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Carbon footprint of tourism in Spain: Covid-19 impact and a look forward to recovery

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A B S T R A C T

Tourism is very vulnerable to climate change and the disruption of Covid-19, facing two challenges: fighting climate change pursuing its carbon emissions goals, and recovering from the complex pandemic effects. We contribute to the incomplete understanding of tourism emissions pandemic impact and in different post-covid recovery scenarios. Using official data on tourists' consumption, we calculate the carbon footprint of tourism in Spain in 2019 and 2020 under different recovery pathways, including changes in consumption patterns and emissions efficiency, using a multiregional input-output model. Results show that the carbon footprint of tourism in Spain fell by 63% in 2020 compared to pre-pandemic levels, which would be aligned with the current sectoral decarbonisation target. However, the new tourists' consumption patterns resulting from the pandemic are insufficient to increase tourism sustainability if they imply pre-pandemic consumption levels. The results provide empirical ground for the binary debate on "recovery or reform".

1. Introduction

Tourism is a driving force for prosperity and development worldwide (Castro-Nuño et al., 2013). Tourism activities sustain jobs and businesses as well as provide value to natural and cultural heritage. The direct contribution of tourism to Gross Domestic Product (GDP) ranges from around 2% to over 10% (UNWTO, 2019), and it was 10.4% globally in 2019 (WTTC, 2021b). Spain is in the upper limit of this range as tourism directly accounted for 12.4% of GDP and 12.7% of total employment in 2019. However, these positive outcomes are threatened because tourism is also a very vulnerable activity to climate change and disruptions, such as the Covid-19 outbreak. This context leads to two crucial challenges for the future of tourism: to recover from the pre-pandemic impact while, at the same time, reducing carbon emissions and increasing their sustainability and resilience against climate change and other external shocks. Consequently, tourism cannot return to pre-Covid-19 normal, but it needs to respond with new strategies taking advantage of the lessons learned from the pandemic crisis. This paper contributes to those challenges providing evidence of the carbon footprint changes before and after the pandemic and under different recovery scenarios that gather changes in tourist behaviour and policies.

Regarding climate change, tourism is, at the same time, a heavy contributor to it. Recent studies find it responsible for about 8% of global greenhouse gas (GHG) emissions in 2013 (Lenzen et al., 2018), a figure that can almost double in typical tourism destination countries like Spain (Cadarso et al., 2015, 2021; Sun et al., 2022; Tian et al., 2021). The tourism industry acknowledges the need to fight against climate change. The World Travel and Tourism Council (WTTC) and the United Nations World Tourism Organization (UNWTO) set emissions mitigation goals consistent with the ambition of the Paris Agreement (Scott et al., 2016; WTTC, 2009). However, tourism emissions have significantly increased globally, despite achieving emissions-intensities reductions (Gössling and Peeters, 2015; Lenzen et al., 2018), and forecasts point to further increases (WTTC, 2021a), even considering efficiency improvements (Gössling and Peeters, 2015).

The Glasgow Declaration, launched at the COP26 United Nations Climate Change Conference, should be a turning point. It proposes a coordinated plan for tourism to support the global commitment to halve emissions by 2030 and achieve net zero by 2050 (UN, 2021). Consequently, a debate has begun since this needs to be translated into specific changes in the economic system, consumer behaviour and policies such as, for example, those proposed by the International Energy Agency for the global economy (IEA, 2021). Some of those would significantly impact the tourism industry, like radical shifts in modes of transport,

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investment into technological advances in renewable energies, energy efficiency, and sustainable fuels, increases in carbon prices, and changes in consumer behaviour (Scott and Gössling, 2022). However, the size and impact of these shifts remain incompletely understood, and our research intends to contribute to this measurement.

In this context of climate change fighting, the pandemic disruption arises, revealing tourism as highly vulnerable to it and the breakdown of global value chains (Gössling and Peeters, 2015; Gössling et al., 2021). Although the Covid-19 pandemic has severely impacted all the economies and sectors worldwide, tourism has been one of the most stressed areas. The imposed confinement measures, the shutting of non-essential activities, the closure of borders, and the breakdown of global value chains, restricted tourism to the point when it even ceased altogether for some months (Gössling et al., 2021). According to the UNWTO, the economic consequences are about eleven times higher than those experienced in the 2008 crisis and bring tourism back to 1990 levels (UNWTO, 2021), and led tourism global contribution to GDP to fall to 5.5% in 2020 (WTTC, 2021b). In Spain, Covid-19 caused a decrease of 77% in arrivals in 2020, resulting in almost seven percentual points lower contribution to GDP (INE, 2022d). The medium and longer-term effects of the pandemic are still far from being clear, as well as their implications on tourism sustainability. So then, the present paper aims to enrich our understanding of the environmental consequences of Covid-19 and the post-pandemic recovery of tourism in Spain.

There is already a relevant number of studies analysing the impact of the Covid-19 pandemic on tourism, as attested by three reviews of the literature that provide a good picture and key insights (Gössling and Schweiggart, 2022; Yang et al., 2021; Zopiatis et al., 2021), with the first one even considering the relevance of the contributions for the management of climate change. This literature shows, nevertheless, some research gaps that our research aims to contribute. Firstly, these studies focus mainly on tourism economic impacts of Covid-19, with little attention being paid to environmental issues. To mention only those regarding the Spanish economy, on the one hand, Cardenete et al. (2022) assess the economic consequences on tourism in the Spanish region of Andalusia, using two scenarios of estimated fall in tourism demand. On the other hand, Rodousakis and Soklis (2022), whose estimations are based on the first aggregate data available on international travel receipts, conclude that the impact is going to be higher for Spain than for Germany, while Vena-Oya et al. (2022) forecast that the probability of a pandemic impact worse than the 2008 crisis is high using fuzzy cognitive maps. Therefore, "sustainability and transformation" is one of the areas where further research is needed (Zopiatis et al., 2021). More specifically, rigorous environmental valuation analysis through environmental impact models (such as carbon footprint analysis) is recommended to evaluate better the pandemic's environmental effects on the tourism system (Yang et al., 2021).

Secondly, various methodologies have been applied to estimate those impacts, at different spatial levels, from countries to regions or cities. In some cases, the methods are criticised for being primarily descriptive (Gössling and Schweiggart, 2022; Yang et al., 2021), and the data used is based on estimations, early available data (as in the examples of the Spanish case), authors-elaborated interviews and, often, many tourists' behaviour indicators rely on measures of intention (Yang et al., 2021). All these features may limit the significance of the results. We overcome these drawbacks by calculating the tourism carbon footprint using a multiregional input-output model (MRIO) that allows including all direct and indirect emissions along the global value chains (GVC), linking the supply of tourism services to satisfy tourists' demand in one country to the CO_2 emissions wherever they are generated (Cadarso et al., 2022). This feature of MRIO footprint is crucial in the assessment of the pandemic disruption impact. When focusing on tourism, MRIO model is combined with Tourist Satellite Accounts (TSA) data. TSA are the most appropriate source of tourism demand data as they can be better used within the footprint analysis (Sun et al., 2020), but they take some time to be produced and published. This means earlier studies on the topic have not been able to apply this methodology. Our analysis uses the newly published data on tourism consumption in Spain from the TSA that provides official data for 2020 (INE, 2022d), avoiding estimations in calculating the pandemic impact.

Finally, Yang et al. (2021) recognise that little insight into future scenarios has been provided. Previous studies are less focused on the post-pandemic situation and paths for recovery, their impact, and how they would affect carbon emissions and tourism environmental goals. Regarding the post-Covid times, the main topics for the so-called "new normal" have been: the health and sanitary measures to reduce outbreak risk, the fiscal measures to support the tourism business (Kuo, 2021; Villacé-Molinero et al., 2021), the need to increase resilience in global value chains (Deb and Ahmed, 2022; Tasnim et al., 2022), and employees' engagement and satisfaction (Shehawy and Abouzied, 2022). Moreover, they focus on growth or business-as-usual strategies, as indicated by Sigala (2020), leaving the environmental issues aside or in the periphery (Hall et al., 2020; Khan et al., 2021; Mkono et al., 2022). As an example of this peripheral consideration, Vu et al. (2022) mentioned the possibility of developing post-covid tourism toward green growth as one strategy out of eight to attract tourists more interested in low-carbon destinations after Covid-19. In addition, there is little attempt to measure the environmental impact of those strategies. Our research covers the lack of analysis regarding the effect of the recovery trends on the environment measuring the tourism carbon footprint in Spain. Gössling and Schweiggart (2022) is one of the few papers devoted to analysing the implications of the net-zero goal for tourism using the 2050 global roadmap of the IEA. However, they only empirically estimate the different risks countries experience in their transition to a net-zero future using four indicators (percentage of electricity supply from fossil fuels, average distance to a top five destination, size of outbound international market, and food import dependency). The research by Sun et al. (2022) is another exception as they evaluate Norway's net-zero emissions goal, assuming tourism returns to its pre-pandemic average growth, using a single region input-output model.

Our analysis goes beyond the contributions of Scott and Gössling (2022) and Sun et al. (2022) because we use a MRIO, first, for calculating the carbon footprint of tourism in Spain in 2019 (pre-pandemic) and 2020 (pandemic) and, second, developing some scenarios to assess possible new trends of recovery and their carbon footprint impact and their sustainability in the new normal (post-pandemic). Moreover, we build two types of scenarios. On the one side, some scenarios capture new tourist consumption patterns. The Covid-19 pandemic not only implied those losses in the amounts of visitors and their consumption but also shifts in tourist behavior and consumption patterns (lower international tourists, more outdoor activities, …). Some of these changes are forecasted to be temporary or short-term. Still, others are expected to persist in the medium term (Marques Santos et al., 2020), adding uncertainty to the recovery phase. On the other side, we build policy scenarios to assess the impact of the measures included in two of the priority lines of the Spanish Government Recovery, Transformation, and Resilience Plans (PRTR), that is, the green and sustainable transition and energy efficiency improvements (Gobierno de España, 2021) making use of the roadmaps of the IEA.

