owners revealed a utilitarian concern about preserving real estate values (Rulleau & Rey-Valette, 2017). Interestingly, the acceptance of managed relocation measures shows an awareness of the necessity for long-term changes. However, owners who would be directly affected show strong opposition to such measures.

Ecosystem & biodiversity change

A change of marine biodiversity might affect sea-based tourism activities as well. An increase in algal bloom as a result of warming waterbodies might have potential negative impacts on water-based tourism. In a survey, respondents stated that they had either shortened or cancelled their holidays in regions affected by algal blooms (Nilsson & Gössling, 2013). In a study featuring camping tourists in Sweden, Foghagen (2014) found that sunnier conditions are rated higher than a lower risk of algal bloom, while warm temperatures are less important than algal bloom. A loss of marine biodiversity might affect the attractiveness of tourism activities such as diving around the Medes Isles in Catalonia (Rodrigues et al., 2016) or recreational fishing (Townhill et al., 2019).

Little research is available for outbreaks of infectious diseases. For the Camargue (France), model simulations show that a risk of the re-emergence of Malaria is quite low and subject not only to climatic but also to land-use changes (Linard et al., 2009). In a choice experiment with frequent travelers from the UK, Germany, France and Sweden, an increased risk of infectious disease outbreaks (Malaria and Dengue fever) turned out to be the greatest deterrent to visiting an island destination (León et al., 2020).

Attractiveness of landscapes could also be affected by climate change. Retreating glaciers have a negative impact on visitors' perception of landscape (Moreau, 2010; Salim et al., 2021b). Studies also show that glacier retreat in the Alps leads to the development of Last Chance Tourism (Salim & Ravanel, 2020) and that stakeholders in glacier tourism need to adapt to the impacts of climate change today (Salim et al., 2021a). Some national and regional reports, such as the OPCC (2019), have also identified the loss of glaciers as a risk to tourism attractiveness in these mountains. The Aragon (Spain) Government, for example, passed an act in 1990 enshrining glaciers as natural monuments in law (vLex, 1990). In Nordic countries, warmer conditions throughout the year and shorter winters will lead to an increase in insects, affecting tourist comfort from insect bites and, in the long term, also landscape attractiveness as some species cause severe tree damage (Kajan, 2014).

Knowledge and implementation of climate change adaptation strategies

The tourism industry has been repeatedly described as being insufficiently prepared (Scott, 2021). Therefore, an important question for sustainable and climate resilient tourism development is the state of knowledge and implementation in the tourism industry. According to Klein et al. (2017) framework of adaptation research, four generations of adaptation research can be distinguished (Table 1). We assigned the reviewed papers to these generations to identify the most visible ones and draw conclusions as to where more adaptation research are needed. From the 320 reviewed climate risk papers (including papers addressing both climate and carbon risk), six could not be assigned to any category as these were review or assessment papers that summarized existing knowledge. As illustrated in Table 1, first and second generation studies still represent the majority of reviewed papers.

While earlier studies on climate change perception among tourism actors found some skepticism about climate projections and doubt about the impacts on the tourism industry (Saarinen & Tervo, 2006; Wolfsegger et al., 2008), more recent studies show that the majority of tourism stakeholders accept that climate change is happening and could have far-reaching consequences for their business (Serquet & Rebetez, 2013; Grdic et al., 2019). However, several barriers to adaptation are identified in the reviewed literature: Carlsen et al. (2013) note that it was difficult for participants in a workshop to relate to a time perspective of 20 years into the future. Structural barriers, such as a lack of long-term planning, funding sources and support (Jenkins & Nicholls, 2010; Csete & Szecsi, 2015) are hard to overcome, slowing down adaptation processes (Wyss, 2013) and leading to a common strategy of maintaining the current business model (Haanpaa et al., 2015). Furthermore, high confidence in the survival of one's own business was found to influence adaptation behavior, potentially leading to more reactive than proactive behavior (Trawöger, 2014; Tervo-Kankare, 2019). Responsibilities are perceived to lie with government bodies (Torres-Bagur et al., 2019) because they are regarded to have better information and more power to initiate and enforce change (Wyss et al., 2014). In a mountain destination in Switzerland, Luthe and Wyss (2016) find that action at the municipal level is more effective for implementing abrupt changes (e.g. hazard events) while the regional level tends to be more suitable for gradual climate-related change.