The Covid-19 crisis is also increasingly seen as an opportunity to develop a more sustainable and resilient tourism sector (OECD, 2020). Several policy measures promoted by the European Union and State members are oriented to foster these goals, as the ones considered in the scenarios built, as commented before. As a combination of all these circumstances, the tourism sector will be different in the so-called "new normal" after Covid-19. Our results confirm the expected significant decrease of 62% in the carbon footprint along with the fall of tourist visitors and how tourism has been more affected than other economic activities reducing its share in the Spanish total carbon footprint from 14,5% in 2019 to 5%. Results from the scenarios provide empirical support for those who claim that a pro-growth agenda or a back-to-normal prospect, improving existing models and implementing measures to transform the production system into a low-carbon one (Prideaux et al., 2020), can be insufficient, requiring a systemic shift in the global tourism economy instead (Gössling and Schweiggart, 2022; Sigala, 2020). The results will help assess the potential of tourism to contribute to the Paris Agreement and Sustainable Development Goals, becoming a low-carbon sector.

2. Material and methods

2.1. The environmentally extended multiregional input-output model

Input-output analysis (IOA) is a widespread methodology to assess the impacts of economic activities, especially in the environmental sphere (Hoekstra, 2010). Multi-regional input-output (MRIO) models describe the structure of the economy as a network between industries in different regions in which the final demand for goods or services from one industry is the trigger that leads to worldwide impacts in other economic sectors and countries.

Environmentally extended MRIO models (Davis and Caldeira, 2010; Minx et al., 2009; Peters, 2008) are the prevailing method to analyse the direct and indirect environmental impacts generated by economic activities along global value chains. These impacts can be different when considering, for instance, emissions (Lenzen et al., 2018; Minx et al., 2009), materials (Lenzen et al., 2022; Wiedmann et al., 2015), water (Cazcarro et al., 2014), land (Dorninger et al., 2021) or energy (Lee et al., 2021). Following Miller and Blair (2022), the environmental extension of the MRIO model with n countries and m industries is defined by Eq. (1):

$$F = \hat{e}(I - A)^{-1}\hat{y} \tag{1}$$

where A is the matrix of technical coefficients; I is the identity matrix and $(I - A)^{-1}$ is the Leontief inverse, for which each column provides the direct and indirect requirements per unit of finished production intended for final demand. $\hat{y}$ is a matrix of final demand diagonalised by blocks, where each block contains a m-element diagonalised vector $\hat{y}^{pq}$ that represents the production of every industry in country p that is consumed by country q final demand. $\hat{e}$ is a diagonal matrix containing the environmental impact per unit of production. In this study, $\hat{e}$ corresponds to the emissions coefficients, i.e. GHG emissions per unit of output. Therefore, the resulting matrix F gives the direct and indirect GHG emissions generated worldwide in all the production stages required to meet the final demand represented by $\hat{y}$. A lecture by rows shows the producer-based accounting (PBA), i.e. the industries and regions that directly release the emissions. Reading by columns provides the consumer-based accounting (CBA) or footprint, which reveals the industries and regions whose final demand embodies those emissions.

Input-output analysis presents some general limitations, such as the assumption of homogeneity between firms inside the same industry, which can be a strong constraint when working with broad sectors; the consideration of fixed proportions between inputs and output, which ignores economies of scale; the assumption of constant prices and the absence of capacity constraints (Miller and Blair, 2022). Other uncertainties are related to the data sources and coefficient variations. In this sense, we have performed a sensitivity test of the model by using Monte Carlo analysis, which can be found in the supplementary information (SI.Section 3).

Despite these limitations, the features of input-output analysis make it an adequate and versatile tool for assessing the impacts generated by tourist activities. Given the current spread and fragmentation of global value chains, a consumption pattern apparently localised in a region -like the expenditure linked to touristic activities- can lead to worldwide impacts in a range of industries. Therefore, the capacity of environmentally-extended input-output models to reveal direct and indirect impacts in a variety of regions and industries, and their feature of taking tourists' expenditure as the driver of these effects, make them an adequate tool to determine the environmental impacts of touristic activities (Sun et al., 2019; Zha et al., 2021).

The characteristics of tourism as an economic activity involving consumers from different origins moving across borders make it complex to define the boundaries for footprint calculations. Sun et al. (2020) find three main perspectives to define tourism carbon inventories: production, consumption, and destination, being the last one specific to tourism accounting. In this work, we rely on a destination perspective by using the Tourism Satellite Account Principle, which measures the domestic and foreign emissions produced to support all touristic activities within the geographic territory of an economy (Sun et al., 2019). Under this approach, the final demand of the MRIO model is built from a tourism satellite account (TSA), which specifies the total expenditure which occurs in a destination, in order to calculate the worldwide emissions (domestic or international) generated directly or indirectly to satisfy the tourism consumption in this destination (Sun et al., 2020). Several studies use a similar approach, such as Lenzen et al. (2018), which quantifies the tourism-related global carbon flows between 160 countries and their carbon footprints under both origin and destination accounting perspectives. Additional examples of the analysis of tourism carbon footprints through input-output modelling are those performed by Cadarso et al. (2015), (2016) for Spain, Sun (2014) for Taiwan, Kitamura et al. (2020) for Japan, and Zha et al. (2021) for China.

In operational terms, the assessment of the carbon footprint of the touristic activities taking place in the Spanish territory implies that the final demand matrix $(\hat{y})$ included in our model only contains non-zero values for the columns involving Spain. The corresponding rows show the origin country and industry that provide the finished products. Thus, for $q = \{Spain\}$, the diagonalised vectors $\hat{y}^{pq}$ include data on finished products from country p consumed by tourists in Spain. Otherwise, for $q \neq \{Spain\}$, all the elements in $\hat{y}^{pq}$ are zero. Expression (2) shows a simplified structure for the model variables assuming that Spain is located in position 1 in the input-output table. Notice that each of the sub-matrixes F^{p1}, $\hat{e}^{p}$, L^{pq} *and* $\hat{y}^{p1}$ represented in Eq. (2) contains m industries for each region, which means that each of the submatrices' dimension is *mxm*.

$$F_t^{SPA} = \begin{bmatrix} F^{11} & 0 & \dots & 0 \\ F^{21} & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ F^{n1} & 0 & \dots & 0 \end{bmatrix} = \begin{bmatrix} \hat{e}^{1} & 0 & \dots & 0 \\ 0 & \hat{e}^{2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \hat{e}^{n} \end{bmatrix} \begin{bmatrix} L^{11} & L^{12} & \dots & L^{1n} \\ L^{21} & L^{22} & \dots & L^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ L^{n1} & L^{n2} & \dots & L^{nn} \end{bmatrix} \begin{bmatrix} \hat{y}^{11} & 0 & \dots & 0 \\ \hat{y}^{21} & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \hat{y}^{n1} & 0 & \dots & 0 \end{bmatrix} \tag{2}$$

where the resulting matrix F_t^{SPA} contains the direct and indirect emissions released all over the world to produce the goods and services consumed by tourists in Spain, distinguishing the emitting industries and regions (PBA) and the finished products that embody those emissions and are ultimately consumed by tourists in Spain (CBA).

2.2. Data sources and data preparation: MRIO database and tourism satellite accounts

The MRIO model applied here relies on the input-output table and emissions satellite accounts provided by Exiobase in its 3.8 version (Stadler et al., 2018) for 2019 and 2020. This database provides details for 49 regions (44 countries and 5 rest of the world regions) and 163 industries. We will, however, aggregate our MRIO model into 59 main sectors instead, as detailed in the following paragraphs. Regarding the Exiobase environmental satellite account, it contains data on industry-specific air emissions for 27 pollutants. To obtain the stressor employed to account for GHG emissions, we have added the emissions of the three top greenhouse gases from combustion (CO_2, CH_4, N_20) after transforming each of them into CO_2 equivalent units for each industry using their global warming potential (GWP) over a 100-year period (IPCC, 2013).[1] Further details about the emissions satellite accounts from Exiobase can be found in SI.Section 2.

The assessment of the carbon footprint for tourism in Spain requires introducing in the model the final consumption linked to tourism within the Spanish territory – both resident and non-resident – as a final demand matrix. We have used the interior touristic consumption data in Spain in 2019 and 2020, retrieved from the National Tourism Satellite Account (TSA) (INE, 2022d). According to the TSA definition, interior touristic consumption refers to the money spent on any tourism activity taking place in the territory, including services linked to own-account holiday accommodation, regardless of the origin of the tourists. Following the principles of the System of National Accounts (SNA), the TSA also includes some spending by outbound tourists when it takes place inside Spain and is provided by domestic suppliers. Therefore, interior touristic consumption is the addition of the internal tourism expenditure–domestic tourist expenditure made by residents in the territory –, the receiving tourism expenditure– made by residents in a different territory –, and other components of tourist consumption such as in-kind tourist social transfers and other imputed consumption. The TSA provides this indicator disaggregated into 11 tourism characteristic products plus a general category of other non-characteristic products.

Before implementing the model, it is necessary to develop several transformations on the TSA data for 2019 and 2020 to convert each of these sets into a final demand matrix suitable to be introduced in the MRIO model. Following the proposal detailed in Cadarso et al. (2022), we have applied the following steps. We have started by translating the 2020 expenditure into 2019 prices using deflators from INE (2022a) to enable comparisons between the footprints of both years without the effect of prices. After that, the category of non-tourism-characteristic products was split into the products reported in the Spanish national accounts –110 products minus 11 considered tourism-characteristic products –. This allocation was made following the product consumption pattern of the Spanish households extracted from the use table in the Spanish national accounts (NA) (INE, 2022 g), reducing the weight of certain products rarely consumed by tourists (for instance, chemical products or concrete) and increasing the share of those more demanded in touristic activities (for example, vessels). Each tourism-characteristic product was allocated into its corresponding category in the national accounts' product structure.

The Exiobase input-output tables (IOT) are expressed in basic prices (Stadler et al., 2018), so the next step was to convert the touristic consumption from purchaser prices into basic prices. We have followed the procedure detailed in Gueddari-Aourir et al. (2022) and García-Alaminos et al. (2022), using the margins and taxes percentages calculated for each product from the supply table in the Spanish NA (INE, 2022f). Once these percentages are calculated, we have removed taxes from the purchaser prices. After that, we have detracted transport and trade margins and reassigned them to the specific products that provide these auxiliary services not included in the basic price of the product (in the case of transport margins, more than 90% of them are reallocated into "inland transport services different from railroad"; and in the case of trade margins, they are split almost equally between wholesale and retail trade services). This process results in a vector of interior touristic consumption expressed in basic prices and disaggregated into 110 products for each of 2019 and 2020.