Table 1. Description of Klein et al. (2017) four generations of adaptation research and examples of reviewed papers.

Klein et al. (2017) framework	Description	Examples in the reviewed literature
First generation (103 papers, 33%)	Descriptive questions related to the potential impacts of climate change, their consequences for the population and the potential costs (or benefits) of such changes.	Studies investigating the evolution of climate conditions and their potential influence on tourism, destinations or activities (Mourey & Ravanel, 2017; Demiroglu et al., 2018; Nastos & Matzarakis, 2019)
Second generation (151 papers, 48%)	Descriptive questions about the social factors that influence vulnerability to climate change and normative questions aiming to evaluate and build on successful adaptation and to find a balance between adaptation and mitigation.	Studies aiming at identifying the adaptive capacity of certain destinations (Dannevig et al., 2021; Rice et al., 2022), the adaptive behavior of the supply side (Spandre et al., 2019a; Salim et al., 2021a) and the perception and adaptive behavior of the demand side (Steiger et al., 2020; Leon et al., 2021).
Third generation (37 papers, 12 %)	Policy and finance questions are introduced.	Studies seeking to identify which policy and institutional tools are needed to support adaptation efforts development (Rech et al., 2019; Welling & Abegg, 2021).
Fourth generation (23 papers, 7%)	Questions related to the technical knowledge that is needed to implement adaptation; lessons that can be learned from maladaptation and failure.	Acceptability of the adaptation measures (Rey-Valette et al., 2019), barriers to adaptation (Matasci et al., 2014) or the reasons for the success of adaptation strategies (Mourey et al., 2020).

The majority of studies involving tourism stakeholders in the research process focus on extracting information from the practitioners, e.g. on their perception of climate change and its impacts (e.g. Kundzewicz et al., 2008; Jarvis & Ortega, 2010), which is an important first step to identifying the willingness and perceived urgency to act and prepare for change. Provided a common understanding exists among practitioners that climate change is a challenge for tourism, participatory research settings can be a useful tool for fostering local adaptation processes. In a Swedish case study (Carlsen et al., 2013), three local level socioeconomic scenarios constructed by the research team were used in a stakeholder workshop to identify challenges and adaptation options for tourism in their region. In an alpine destination, an agent-based model was used to simulate changes in the tourism system based on scenarios and adaptation strategies jointly developed with local tourism stakeholders (Balbi et al., 2013; Bonzanigo et al., 2016). Welling et al. (2019) set up a four-stage participatory scenario planning process in South-Eastern Iceland with glacier tourism as the main product. Modeled glacier retreat was used as input in three stakeholder workshops. In the first workshop, participants identified the elements of the tourism system, important interconnections and exogenous factors and relevant drivers of land-use change by cognitive mapping. In the second workshop, participants developed plausible future scenarios of land-use change within the study area. In the third and final workshop, stakeholders developed adaptation options to main threats and opportunities along with their practical applicability considering the previously developed land-use change scenarios.

Carbon risk

Carbon emissions and tourism's footprint

Only 26% of reviewed papers address carbon risks for tourism on the European continent.

In an analysis of global tourism-related carbon flows between 160 countries in 2013, Germany is ranked 3rd worldwide in terms of resident-based carbon footprint (Lenzen et al., 2018). The highest carbon footprint (CO_2 equivalent) to/from Europe is accounted for by travel between the UK and the US (12 Mt), followed by Russia/Ukraine (7.8 Mt) and Germany/France (6.2 Mt).