Considering that we are working with the industry by industry Exiobase IOT, a homogenisation process is required. First, we must transform the vector from products to industries, using model D (Mahajan et al., 2018), which implies keeping technology constant by product. We use data from the supply table in the Spanish NA (INE, 2022f), in which we divide each element by the row sum, and we multiply the transpose of the resulting matrix by our vector of tourism consumption. This method allows reallocating the consumption of each product to the corresponding industries where they are fabricated, as some of those industries are the source of more than one type of good or service. In this way, we have moved from 110 products to the 81 industries covered by the NA. Second, we must harmonise the sectoral detail for the two databases employed, so we have converted the 163 Exiobase industries and the 81 NA industries into 59 sectors (see Tables SI.1 and SI.2 for more information about this aggregation process).

After this process, we achieved a vector of interior touristic consumption expressed in basic prices and disaggregated into 59 industries for each year. However, this vector lacks detail on the geographical origin of the goods and services demanded from each industry by tourists in Spain, except for the tourism-characteristic activities, which can be assumed to be fully provided by the corresponding Spanish industries given the characteristics of touristic services. Therefore, it is essential to distribute the expenditure in non-tourism-characteristics industries among the 49 regions (including Spain) that may act as suppliers in our MRIO model. Given the data limitations in the TSA, we have applied this distribution to the 49 Exiobase regions according to the import structure of the Spanish households' final demand provided by this database for 2019 (Stadler et al., 2018). In this way, we obtain a vector of 2891 elements (59 industries x 49 regions) suitable to be diagonalised by blocks as exposed in Expression (2).

As mentioned before, the model is run for 49 regions and 59 industries. However, results are presented aggregated into 10 regions (Spain, Germany, France, United Kingdom, Italy, Rest of Europe, China, United States, BRIIAT – which contains Brazil, Russia, India, Indonesia, Turkey, and Australia – and Rest of the World) and 14 sectors (Agriculture and mining; Manufactures; Electricity, water, gas and waste; Construction; Wholesale trade; Retail trade; Land transport; Air transport; Other transport; Accommodation and food services activities; Professional services; Real state and rental activities; Leisure; and Other activities). The calculations are performed for three vectors of final demand (that add up to the total interior touristic consumption): resident tourists' expenditures, non-resident tourists' expenditures, and other components of touristic consumption (mainly imputed rents of owner-occupied dwellings).

2.3. Scenario setting

Our aims go beyond assessing the short-term effects of Covid-19 on the environmental impact of tourism in Spain. What can this extreme event tell us about the future trends in tourism? Can any of those changes reduce the total carbon footprint of tourism in a significant way? To shed some light on these questions, we will present potential scenarios based on the most recent data on tourism behaviour and spending in Spain.

The configuration of the new normal is highly uncertain for every industry, as well as for the tourism sector. The uncertainty linked to the pandemic recovery has been recently increased by the Russia-Ukraine war, mostly in Europe, and by the increasing inflation with unclear outcomes. Previous studies that estimated the impact of terrorism, corruption, and economic policy suggested that their monetary impact on tourism could vary as much as a 14% increase with scenarios of minimum insecurity to a decrease of around 17% in the opposite case (Manrique-de-Lara-Peñate et al., 2022), and, besides, the pandemic has seemed to change people's perception about public health risks derived from tourism (Qiu et al., 2020). In addition to this uncertain context, tourism is also committed to the fight against climate change, bringing further changes to the sector.

To deal with that uncertainty, we build several scenarios to assess possible new trends of partial and total recovery of tourism and their carbon footprint impact (post-pandemic), as summarised in Table 1. The scenario-building process takes the Spanish TSA data for 2019 and 2020

[1] CO_2 GWP 100-year = 1; CH_4 GWP 100-year = 28; Fossil CH_4 GWP 100-year = 30; N_2O GWP 100-year = 265

Table 1
Scenarios overview.

	Short description	*Resident tourist Consumption pattern*	*Non-resident tourist consumption pattern*	*Level of tourist expenditure*
Scenario 1 (SC1)	Recovery led by resident tourist	Pre-Covid-19 pattern (year 2019)	Pre-Covid-19 pattern (year 2019)	2019 (total recovery)
Scenario 2 (SC2)	Covid-19 consumption changes persistence	Covid-19 pattern (year 2020)	Covid-19 pattern (year 2020)	2021 (partial recovery)
Scenario 3 (SC3)	Return to pre-Covid-19 patterns	Pre-Covid-19 pattern (year 2019)	Pre-Covid-19 pattern (year 2019)	2021 (partial recovery)
Scenario 4 (SC4)	Covid-19 consumption changes persistence and total recovery	Covid-19 pattern (year 2020)	Covid-19 pattern (year 2020)	2019 (total recovery)
Scenario 5 (SC5)	More sun and beach type tourism	Sun and beach pattern (year 2019)	Sun and beach pattern (combination of INE (2022b) and INE (2022h))	2019 (total recovery)
Scenario 6 (SC6)	Shift to more sustainable means of transport	Pre-Covid-19 pattern (2019) with a shift from air to railway transport for mainland tourism	Pre-Covid-19 pattern (2019) with a shift from air to railway transport for Portuguese and French tourists	2019 (total recovery)
Scenario 7 (SC7)	Shift to more sustainable means of transport (SC6) + Increase in energy efficiency in road transport, air transport and accommodation and food services	Pre-Covid-19 pattern (2019) with shift from air to railway transport for mainland tourism	Pre-Covid-19 pattern (2019) with shift from air to railway transport for Portuguese and French tourists	2019 (total recovery)

Source: own elaboration

as a starting point (INE, 2022d), implementing modifications both in the relative and absolute magnitude of the expenditure items and in the domestic-receiving composition of the tourist interior expenditure. We employ different assumptions and trends identified from additional sources, which are exposed in this section.

All seven designed scenarios deal with changes in consumption patterns, while only one (the last one) estimates the impact of an increase in energy efficiency. Two scenarios assume a partial recovery (that is, the tourism consumption level is the actual level of 2021), while the other five assume a total recovery (that is, the consumption level is that of 2019, the pre-pandemic level). In doing so, we aim to obtain an estimate of the evolution of the carbon footprint in 2021 and beyond. We explain each scenario in more detail as follows, and the details on the touristic interior consumption for each is shown in Tables SI.6, SI.7, and SI.8.

One of the observed trends in tourism worldwide is concerned with the different behaviour of resident and international tourism. International tourism experienced a higher breakdown than domestic tourism in accordance with the strictest and most prolonged restrictions on mobility between countries. Besides, the tourism recovery is being headed up by domestic tourism since international tourists are waiting to see good pandemic results, vaccines, and treatments before regularly returning to normal, with expected growth in international spending only starting in 2022 (WTTC and Trip.com Group, 2021). This led to an expected 38% lower level of international tourists postCovid-19 in Spain (being the highest decrease in Europe and the third worldwide (Marques Santos et al., 2020). In Spain, the drop in non-resident tourist expenditure was 73.9% compared to 47.2% for residents in 2020, resulting in a reversed share of resident and inbound tourism expenditure in total expenditure (from a split 39–61% domestic vs. inbound tourism, quite stable in the previous years, to 57–43% in 2020 (INE, 2022d)).

This evolution is the basis for the first proposed scenario, **scenario 1**, which points to the analysis of the tourism carbon footprint if the Staycations (generally understood as vacations in the home country (WTTC and Trip.com Group, 2021) trend continues over time. This scenario takes into consideration the different expenditure distribution of residents and international tourists and calculates emissions considering the novelty of an increased weight of resident tourism that recovers faster than the international one. This higher weight of domestic destinations and activities implies spending increases in Food services and Travel agencies, and reductions in Accommodation, Leisure, Cultural services, and non-tourism-characteristic products.

The Covid-19 pandemic has also caused changes in tourist consumption patterns that are expected to persist in the medium term. These changes are a combination of a number of trends, such as an increased preference for destinations with low tourist density, away from big cities, with more outdoor activities and contact with nature, use of private vehicles (Marques Santos et al., 2020), or a reduction in business travels and an increase in wellness tourism, destinations where people can spend more time and money on self-care, wellness, and stress relief (WTTC and Trip.com Group, 2021). **Scenario 2** takes into consideration the mentioned trends in tourism patterns and the actual real increase in tourism expenditure experienced in 2021 with respect to 2020, that is a partial recovery of 50.4% for resident tourists (according to the Survey of Resident Tourism (INE, 2022h) and 72.2% for non-resident tourists (following EGATUR data (INE, 2022b). It considers that the changes in tourism consumption patterns caused by the pandemic remain both in the behaviour of domestic and foreign tourists. Consequently, scenario 2 aims to estimate the Spanish tourism carbon footprint in 2021 if the changes in tourists' distribution of spending due to the pandemic are applied to the partial recovery levels.

However, what if those "pandemic" consumption patterns returned to normal, that is the pre-pandemic ones? This is considered in scenario 3. **Scenario 3** includes the same rate of growth of tourism consumption as scenario 2 (the actual increase of tourism consumption experienced in 2021 regarding 2020) but, in this one, the partial recovery implies that tourists go back to the pre-pandemic behaviour and patterns of consumption (those of the year 2019).

Both scenarios 2 and 3 account for a partial recovery (the one recorded by 2021 data). However, a total recovery is expected around 2023 or even sooner. For instance, provisional data of international tourist expenditure in Spain shows that in May 2022 (the last month available at the time of writing) was only 1% lower than the pre-Covid-19 one (May 2019) (INE, 2022b). The following scenarios, then, include a total recovery, meaning that the level of tourism consumption goes up to pre-pandemic times, that of 2019. **Scenario 4** considers a total recovery and replicates the pandemic tourism consumption pattern, under the assumption that the changes induced by the pandemic are medium-long term. As a result, scenario 4 shares with scenario 2 the consumption pattern while it differs in the level of consumption.

Scenario 5 evaluates the observed new trend in Spanish tourism, for both domestic and foreign tourists, of more sun-and-beach tourism, as a reflection of an increased general preference for outdoor activities, as well as destinations away from big cities and overcrowded places. For resident tourists, the share of sun-and-beach over all motivations for tourism increased from 21.1% in 2019 to 26.4% in 2021 (INE, 2022b), while for inbound tourists it grew from 29.3 to 43.4% (INE, 2022b). Conversely, there was a reduction in cultural tourism. This type of tourism (sun and beach) implies a different consumption pattern than other tourism motivations, for instance, a higher share of Accommodation and food services and a lower share of Travel agencies, Leisure and Cultural services, and Transport than other types of tourism (as shown by microdata from INE (2022h).