A number of studies investigate tourism's contribution to national GHG emissions. However, the results are hardly comparable as the analyses took place at different points in time and employed different methods, e.g. in- or excluding emissions related to international travel beyond national borders. One of the earliest studies (Peeters et al., 2007) carried out an EU-wide (the then EU-25 plus Switzerland, Norway, Bulgaria and Romania) environmental assessment of tourist transport and concludes that climate change is the most important externality, when compared to other factors like noise, air quality, landscape and accidents. The main problem lies not in intra-European transport but rather intercontinental, long-haul air travel, which was expected to grow back then. On a national level, tourism-related emissions range from 2.5% in Romania (Surugiu et al., 2012), 5.2%–5.3% in Switzerland (Perch-Nielsen et al., 2010a) and Austria (Neger et al., 2021), compared to 10%–11% in Portugal (Robaina-Alves et al., 2016), Spain (Cadarso et al., 2015; Cadarso et al., 2016), Sweden (Gössling & Hall, 2008), France (ADEME, 2021) and the Netherlands (CBS, 2017). On a sub-national level, 9.2% is reported for Wales (UK) (Jones, 2013) and 12% for Galicia (Spain) (Roibas et al., 2017). Isolating tourism-related emissions generated by air transport, Antequera et al. (2021) estimated international air transport CO_2 emissions to be 54.3% of total emissions of the Canary Islands (Spain). This shows that the carbon intensity of island tourism is considerably higher due to the high share of air transport and in this case also due to larger travel distances from the main source markets compared to other European destinations.

In most of the studies, tourism transport has the highest share of tourism-related emissions (e.g. Unger et al., 2016; Gössling et al., 2017; Neger et al., 2021). Consequently, the distance and transport mode from origin markets to a destination have a huge impact on CO_2 emissions per tourist (Gössling et al., 2005; Gössling et al., 2015). In the UK's South West region, CO_2-equivalent emissions per day for visitors from overseas (196 kg) are about four times higher than that of domestic visitors (49 kg) (Whittlesea & Owen, 2012). In Barcelona (Spain), the carbon footprint of overnight tourists (mainly arriving by plane) is 111.6 kg, while for day-trippers it is 43 kg per day (Rico et al., 2019). For the island of Menorca (Spain), Sanye-Mengual et al. (2014) show that the carbon footprint of an average stay is comparably low with 277 kg, which is mainly due to a long average length of stay of 20 days. For cruise tourism in Norway, average emissions are 589 kg CO_2 per passenger (Simonsen et al., 2019). Adamiak et al. (2016) studied travel behavior and related emissions of second home owners in Finland and found that owners have fewer trips per year than non-owners. However, their footprint is considerably higher than that of non-owners, as the number of long-haul trips is not different but the flown distance is higher for owners than for other groups. Wicker (2019) investigates the carbon footprints of sports activities in Germany based on the number of trips and distance and finds that nature sports (1455 kg CO_2 per year) cause more emissions than individual (1006 kg) or team sports (514 kg). All these studies reveal a high heterogeneity of GHG emissions between tourists. For Austria, emissions from holiday air travel were found to be higher for people with university degrees, young adults without kids and residents from the capital city (Falk & Hagsten, 2021).

Econometric studies on the carbon risk of tourism analyze the relationship between tourism-related emissions and economic growth. On the global level, using long-term panel data of multiple countries, including those of Europe, several studies (Zaman et al., 2016; Pablo-Romero et al., 2017; Kocak et al., 2020; Pala, 2020; Simo-Kengne, 2022) substantiate how tourism growth leads to increased emissions. Similar evidence is also found for cases on a country scale such as for Cyprus (Katircioglu et al., 2014), Turkey (Pata & Balsalobre-Lorente, 2022; Katircioglu et al., 2014; Eyuboglu & Uzar, 2020), Romania (Surugiu et al., 2012; Ioncica et al., 2016), Greece (Işik et al., 2017) and Latvia (Grizane et al., 2019). However, others highlight the validity of the environmental Kuznets curve, which asserts that tourism growth could amplify emissions in the short run but that these emissions, and other environmental degradation indicators, would eventually be reduced as the growing economies of such countries could help advance their environmental sustainability (Lee & Brahmasrene, 2013; Grizane & Jurgelane-Kaldava, 2019; Leitão & Lorente, 2020; Gyamfi et al., 2021). Alam and Paramati (2017), for example, showed that a 1% increase in tourism investments reduces CO_2 emissions by 0.098%. However, a recent review paper finds contradictory results concerning the validity of the Kuznets curve related to tourism (Dogru et al., 2020).