Scenario 6 deals with the need for tourism to address its high carbon footprint, and it, therefore, proposes a radical change in the pattern of consumption, shifting part of the expenditure from air transport to rail transport as a more sustainable-low carbon travel mode. This change would follow the French proposal of banning the short continental flights that can be covered by train in less than 2.5 h, as part of the French package directed to cut emissions by 40% by 2030 (Reuters, 2021). This can be considered the first law that results from the *flygskam* ("flight shame") trend, born in Sweden, that encourages people to stop flying and use lower-emission travel modes like train instead (Chiambaretto et al., 2021). To make this scenario more feasible, we substitute air by railway expenditure for international tourists arriving from nearby countries (France and Portugal). Tourists from these two origins accounted in 2019 for 6.5% of total foreign tourists traveling to Spain by flight (INE, 2022i). We also substitute all mainland flights by railway displacements for resident tourists (which means that we exclude from the reallocation process the resident tourists flights with origin or destination to the Spanish islands and the Autonomous Spanish cities in Northern Africa, which accounted for 60% of total national flights in 2019 (INE, 2022c)). Given the volatility in flight ticket prices and railway fares, we have applied the reallocation of expenditure considering both means of transport equivalent in terms of price per distance.

In **Scenario 7,** we propose, in addition to the more far-reaching changes in the consumption patterns of Scenario 6, improvements in energy efficiency. This is one of the pillars of both EU and Spanish strategies to involve the tourism sector in the Green transition (European Commission, 2022) (MINCOTUR, 2021a). To address the expected impact on energy and emissions efficiency of present policy measures and commitments, we use estimations from the International Energy Agency (IEA, 2017) in their reference technology scenario regarding buildings in services for the EU and the World. Based on this, we estimate total emissions per unit of energy consumed and their variation rate from 2014 to 2030 and apply it to the emission intensity (or emission coefficients) in monetary units of the accommodation and food services sector, assuming they change at the same rate. Specifically, we assume energy efficiency improvements in the food service and accommodation sector due to a decrease in the building emissions coefficient by 16% in the EU and 22% elsewhere. Another crucial sector in the evolution of tourist emissions is the transport sector and this is the focus of several policy measures aimed at increasing the electrification of the transport fleet, as in the EU Green Deal and in the Spanish Recovery, Transformation, and Resilience Plan (European Commission, 2019; MINCOTUR, 2021b). To include the expected impact on transport emissions of increasing electrification, we use estimations from UNWTO and ITF (2019) that provide the global average emissions per passenger kilometer (PKM) until 2030 distinguishing by travel mode under a current ambition scenario. Using these estimations, we calculate the corresponding variation rate of emissions PKM and apply it to the emission intensity of car and bus vehicles, assuming they evolve in the same way. As a result, we also introduce in scenario 7 energy efficiency improvements in land transport (23%) and road transport (34% in cars and 19% in buses) due to electrification (UNWTO and ITF, 2019). (See additional explanations and Table SI.9 in SI).

3. Main results

3.1. Tourism consumption patterns for 2019 and 2020

As seen before, due to the Covid-19 pandemic, many tourists have changed the way they travel: their purposes for travelling, the means of transport they choose, where and how many days they stay in Spain, and what they spend their money on. All these consumption patterns have an associated environmental impact, which is the subject of study in this paper. Although tourism has a positive impact on the Spanish economy and creates jobs in many sectors throughout the value chain, the environmental impact must be considered to achieve the Paris Agreement Goals.

The next subsection will start our analysis of the tourism carbon footprint in Spain by comparing 2019 and 2020 to study the main changes and factors behind them. These are closely related to the evolution of tourism expenditure, which can be seen from the data available from TSA (INE, 2022c), transformed as described in Section 2. Consequently, it is important to analyse, first, the consumption patterns and how they have changed. The vector of tourism consumption (aggregated to 14 sectors), with no distinction between the regions of origin of the goods or services, is shown in Table SI.5. The distribution of expenditures of tourism consumption shows a clear cut between Accommodation and food services activities (36%) and Real estate (16%), followed at a distance by Leisure (10%), Other activities (9%), Air transport (7%), and Land transport (5%), that altogether account for 84% of total tourism consumption in Spain (in 2019). It is important to note that we include the imputed rents of owner-occupied dwellings in Real estate, which explains that high share.

The impact of the pandemic was acutely felt by the tourism sector in Spain. Our figures show a decrease in total interior consumption of 63% between 2019 and 2020 (48% for resident consumption and 74% for non-resident). Before the pandemic, tourism accounted for 12.4 % of GDP, and Spanish tourism was in a moment of an economic boom in 2019, breaking a record in international tourist arrivals (83.7 million), which was 1.1% more than in 2018. Drilling down by origin of tourism, both non-resident and resident tourist also reached records of expenditure, as non-resident was growing at an annual rate of 2.8%, and resident tourist was growing at an even higher annual rate (3.7%) according to INE (2022b, 2022h).

Not only did total spending decrease drastically, but there were also other relevant changes when looking at its composition: an increase in the share of resident vs. non-resident tourists' expenditures, and changes in the weight of expenditure categories, are the two most relevant factors that can be identified (Fig. 1). All of this influence the resulting emissions, as we will comment on below.

Accommodation and Food services concentrate half of total expenditure for resident tourists, followed by Other activities. For non-resident tourists, Accommodation is even more important, but spending is more spread, so other categories such as Leisure, Real estate, Air transport, and Manufactures are at or above 9% of total expenditure. In terms of the change in patterns from 2019 and 2020, there was a reduction in the share of Accommodation and Air travel, and an increase of Food services, for resident tourists, while Accommodation and Air Travel kept its weight, and it was reduced for Food services, for non-resident tourists.

3.2. Carbon footprint results for 2019 and 2020

The changes in spending levels, origin of tourists, and consumption patterns explain the behaviour of emissions and their evolution between 2019 and 2020. Our results show that Spanish tourism generated a total carbon footprint of 47,825 ktCO_2e in 2019, both in direct and indirect production, to cover all tourism consumption in Spain (14.2% of the total Spanish carbon footprint), and these emissions fell by 62.6% overall in 2020, amounting to only 17,970 ktCO_2e (5.1% of the total Spanish carbon footprint). This reduction is detailed in Fig. 2, distinguishing the origin of tourists (resident and non-resident). A distinctive feature of the effect of Covid-19 on tourism is the different impacts depending on that distinction, resident or non-resident tourists. Even though there is a substantial decrease in emissions from resident tourism (51%), the fall is much larger for inbound tourism (73%), replicating the evolution of expenditure with very similar percentage drops.

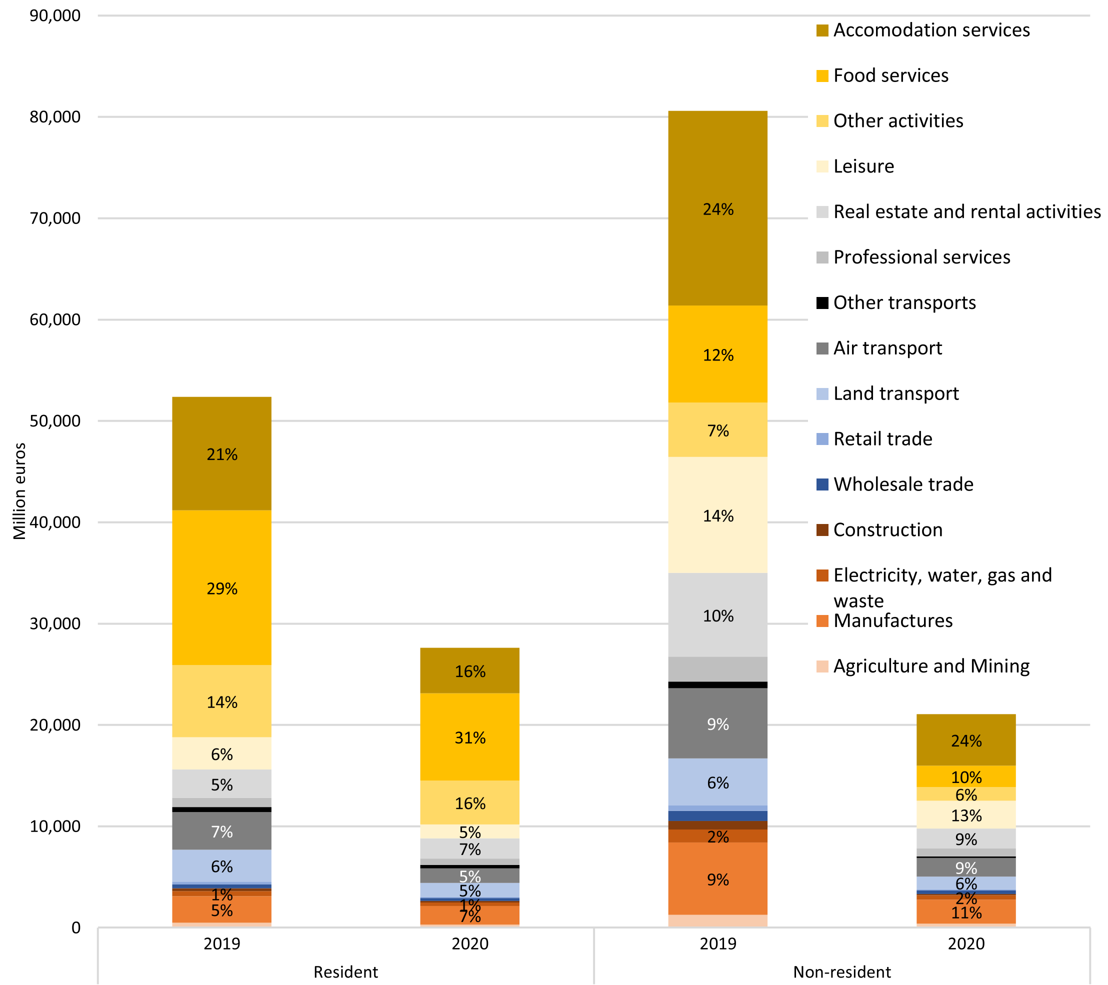

Fig. 1. Expenditure patterns in 2019 and 2020 distinguishing between resident and non-resident tourists (million € and %)
Source: own elaboration based on data from INE (2022d).