Carbon emission reductions

The reviewed literature provides technical showcases on the supply side about how the industry could reduce its emissions in the future. This includes improved financial viability and environmental sustainability through the use of renewable energies at hotels and other touristic facilities in Croatia (Nizic et al., 2017), Cyprus (Michopoulos et al., 2017), Serbia (Ristic et al., 2019), Italy (Comodi et al., 2014), Spain (Moià-Pol et al., 2014) and some Alpine ski resorts (Polderman et al., 2020) and reduction in intra-destination transport emissions through a modal switch from cars to public transport (Cavallaro et al., 2017b, 2021), optimal site selection for a hotel location in Greece (Pieri et al., 2016) or the renewal of car fleets used for recreational fishing trips in Latvia (Grizane & Blumberga, 2020). In an analysis of accommodation providers in the UK, only weak responses of these actors to current mitigation policy were found (Coles et al., 2013). A cluster analysis in the same region revealed three different mitigation behavior types (early adopters, early/late majority and laggards) and the authors concluded that policies should be tailored to these types to improve mitigation efforts (Coles et al., 2014). Pace (2016) examined how tourism operators innovate for energy consumption in Malta and showed that energy management capabilities (e.g. technology replacement, internal knowledge, seizing) increase the potential to reduce consumption. Perfetto et al. (2018) study energy efficiency in hospitality in the south of Italy, showing that building information modeling, i.e. including different stakeholders (e.g. architects, owners, managers) in a collaboration network when designing a new hotel building, can be an effective approach.

For transport-related tourism emissions, an agent-based model for inbound and outbound tourists of Austria was used to investigate different travel demand scenarios (Kapeller et al., 2019). In a business as usual scenario (extrapolating current travel behavior trends), an emission increase of 26% was modeled for 2018–2030. Remarkable emission reductions could be reached in a 'green transition' scenario, with an assumed annual increase of airline ticket prices and a higher share of public transportation (25% instead of 18%) leading to a modeled emission reduction of 38% (Kapeller et al., 2019). However, the realization of such green scenarios requires a change in traveler's behavior.

Consumer behavior research has revealed little willingness of travelers to change their behavior (Barr & Prillwitz, 2012). Common reasons for non-action are denial, limited knowledge, scientific skepticism, necessity and that responsibility lies with others (Dickinson et al., 2010; Hares et al., 2010). Applying the norm activation model, Vaske et al. (2015) show that 44% of variance in reported behavior is explained by environmental attitude, feeling responsible and awareness of the consequences. Others identified an attitude-behavior gap (Kroesen, 2013) and show that 'deservingness' is used as legitimation (Hanna & Adams, 2019). Studies note a higher concern for short-haul, rather than long-haul trips in the case of Norwegian outbound tourism, especially regarding discretionary travel (Higham & Cohen, 2011), while in-depth research among students from Sweden highlights the subjectivity of what is 'discretionary' (Gössling et al., 2019). In Poland, an earlier study (Dickinson et al., 2013) finds that, despite strong concern for climate change, the main contributors, such as international air travel, are not well-acknowledged, while a couple of later studies show the significance of national cultures in determining pro-environmental behavior (Filimonau et al., 2018a) as well as the need for knowledge reinforcement for the uptake of contemporary mitigation measures such as aviation biofuel technology (Filimonau & Hogstrom, 2017; Filimonau et al., 2018b). Regarding such barriers to mitigation, Juvan and Dolnicar (2014) show how confusing carbon calculators can be for users (tourists from Slovenia and Australia) and that they are possibly not useful for people wanting to reduce their carbon footprint.

Nevertheless, a positive general attitude of tourists toward mitigation is also reported. In a tourist survey in alpine destinations, a high acceptance of wind parks at these destinations was found, although concern about climate change was no predictor variable for acceptance (Brudermann et al., 2019). Other examples are a strongly engaged consumer activism as in the case of the nonprofit organization Protect Our Winters (POW) (Demiroglu & Turhan, 2021) and a high preference or willingness-to-pay for green facilities and destinations (Tsagarakis et al., 2011; Navratil et al., 2019; Saseanu et al., 2020).

Blanc and Winchester (2013) model the impact of a price of 10 euros/t CO_2 on arrivals to range between −1.4% and −2% within the EU and −0.4% on all arrivals. A choice experiment with skiers in Norway reveals that consumers are willing to pay 11.5% more for a ski season pass that includes CO_2 compensation (Haugom et al., 2021). Carbon labels were found to improve the perceived environmental sustainability of a holiday package, but they did not affect the intention to book in a study with Dutch travelers (Eijgelaar et al., 2016).

Despite its relatively high accountability for global emissions (UNWTO/UNEP/WMO, 2008; Lenzen et al., 2018), the tourism industry is often neglected in the highest level climate policy documents such as the Nationally Determined Contributions (NDCs) (UNFCCC, 2021). The NDCs (UNFCCC, 2022) created by the EU and its member states, for instance, do not specifically refer to the tourism industry, even when it comes to the suggestions on yielding mitigation co-benefits through economic diversification where tourism could play a vital role. Few other European countries such as Armenia, Bosnia-Herzegovina and San Marino mention tourism as a climate risk focus, while Albania, Georgia and Montenegro are the only countries with specific mitigation perspectives relating to tourism. In the case of Albania's Updated First NDC, hotels, restaurants and travel agencies are acknowledged as part of the service sector accountable for future energy demand. Georgia and Montenegro, on the other hand, clearly highlight the need to pursue a low carbon approach to future tourism development, e.g. by erecting energy-efficient buildings, but also, in the case of Georgia, by promoting agritourism to mitigate agricultural emissions (UNFCCC, 2022).

Climate change is also addressed in several tourism strategy papers. On the EU level, climate change adaptation and mitigation is included as one of the ten points of action toward sustainable and responsible tourism (TSG, 2012). In a more recent study commissioned by the European Parliament, the need for more climate action is stressed and references to EU funding schemes to finance climate mitigation action are made (Weston et al., 2019). On the national level, there is a broad range of ways in which climate change is addressed, if at all. For the Nordic countries, Landauer et al. (2018) conclude that national tourism strategies do not present actions that actors should consider. Most of the climate actions in national tourism strategies are demands directed at governments to invest in sustainable mobility, e.g. by improving train connections in a 500 km radius around the Netherlands (NBTC, 2019). A notable exception is the tourism strategy of the federal state of Tyrol (Austria) (Land Tirol, 2020). Here, goals for 2035 include an increase in the share public transport used by tourist arrivals from 10% to 20%, a 100% use of renewable energies for local public transport at the destinations and climate-neutral ski areas.

Discussion and conclusion

In this study, a total of 423 papers were identified to reflect climate (n: 313) and/or carbon (n: 110) risks of tourism in European countries and reveal a clear lack of studies in the carbon risk domain. This uneven split between the two main themes is even more evident from a spatial perspective (Figure 2), as many Western European and Mediterranean countries receive the most coverage under each theme while many former Soviet Union and former Yugoslavian countries and Albania lack research on both fronts. This research gap is, however, somewhat consistent with the limited economic contribution of tourism (Figure 1) in the said countries, that is, with the exception of Albania and Montenegro, where tourism dependency is among the highest. It should also be noted that this gap indicator is aggregated at the national level and does not necessarily point to the situations in all critical subnational regions.

The reviewed literature shows that tourism's share of greenhouse gas emissions is remarkable, with values on the national level between 5% and 11% of total emissions. The greatest potential for emission reduction lies in the transport sector (Gössling et al., 2015; Lenzen et al., 2018). European destinations are characterized by potent domestic or nearby international source markets. This represents a large potential for a shift to less carbon-intense transport modes like the train. After two decades where night train connections were ceased, new night train connections have been established more recently (Energiezukunft.eu, 2022). In this context, the Trans-European Transport Network (TEN-T) is important as a political framework. The TEN-T consists of a core and a comprehensive network which should be finalized by 2030 and 2050, respectively (European Commission, 2022). Although it includes the construction and better integration of all transport modes, an improvement and expansion of the rail network in Europe is an important part of this plan.

This review identifies a number of research gaps that urgently need to be filled in order to provide better knowledge to reduce this sector's emissions and improve its preparedness and adaptive capacity. The following research agenda summarizes the key points this review revealed:

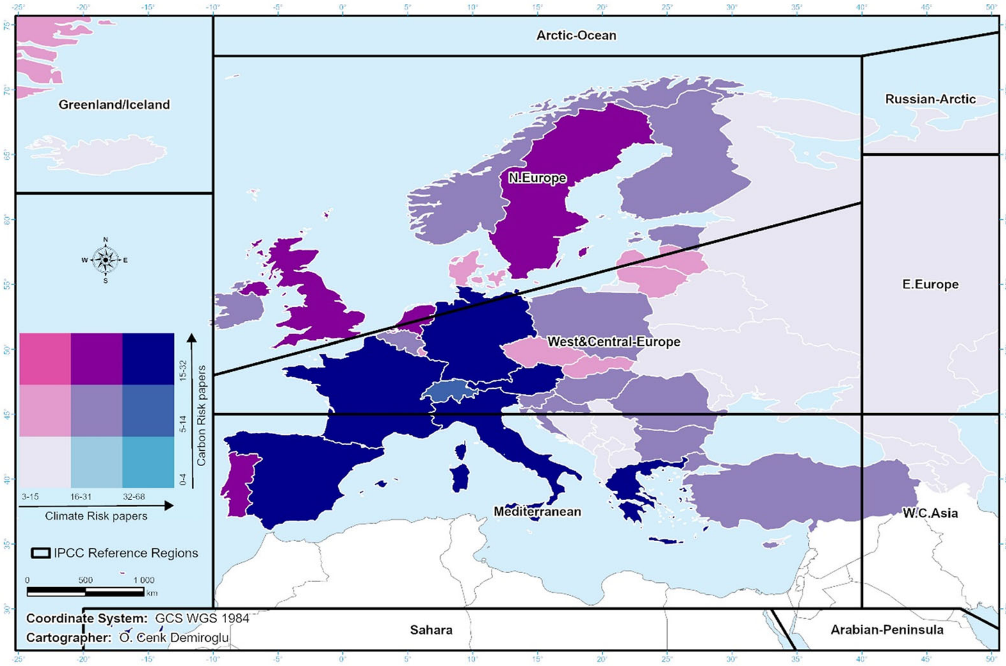

Figure 2. Research coverage on climate and carbon risks of tourism in Europe.
For detailed data, see Table A1 in the Appendix

The lack of coherent studies on national tourism and its sub-sectors' emissions call for better methods to accurately measure emissions and monitor progress towards achieving emission reduction targets. To achieve the aim of the Paris Climate Agreement (United Nations, 2015), CO_2 emissions would need to be reduced by approximately 50% by 2030 and reach net-zero by mid-century (IPCC, 2021). As shown in this review, tourism is almost not mentioned in NDCs and even in national tourism strategy papers, little ambition defining clear reduction targets could be found. Therefore, the research community needs to provide information on how tourism could achieve the required emissions reductions, also considering the projected growth rates in tourism. This also includes better knowledge of options to influence travelers' behavior reducing their emissions.

Given these very ambitious reduction targets, it is likely that national and international climate policies will affect tourism at all spatial scales (from global to regional). More research is needed addressing how climate policies might affect tourism demand (e.g. number and length of trips, spending), if and how the distribution of tourists could be affected (e.g. destination choice) and what impacts such changes might cause at the destination level, e.g. increase/decrease of demand, changing expectations and needs.

On the one hand, carbon risks are likely to increase if policies are implemented to achieve the required emission reductions to slow climate change. On the other hand, climate risks in the upcoming decades are expected to increase due to accelerating climate change regardless of emission paths (IPCC, 2021). Therefore, the integrated carbon and climate risks deserve more attention by the scientific community as it increases complexity. This complexity represents an important constraint concerning tourism planning and climate policy development.

In the climate risk theme, there are many studies using e.g. indices to assess changes of climatic conditions for tourism, but there are comparably few studies investigating the impact of such changes on demand and the local-regional tourism system. Questions such as how important climate is in comparison to other destination choice factors or what a change of

10% in a climate suitability indicator would mean for visitor numbers or spending remain unanswered. From a conceptual point of view, a clearer distinction is required between tourism activities being dependent on resources affected by the weather, like snow, ice, waves and wind, on the one hand, and tourism activities where weather is only relevant for comfort (e.g. temperatures) and attractiveness (e.g. visibility) on the other hand. A potential gap between stated preferences and behavior in hypothetical situations and real behavior when such conditions occur is often mentioned, but rarely addressed. The increasing occurrence of formerly unusual conditions (hot, lack of snow, drought and wildfires) could be used as natural experiments where tourists' real perception (e.g. through interviews, surveys) and impacts on demand can be investigated.