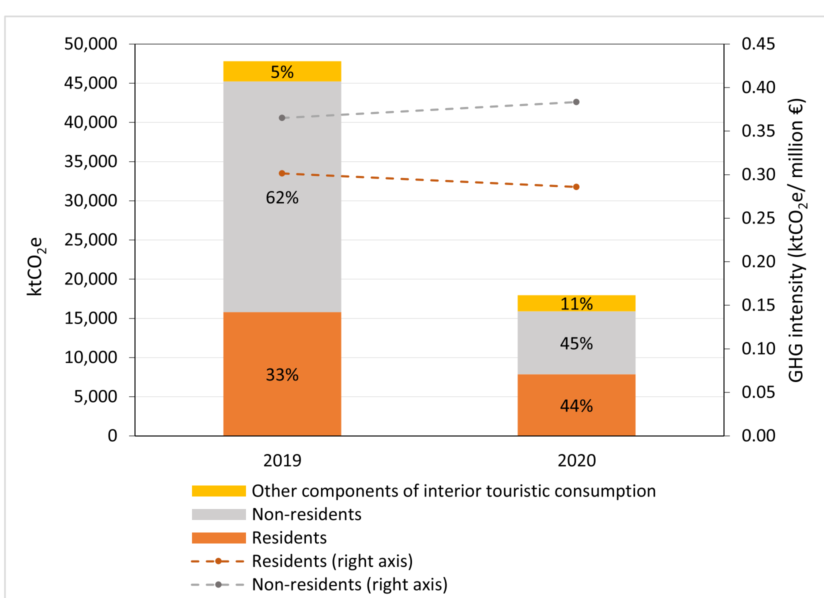

Fig. 2. Carbon footprint and intensity of tourism in Spain by origin of expenditure, 2019 and 2020 ($KtCO_2e$ and $KtCO_2e$ per million €).
Source: own elaboration based on data and methods described in Section 2.

Out of the total tourism emissions generated in 2019, 33% were associated with the consumption of resident tourists (15,792 ktCO2e), while 62% were linked to non-resident visitors (29,428 ktCO2e). The remaining 5% corresponded to other expenditures related to tourism activities (imputed consumption of self-accommodation and other activities, and tourist transferences by public administration and non-profit organisations). One of the consequences of the pandemic is that the contribution of resident tourism to the 2020 carbon footprint increased to 44% while that of non-resident tourism decreased to 45% (Fig. 2). Other tourism-related expenditures increased their share to 11% as their carbon footprint almost maintained 2019 levels.

Given these changes in the composition of tourism's carbon footprint, the question arises as to whether resident tourism is more or less polluting than foreign tourism. This comparison is represented by the dashed lines in Fig. 2, which indicate the direct and indirect emissions generated per million euros of consumption by resident (orange dashed line) and non-resident tourists (grey dashed line). The chart shows that, on average, the consumption of non-resident tourists has a higher carbon intensity than that of residents in both 2019 and 2020. Besides, the evolution of the resident tourists' intensity is better than that of non-residents. Interestingly, the outbreak of the pandemic and the change in tourist consumption patterns in that year caused a slight decrease in the carbon intensity of resident tourism, from 0.30 to 0.28 ktCO$_2$e/million€ (-7%). In contrast, non-resident tourists' consumption shows a slight increase in carbon intensity, from 0.36 to 0.38 (+3%).

This implies that the different evolution of emissions is not only related to changes in expenditure levels but also to differences in their consumption pattern. The spread found between the carbon intensities of resident and non-resident tourism is mainly explained by the distribution of their consumption by product. That is, non-resident tourists spend a higher proportion on goods and services with higher carbon intensities, especially Air transport, Manufactured goods, and Accommodation services, whereas resident tourists spend less on Transportation and have a greater tendency to spend on Food services and Other activities (Figs. 1 and 3). This can be illustrated by comparing the shares of the different product categories for expenditure (Fig. 1) and emissions (Fig. 3). For example, 24% of spending on Accommodation for non-resident tourists generates 8% of their emissions, while 9% of expenditures for Air travel results in around 30% of emissions.

These disparities in consumption patterns translate into differences in the sectoral composition of the carbon footprint of each type of tourism. Fig. 3 presents the distribution of the carbon footprint of resident and non-resident tourists by type of products consumed in 2019 and 2020.

The adaptation of tourism to the pandemic-related restrictions reduced the share of some sectors in tourism consumption and carbon footprint. Both for resident and non-resident tourism, the carbon footprints of Air and Land transport were considerably diminished, reaching

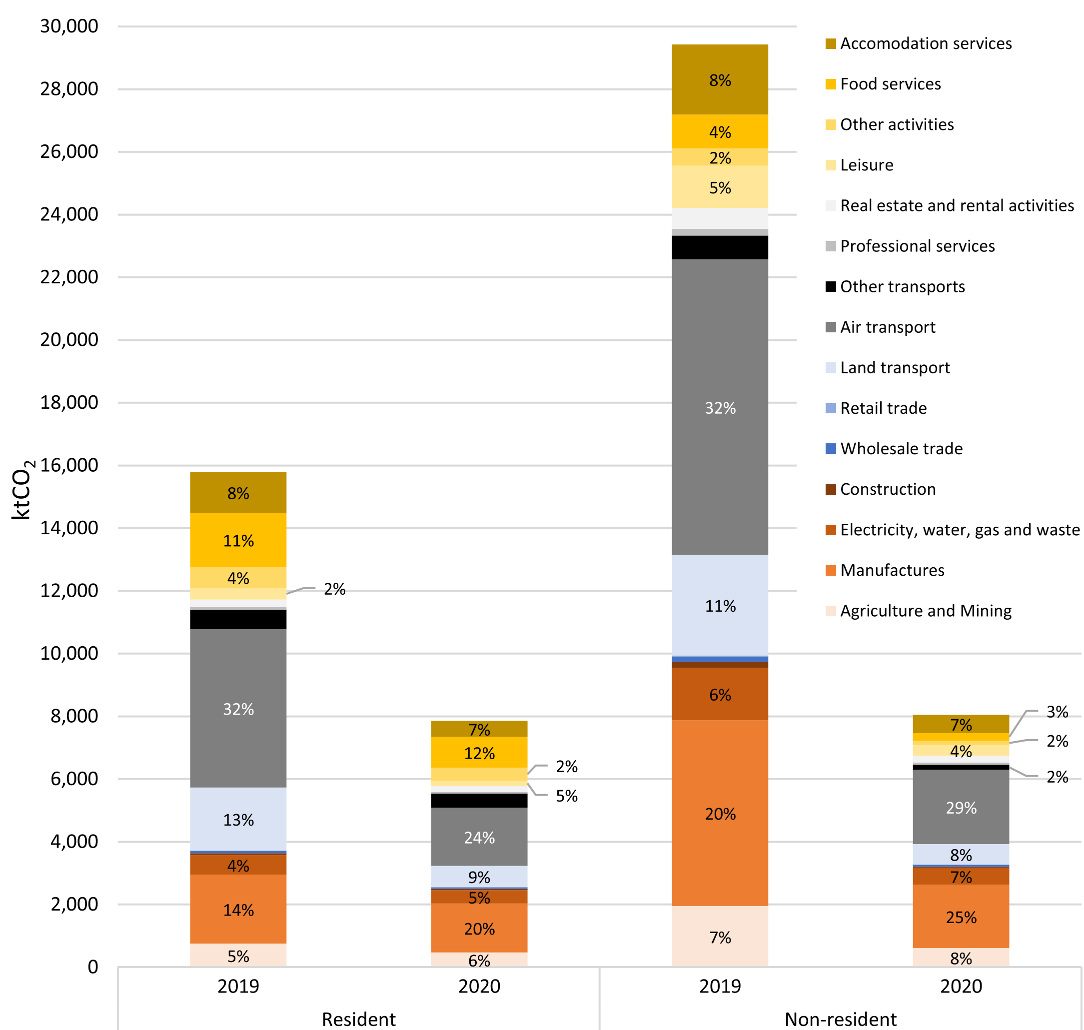

Fig. 3. Carbon footprint for resident and non-resident tourists by sectoral category of expenditure, 2019–20 (KtCO$_2$e and %)
Source: own elaboration based on data from INE (2022d) and Stadler et al. (2018).

a reduction of -4,513 ktCO_2e for resident tourists (57% of the total decrease between 2019 and 2020) and -9,616 ktCO_2e for non-residents (45%). As a consequence of these sharp drops, the percentage share of Air and Land transport in the total carbon footprint of resident tourists contracted by 8 and 4 percentage points (pp), respectively. In the case of non-resident tourists, the fall in percentage participation was less pronounced, with -3 pp for both Air and Land transport. In both types of tourism, the reduction in the percentage share of transport in tourists' spending and carbon footprint was replaced by increases in the share of manufactures, which went up by 6 pp in the carbon footprint of resident tourists and 5 pp in that of non-residents. There are also other noticeable changes in many tourism-characteristic sectors: the Leisure sector has a higher share in non-residents emissions than in residents both in 2019 and 2020, while Food services and Other activities have a more significant role in resident emissions. Besides, Food services increase their weight in resident carbon footprint (2 pp), while Accommodation services decrease their participation (2 pp) in 2020.

Another way to illustrate this point is to look at percentage changes in emissions, rather than in terms of shares, between 2019 and 2020. By industries (Fig. 4), the transport sectors led the great drop in emissions for both resident and non-resident tourists. In resident tourism, Land transport dropped by 67%, and Air transport decreased by 63%, while for non-residents, the highest reduction in emissions was in the Construction sector (81%) as well as transport sectors such as Land transport (80%), Other transport (79%) and Air transport (75%). In addition, sectors highly related to tourism also suffered significant falls, such as Accommodation (60%), Leisure (55%), and Food services (43%) in the resident carbon footprint, while in the case of non-resident tourists' emissions, the reduction was even more profound. For example, Food services emissions by non-resident tourism decreased by 78%, Leisure activities by 75%, and Accommodation by 74%.

The MRIO analysis also allows us to account for how many emissions are generated in each region and industry (where GHG are ultimately emitted). In terms of the origin of emissions for Spanish tourism, 56% of the total carbon footprint in 2019 (26,903 out of 47,825 ktCO_2e) was generated in Spain, while the remaining 44% was embodied in imported products, with very similar percentages for resident and non-resident tourists (although slightly higher imported emissions for these last ones, 45% compared to the 43% of resident tourists).

In 2020, the impact of the pandemic on this aspect was very limited, as the percentage of emissions embodied in imports increases by 1 pp. Out of the total 17,970 ktCO_2e that constitute the carbon footprint of interior tourism in Spain in 2020, 9,932 ktCO_2e were domestic emissions (55%), and 8,038 ktCO_2e were imported (45%), so it is, directly or indirectly, embodied in the global production chains. As Fig. 5A shows, a large part of the imported emissions come from European countries such as France (2.6%), United Kingdom (1.4%), Germany (1.1%), Italy (0.6%), and other EU (4.4%), from China (3.1%), BRIIAT (5.6%), and the United States (1.8%), but a significant amount (24.3%) also fall within the Rest of the world category (RoW) due to the high contribution of Transport and Manufactures (that includes coke and refined petroleum), as well as Agriculture and mining.