The present review revealed a clear lack of climate change and tourism studies that can be assigned to Klein et al. (2017) third and fourth generation of adaptation research. Third-generation studies would identify policy and institutional tools that support the industry's adaptation to climate change. Considering this research gap, it is not so surprising that the tourism industry is considered insufficiently prepared (Scott, 2021). More research is urgently needed to address these questions to support the industry in preparing for the (uncertain) future. Fourth-generation studies would address the implementation of adaptation measures at the destination level. Furthermore, limits to adaptation (e.g. physical, economic or social) as well as if adaptation can be considered as maladaptive or successful adaptation (Scott et al., 2022) are rarely assessed. Although there is a rich body of literature on climate change impacts also on the destination level, there is a lack of studies addressing the interactions between different impacts on the destination or market level (Scott, 2021). Tourism can inherently be seen as a complex and multidimensional system. Even these different dimensions interrelate and have strong interdependencies. However, to date, most studies focus on one interdependency, for example the link between a climatic resource/variable (i.e. temperature and snow availability) and tourist attendance. A better understanding and further research between these crossed-interdependencies, for example between climatic changes with feedback on the health, energy or biodiversity dimensions of destinations, are one of the big challenges academia has to face in the coming years. Such complex interrelationships require interdisciplinary research teams.

It is surprising that so little research exists on rising sea levels and coastal erosion, given that about half of tourism volumes in Europe is generated in coastal municipalities (Eurostat, 2022). There is a substantial body of literature on coastal erosion, but obviously tourism is not or hardly mentioned in these studies. Therefore, a possible research avenue could be to link this body of research with tourism aspects or to analyze existing results through the lens of tourism. Furthermore, more local integrated assessments are needed to investigate the cost effectiveness of potential adaptation measures, the magnitude of potential beach loss and infrastructure damage and the resulting impacts on tourism. Important but so far unanswered questions include: How can revenues from tourism be used to (co-) finance expensive protective measures? Are alternative adaptation options to rising sea levels (e.g. relocation) available and suitable from a tourism perspective?

As shown in this review, tourism in Europe urgently has to prepare for diverse climate and carbon risks and at the same time increase its efforts to reduce tourism-related GHG emissions. A decarbonized and better prepared tourism industry can benefit from higher quality natural resources and provide more sustainable benefits for regional economies that are dependent on tourism.

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Appendix

Table A1. Contribution of tourism to GDP and number of reviewed papers.

Country	Tourism in % GDP (2019)*	Papers reviewed	
		Climate risk	Carbon risk
Albania	20.5	11	2
Andorra	n.a.	15	1
Armenia	12.9	3	2
Austria	11	51	16
Azerbaijan	7.7	3	2
Belarus	6.1	7	4
Belgium	5.6	17	12
Bosnia and Herzegovina	9.8	11	2
Bulgaria	10.7	18	10
Croatia	24.3	21	9
Cyprus	13.4	18	13
Czechia	6.2	13	12
Denmark	6.4	12	12
Estonia	11.8	16	11
Finland	7.8	31	14
France	8.5	60	23
Georgia	26.8	6	2
Germany	9.8	47	16
Greece	20.3	38	17
Hungary	7.9	21	11
Iceland	21.8	9	3
Ireland	4.2	16	10
Italy	13.1	48	21
Kazakhstan	5.2	3	2
Kosovo	n.a.	8	1
Latvia	7.7	14	14
Liechtenstein	n.a.	8	1
Lithuania	6	14	11
Luxembourg	8.9	11	11
Malta	15.9	17	11
Moldova	6.6	7	2
Monaco	n.a.	7	1
Montenegro	30.9	9	2
Netherlands	10.8	16	17
North Macedonia	6.6	9	2
Northern Cyprus	n.a.	5	0
Norway	7.9	24	13
Poland	4.7	17	14
Portugal	17.1	27	15
Republic of Serbia	5.9	14	3
Romania	6.1	20	12
Russia	4.9	8	4
San Marino	n.a.	7	1
Slovakia	6.4	15	11
Slovenia	10.6	21	12
Spain	14.1	68	28
Sweden	7.3	23	17
Switzerland	7.4	41	11
Turkey	11	19	11
Ukraine	6.3	9	0
United Kingdom	10.1	22	32
Vatican	n.a.	7	1

*WTTC, 2021.