The percentage of domestic or imported emissions in the tourism carbon footprint differs significantly by sector when accounting for all the emissions embodied in their final product (including then emissions embodied in all the inputs the final product requires). On the one hand, emissions in Electricity, water, gas, and waste industry products (85%), Air transport (75%), and Other transport (90%) are primarily domestic. In contrast, emissions in Manufactures (78%), Agriculture and mining (67%), and Land transport (68%) are predominantly imported. There are other sectors, such as Leisure activities, Accommodation services, and Food services, in which at least 40% of their emissions are imported, which shows the relevance of global value chains in Spanish tourism-characteristic products. From the point of view of the ultimate sectors where emissions are generated, Agriculture and mining is the main responsible (32.5%, of which 79.8% are emitted abroad), followed by Air transport (21.9%, of which only 7.7% are imported), and Electricity, water, gas, and waste (18.5% of total carbon footprint, of which one third takes places outside the Spanish borders).

3.3. *Carbon footprint results for scenarios and reduction targets*

Given the differences in consumption patterns and tourist origin identified in the previous subsections, we now proceed to analyse the carbon footprint for tourism within the Spanish borders for the scenarios described in Section 2 (Table 1). These combine the different factors identified in the descriptive section: drop in tourism expenditure, changes between the share of resident and non-resident tourists, and

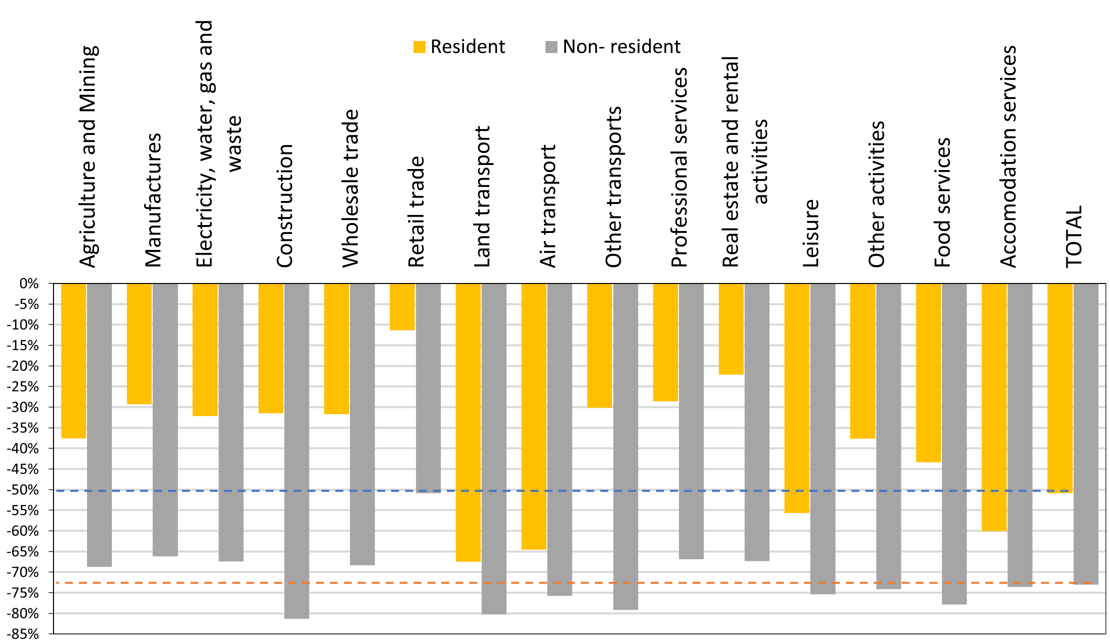

Fig. 4. Change rates (2019–20) of carbon footprint by sectoral category of expenditure and origin of tourists (%)
Source: own elaboration based on methods and data described in Section 2.

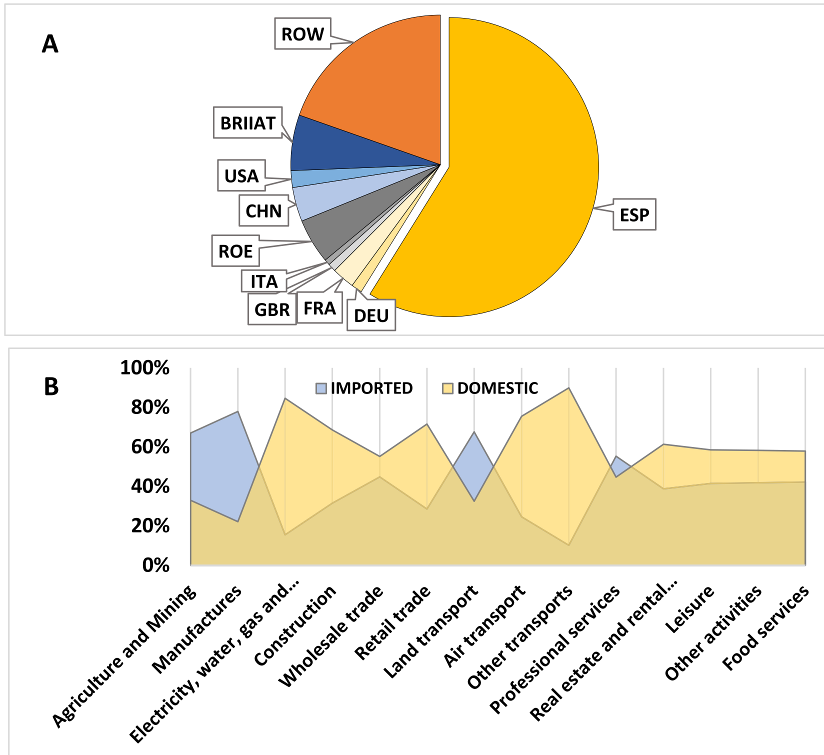

Fig. 5. Carbon footprint of interior touristic consumption in Spain in 2020 A) By emitting countries (%), B) By product of final demand (%)
Source: own elaboration based on data and methods described in Section 2.

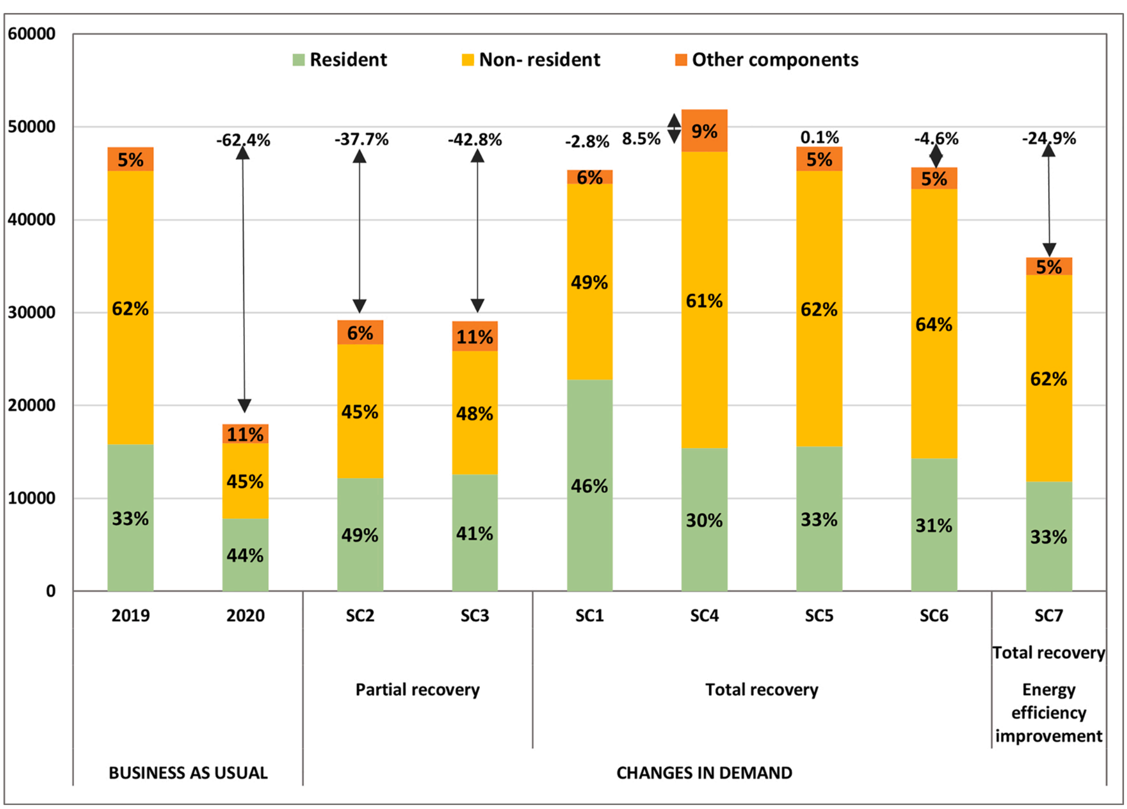

Fig. 6. Spanish tourism carbon footprint in BAU 2019 and 2020 and in the scenarios proposed for 2021 (ktCO_2e and %).
Note to Fig. 6: The reduction percentages shown at the top of the bars have been calculated based on the 2019 level.
Source: own elaboration based on data and methods described in Section 2.

changes in consumption patterns (due to variations in means of transport, destination, or type of tourism activities). We also include the potential effect of policies aimed at increasing energy efficiency and inducing changes in transportation.

The first scenario (SC1) considers a full recovery of the 2019 expenditure level led by resident tourists (whose carbon intensity is lower, as shown before) with a return to the 2019 consumption pattern. SC1 generates a carbon footprint of 46,471 ktCO_2e, for which resident tourism is responsible for 49%. Specifically, resident tourism generates 7,000 ktCO_2e more than in 2019, but non-resident tourism reduces its emissions even more, so the total carbon footprint decreases by 3%. This scenario shows a cleaner recovery in relation to the 2019 level even if we continue with the 2019 emissions pattern, which implies higher spending shares related to products characteristic of tourism and transport (highly polluting) than in 2020. This is because resident tourism spends more on Accommodation and Food services (which are less carbon-intensive) and less on Air transport and Manufactures than non-resident. Hence, its leadership in the recovery offsets the effect of the back-to-2019 consumption pattern.

In 2020, Spanish tourism broke another record (downward) with a drop in expenditure never seen before, and tourism lost more than half of its weight in GDP. The economic and social disruption caused by the pandemic led to an increase in the percentage of tourists staying in their own homes or in friends' or relatives' homes, both for resident (from 64% to 68%) and non-resident tourists (from 18% to 27%), probably due to health reasons as well as economic problems (INE, 2022b, 2022h). That year, the carbon footprint amounted to 17,970 ktCO_2e, as it changed both the pattern and the level of expenditure. Regarding resident tourists, they spent less on accommodation and food services, leisure activities, and land and air transport, while other activities and real estate/rental activities increased their share of total spending. In the case of non-resident tourists, the share of accommodation and food services fell by a smaller percentage than for resident, leisure also decreased its share, while expenditure on manufactures increased its participation in total expenditure. These changes between sector shares are introduced in scenarios 2 (SC2) and 4 (SC4), which include the consumption pattern resulting from the impact of Covid-19.

Beginning with the SC4, it proposes a full recovery of the 2019 expenditure level but considering the changes in the consumption pattern due to health and psychological reasons. Under this scenario, an additional 4,059 ktCO_2e are emitted compared to 2019 (8% higher) due to increased emissions generated by non-resident tourism and other components. This means that the persistence of consumption pattern changes derived from the pandemic would result in a highly polluting scenario if the pre-pandemic level of expenditure is reached, making it harder for the tourism sector to reverse course in the fight against climate change.

Unlike the previous scenarios that propose a recovery of the 2019 spending level, scenario 2 presents a partial recovery considering the actual figures of tourists' expenditure in 2021. In that year, with the relaxation/easing of restrictions and the improvement of the health and economic situation, total expenditure and number of visitors have increased rapidly, although they are still far from reaching the pre-pandemic level. Given this partial recovery, SC2 asks what would happen if tourists returned to their pre-Covid-19 consumption pattern. Our results show a carbon footprint of 29,797 ktCO_2e, in which resident tourists account for 41% and non-resident tourists for 48%. This implies an increase of 11,826 ktCO_2e with respect to 2020 (66% more) but 18,028 ktCO_2e less (-38%) than in 2019.

Moving on to scenario 3 (SC3), this suggests a partial recovery in spending (as in SC2), but assuming tourists return to the same pre-Covid-19 consumption patterns since their changes in 2020 were temporary and part of exceptional health and economic circumstances. This recovery scenario leads to a lower carbon footprint (27, 352 ktCO_2e) than SC2, with a higher share of emissions from resident tourism (46%), whose carbon intensity is lower.

Another question we try to answer with these scenarios is whether trend changes in the motivation for tourism, as observed during 2020 and 2021, could have a relevant impact on emissions. Scenario 5 (SC5) is slightly different from the previous ones since we apply a full recovery (as in SC1 and SC4) but increase the type of sun and beach tourism and decrease cultural and other leisure tourism, which also implies a change in consumption patterns. Taking this into account, we show that the corresponding changes in consumption patterns do not result in significant changes in emissions, as they tend to compensate for each other in terms of pollution. Specifically, under this scenario, 47,869 ktCO_2e are emitted, practically the same as in 2019, with a negligible increase of 0.1%. Furthermore, differentiating by tourism origin, non-resident tourism increases slightly while resident tourism decreases so that overall, both effects are neutralised.

In any case, the lesson from those first five scenarios is that the only significant reductions in emissions are due to the decrease in the level of expenditure, as reflected in SC2 and SC3 (partial recovery). Changing the distribution between resident and non-resident tourists only reduces emissions by 3%, while other trends leave the total carbon footprint unchanged or it even increases. These scenarios show the need for more radical and far-reaching changes both in the level and pattern of consumption, as even continuing with the pattern adopted due to Covid-19 would worsen the emissions results and require greater efforts to reduce them. Thus, scenario 6 (SC6) and 7 (SC7) point to these more radical changes.

SC6 shows what would happen if tourists shifted their demand from air transport to land transport (which is more sustainable), only where this is more feasible for both domestic and international journeys of nearby countries (see Section 2.3). The results show that, if the recovery path continues and the pattern of expenditure remains as in 2019 except for the shift in transport, the carbon footprint would only be reduced by 2,184 ktCO_2e compared to 2019 (5% lower), where 1,500 ktCO_2e are due to a fall in resident tourism. Within resident tourism, Air transport would lose more than 10 pp share in the carbon footprint (from 32% to 21%), while in non-resident tourism Air transport would decrease its weight in the carbon footprint from 32% to 30%.

The aforementioned scenarios are based on changes in emissions from consumer responsibility and are focused on tourists' final demand. The novelty of Scenario 7 (SC7) is that it continues along the lines of radical change to considerably reduce emissions (as SC6), but adds changes on supply, incorporating improvements in energy efficiency, resulting from current policy measures and understanding that the evolution towards sustainability must also be driven by technology. SC7 achieves the largest reduction in carbon footprint in relation to the other scenarios that also consider full recovery at the pre-pandemic-2019 level. Specifically, the carbon footprint would amount to 35,919 ktCO_2e, which is double the figure in 2020 but represents a 25% reduction compared to 2019.

In summary, under a partial recovery of the economy, SC2 and SC3 show tourism emissions reductions near 40%, while under a full recovery there would be a 25% reduction in emissions only if we adopt the strategies of SC7. The other proposed scenarios show that changes in consumption patterns have a slight impact on the tourism carbon footprint and are insufficient to reduce emissions if they are not coupled with reductions in the spending level or energy efficiency improvements. At this point, the question arises of how much the tourism sector must reduce emissions to achieve the 2030 and 2050 reduction targets and whether the proposed scenarios are aligned with these targets.

As an intermediate step towards climate neutrality in 2050 (the so-called Net-Zero), the EU has set a reduction target of at least 55% by 2030 from 1990 (EU, 2021). Table 2 shows how to achieve these reduction targets (2030 and 2050) under a scenario of the Spanish economy and tourism growth. First, the reduction goals require the GHG emissions footprints shown in Table 2 for the whole Spanish economy and for the interior tourism in Spain, which have been calculated by applying the percentage reductions proposed by the EU to the 1995

Table 2
Decarbonisation rates for tourism in Spain and Spanish economy to net-zero target.

		Spanish economy				Interior Tourism in Spain			
		Final demand (mill €)	GHG emissions footprint ($ktCO_2e$)	Annual decarbonisation rate (from 2019)	Annual decarbonisation rate on emissions intensity (from 2019)	Final demand (mill €)	GHG emissions footprint ($ktCO_2e$)	Annual decarbonisation rate (from 2019)	Annual decarbonisation rate on emissions intensity (from 2019)
2019		1,207,300.0	336,480.0			152,360.0	47,824.9		
2030 (ref 1995)	-55%	1,600,255.7	123,029.6	-8.7%	-11.3%	201,950.6	17,254.6	-8.9%	-13.6%
2050 (ref 2019)	-90%	2,671,086.2	33,648.0	-7.2%	-9.8%	337,088.3	4,782.5	-7.2%	-11.9%
	-95%		16,824.0	-9.2%	-11.8%		2,391.2	-9.2%	-13.9%
	-99%		3,364.8	-13.8%	-16.4%		478.2	-13.8%	-18.5%

Source: own elaboration based on data and methods described in Section 2.

Note to Table 2: The annual decarbonisation rate on emissions intensity has been calculated as the difference between the annual decarbonisation rate and the annual growth rate applied to the final demand (2.5947% in the case of the Spanish economy and 4.7091% in the case of the interior tourism in Spain), obtained from (INE, 2022d, INE, 2022e). 2050 targets are calculated as percentual reductions on 2019 values following the goals set in (EU, 2021). Reduction targets in 2030 are calculated by taking 1995 GHG emissions footprints according to the goal set in (EU, 2021). Data for 1995 has been retrieved from Cadarso et al. (2016).

footprints from Cadarso et al. (2016) estimations and the 2019 footprints calculated in this paper. In addition, the expected final demand in 2030 and 2050 for the whole economy and the interior tourism demand in Spain have been estimated by assuming a constant average growth of tourism GDP equal to the recent pre-Covid years (INE, 2022d). This implies that tourism final demand would grow by more than 65% by 2030. Besides, the Spanish carbon footprint of tourism has increased by 25% since 1995 (based on (Cadarso et al., 2016) estimations). Therefore, tourism needs to make additional efforts to be on track toward decarbonisation.

According to Table 2, if production continues to grow, the annual decarbonisation rate should be between 7% and 14% for the Spanish economy and tourism, and emissions intensity should be reduced by at least 10% in the Spanish economy and 12% in tourism annually. However, it must be considered that the interior tourism footprint gathers emissions from both tourism-characteristic sectors and other industries included in its supply chain. For this reason, the reduction in tourism-specific sectors could be less ambitious than shown in Table 2 if the decrease in other activities, such as energy generation or manufacturing, is higher. Nevertheless, transport -a tourism-characteristic industry- is the main component of the tourism carbon footprint, as previously shown in Fig. 3, so decarbonisation efforts to reduce the tourism footprint should be directed to these activities.

Linking it with the proposed scenarios, Table 3 shows how much emissions reduction each scenario generates over the total emissions reduction needed to reach the Net Zero target. Overall, they are insufficient to achieve decarbonisation, even in the last scenario (SC7), which is the most ambitious and contributes to a total reduction of 26% (-43% for domestic and -4% for imported) to the necessary 95% reduction in 2050. The other scenarios, under a total recovery of the 2019 tourism demand, are absolutely not aligned with the decarbonisation pathway, as they only contribute to reducing between 3 and 5% of the required total carbon footprint drop, and some of them even generate additional emissions.

This is consistent with previous findings for the global economy, like Peeters and Dubois (2010), that backcasted required annual increases in energy efficiency of 2.3% in air travel, 3% for cars, and 2% in accommodation, for a period of 30 years. This would amount to double the technological advances introduced in our SC7. In terms of changes in transportation, land transportation would need to increase more rapidly, up to 4.4% per year, to substitute short-haul air travel, according to Dubois et al. (2011). We must add that this increase must come together with the electrification of new vehicles as set in EU and Spanish strategies.

4. Discussion and conclusions

The Glasgow Declaration on Climate Action in Tourism, which set the goals of reducing emissions by 50% before 2030 and achieving Net Zero by 2050 at the latest, proposed five lines of action: measurement, decarbonisation, regeneration, collaboration, and finance. In terms of measuring, the use of carbon footprints, with a clear and established methodology, as in this paper, is an important step, moving from producer and territorial towards consumer responsibility.

Tourism's potential to contribute to SDG has been highlighted by many studies (Lasisi et al., 2020; Palacios-Florencio et al., 2021; Scheyvens and Hughes, 2019) and policy initiatives (for example, the Tourism for SDGs platform by UNWTO). In this paper, we have focused on their contribution to carbon emissions and climate change, quantifying the results from some of the recent trends in the sector, with particular attention to the transformative events from Covid-19 and beyond, and assessing their impact on tourism carbon footprint. The tourism sector was one of the hardest hits by the pandemic, and its recovery process faces significant challenges because it needs to increase resilience and, in the EU, accelerate its transition to a greener and digital model.

Table 3
Output, emissions, and emissions efficiency of tourism and national economy for Spain, 2019 and scenarios (million €, $ktCO_2e$, $ktCO_2e$ per million €).

	DOMESTIC Final demand (mill €)	GHG emissions ($ktCO_2e$)	Emissions intensity ($KtCO_2e$ / mill €)	IMPORTED Final demand (mill €)	GHG emissions ($ktCO_2e$)	Emissions intensity ($ktCO_2e$ / mill €)
Spanish economy						
2019	1,045,600	156,320	0.1495	161,700	180,160	1.1142
Tourism						
2019	144,960	26,903	0.1856	7,400	20,922	2.8273
2050	320,716	1,342	0.0042	16,372	1,046	0.0639
SC1	145,490	26,203 (-2.7%)	0.1801	6,890	20,268 (-3.3%)	2.9417
SC2	85,984	16,472 (-40.9%; *3.4%*)	0.1916	5,129	13,325 (-38.2%; *10.1%*)	2.5980
SC3	85,048	15,399 (-45.1%; *-2.6%*)	0.1811	4,092	11,953 (-45.1%; *-5.4%*)	2.9210
SC4	142,620	28,370 (5.8%)	0.1989	9,230	23,515 (13.0%)	2.5476
SC5	145,110	26,805 (-0.4%)	0.1847	7,380	21,064 (0.7%)	2.8542
SC6	145,170	24,859 (-8.0%)	0.1712	7,450	20,783 (-0.7%)	2.7896
SC7	145,170	15,830 (-43.4%)	0.1090	7,450	20,090 (-4.2%)	2.6966

Source: own elaboration based on data and methods described in Section 2.
Note to Table 3. Percentages in parenthesis correspond to the reduction (<0) or increment (>0) in GHG emissions that each scenario represents on the fall of 42,990.3 tCO_2eq that should be achieved in the tourism footprint in 2050 concerning the 2019 value (95% of reduction) distinguishing between domestic and imported. Scenarios 2 and 3 contain an additional percentage in italics corresponding to the reduction/increment calculated by extrapolating the emissions that these scenarios would generate with a total recovery of the 2019 final demand.

Our calculations show that the decrease in tourism activities due to the pandemic, extreme as it was, reduced emissions to the level where the objectives of decarbonisation for the sector are currently aimed. This is the most precise illustration of how complex, in the present context of forecasted demand increases, the net zero goal can be unless drastic changes in carbon efficiency, particularly in transport, but not restricted to it, occur. In line with the reflections of Becken (2019), higher ambition is needed, and only changes at a large scale would have the required impact.

These results are consistent with previous literature looking at impacts from tourism scenarios, both pre- and post- pandemic. For example, Peeters and Dubois (2010), Dubois et al. (2011), Jones (2013) for Wales, Ghislain and Jean Paul (2019) for Brazil, and Sun et al. (2022) for Norway. All those find it very difficult to reduce emissions below current levels, even after including substitution for air travel and increases in energy efficiency beyond those shown in recent trends. The most common conclusion remains committing to decrease emissions as much as possible with large-scale changes, including relevant reductions in global tourism demand (starting with business and frequent travel), reductions in air travel in particular (especially short-haul), and distances travelled, together with essential investment plans to speed up technological advances (such as digitalisation), retrofit buildings, and improve the infrastructure. We discuss more profound some of these in the following.

Regarding tourism demand, economic crises, rising energy prices, and other unforeseen events may delay the growth in demand and, therefore, emissions. But if our development strategies are still focused on tourism as a source of GDP and employment, we must consider various tools to mitigate its environmental impact. Although there is a consensus on taking the pandemic impact as an opportunity to increase tourism sustainability and resilience (Gössling and Schweiggart, 2022), the risk of prioritising growth and forgetting the environmental goals also arises (Mkono et al., 2022). The results obtained in the recovery scenarios provide empirical support to those who consider returning to pre-Covid tourism situation undesirable in the recent binary debate "recovery or reform" (Higgins-Desbiolles, 2021). Furthermore, special care should be taken regarding possible rebound effects once the pandemic situation is finally under control and confidence indicators recover. The longing to return to normal or make up for a lost time, together with the savings due to lower consumption during pandemic times, can boost tourism, as it has already started to become apparent in tourism figures for 2022, making it harder to achieve the emission reduction goals.

Another large-scale change is digitalisation. An increasingly digitalised tourism sector can help to meet demand in a sustainable manner, particularly for some forms of tourism, for instance, cultural and leisure. Virtual tourism was one of the avenues proposed to keep the tourism industry going, but it can also serve as a launching platform for the future (Pillai, 2021). Augmented, virtual, or mixed reality could help reduce some of the longest travel distances, particularly in already massified destinations.

Changes in tourists' consumption patterns resulting from the pandemic are not enough to make tourism more sustainable, and less carbon emitter if they imply pre-pandemic consumption levels (even worse, demand growth), as our results show. Only more radical behavioural changes significantly impact the tourism carbon footprint, especially if they are combined with improvements in industry energy and emissions' efficiency (for example, reducing the energy intensity per euro and increasing energy from renewable sources). However, changes in consumption patterns as a source of emissions reductions could have untapped potential, based on the last Eurobarometer survey. The survey results are promising to effectively achieve deeper changes because they pointed out that 82% of Europeans are willing to change their travel habits for more sustainable practices, including consuming locally sourced products, reducing waste and water consumption, travelling off-season or to less visited destinations, and choosing transport options based on their ecological impact (European Commission, 2021).

Reducing the distances tourists travel and substituting air with rail travel (and/or electric vehicles) when possible is an obvious policy that is considered. For example, the Spanish and French green strategies recommend banning flights when there is a viable rail alternative (trips of less than 2.5 h, but it could even be reduced to 1 h, following the International Energy Agency net-zero roadmap (IEA, 2021), that also proposes holding long-haul, over 6 h, flights to 2019 levels). Our results show a limited impact for the Spanish case if applied to the minimum (domestic and nearby countries), but still worthwhile. It is also essential to notice that we have not included any reduction in flights to the Spanish Canary and Balearic archipelagos, a specific part of tourism in this country that will continue to be met mostly with air travel.

Furthermore, regarding the green transition, the EU proposes harmonised rules on the uptake and supply of sustainable aviation and maritime fuels. But as they can take some time to effectively impact the emissions intensity of maritime and air transport, the EU also looks to boost a smart and sustainable network with long-distance, night, and cross-border passenger rail services (European Commission, 2022). This should allow for increasing the potential substitution of air travel by further spreading the distance range of accessible rail trips.

Offsetting emissions has also become a more common strategy, both for airlines and hotels, and it is also promoted by international organisations (UNWTO, 2021). For the focus of this paper, GHG emissions, the traditional carbon credits exchanged in carbon trading markets and aimed at compensating emissions with other activities that capture CO_2 (tree planting, for example), could also be a contributing element. Nevertheless, for a more global approach to sustainability, it would also be crucial to target those offsetting measures so that they tend to compensate for the negative impacts from other policy tools on employment or GDP, wherever those effects are mostly felt.

Other policies that could help reduce the impact of tourism should be centred on improving the infrastructure so most tourism-related activities should be accessed using public electric transport, rather than relying on private cars. Similarly, infrastructure policies should also be directed so passengers can move better from airports to city centres using public electric transport. Subsidising rental car companies to go full electric is another measure that could provide some positive results, particularly in the coastal and island destinations. In addition, current campaigns in favour of using seasonal produce should be better targeted to tourism food services, in the same way that awareness campaigns about the indoor temperature in tourism accommodations. Finally, current policy measures destined to improve building energy efficiency and insulation could also be ramped up for hotels and other types of accommodation.

General policies for most national industries can also be relevant when focusing on the tourism sector. Our results show the relevance of global value chains in generating those emissions, with 44% of total emissions embodied in imports required for the tourist sector on average. Changes in the structure of those chains (nearshoring and source shifting) could reduce the embodied emissions of the inputs needed for this sector by decreasing the distances travelled by those products and reallocating activity to lower carbon-intensity production centres. Efforts directed to transform our economies towards a more circular approach, for example, reducing waste (particularly food waste) and increasing recycling, can also improve our chances of making tourism cleaner.

Finally, it is relevant to conclude this paper by commenting on the feasibility of these potential changes for the Spanish tourism industry. When analysing the transition risks involved, four key indicators have been proposed (Scott and Gössling, 2022): (1) fossil fuels share in electricity generation, (2) average distance from the top five countries of regions where income tourism originates, (3) size of the outbound international tourism, and (4) dependency on imported food. Spain is one of the leading countries in renewable energies, and it has developed a reasonably advanced (high-speed and electrified) rail system over decades. It is, however, well behind other EU countries in its share of electric vehicles and the required charging infrastructure. Over 90% of international tourists are European, but around 14% are British (INE, 2022i), and a significant proportion of arrivals are directed to the islands. Expenditure from outbound tourism represented 34% of that of inbound tourism in 2019 (INE, 2022d), showing some capacity for substitution. Spain is also a net food exporter, but it remains vulnerable to potential increases in carbon taxes or costs for transported goods, particularly for manufactures. Therefore, we can conclude that Spain is not worse off than most countries heavily reliant on tourism, but that the challenges for global tourism to achieve a net-zero path are so immense that except for fast technological advances and decided investment plans, radical shifts in touristic level and behaviour will be required. These will also need joint mitigation programs and compensating policies for those regions and workers most affected.

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CRediT authorship contribution statement

Pilar Osorio: Methodology, Writing – original draft, Visualization. **María-Ángeles Cadarso:** Conceptualization, Methodology, Writing – original draft. **María-Ángeles Tobarra:** Conceptualization, Methodology, Data curation, Writing – original draft. **Ángela García-Alaminos:** Methodology, Data curation, Software, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.strueco.2023.03.003.

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