Science of the Total Environment 896 (2023) 166242

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Life cycle assessment to address the environmental impacts of tourism in a Spanish tourist destination: The case of Rias Baixas (Galicia) holidays

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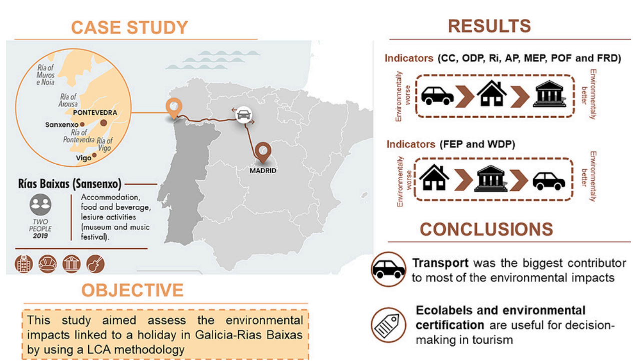
HIGHLIGHTS

- Tourism has grown steadily in recent decades, becoming a strategic sector for the economy in Spain.
- A typical trip of a couple made from Madrid to Rías Baixas (Galicia) is assessed.
- Life Cycle Assessment is key to climate change mitigation, tourism sustainability and resilience post-pandemic.
- Transport was the biggest contributor to most of the environmental impacts.
- Ecolabels and environmental certification are useful for decision-making in the desired sustainable tourism.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Deyi Hou

Keywords:
Life cycle assessment (LCA)
Tourism
Sustainability
Carbon footprint

ABSTRACT

Tourism has grown steadily in recent decades, becoming a strategic sector for the economy in many countries. However, the environmental impacts associated with tourism have also experienced an upward trend. In this sense, innovation is needed in the tourism sector, to move towards new models and strategies that integrate environmental sustainability with the social aspects of the sector. In this study, a holistic assessment of the environmental impact of tourism has been carried out using the Life Cycle Assessment (LCA) method, considering all stages of tourism activity: transportation from the place of origin to destination and back, accommodation, catering, and activities conducted. For this purpose, a case study has been carried out based on a typical trip made from Madrid to Rías Baixas (Galicia), considering a four-night stay and the performance of two activities (music festival and cultural museum) at the destination. Two alternative transportation scenarios (train or plane)

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https://doi.org/10.1016/j.scitotenv.2023.166242
Received 14 March 2023; Received in revised form 27 June 2023; Accepted 10 August 2023
Available online 16 August 2023

have been defined to analyze the influence of the type of transportation on the overall impact. Other touristic activities such as visiting gardens or thermal baths instead of visiting a cultural museum or attending a music festival have been analyzed and it has been found that the thermal baths and the museum have the greatest environmental impacts.

Transportation was the biggest contributor to most of the environmental impacts in the selected categories. On the other hand, the stay at the destination has stood out due to the impact of the consumption of food and energy used at the accommodation facility. The impact of the activities conducted at the destination is also worth highlighting. Finally, alternative scenarios for transportation have shown that the mode of transportation selected is key for lowering the overall environmental impact of the stay at the destination, highlighting the public transportation alternative, such as the train, as the most environmentally friendly option.

1. Introduction

Tourism has become one of the sectors that contribute most to the current economic system, both nationally and internationally (Gössling et al., 2022). It is globally considered a competitive and dynamic sector and a key driver for socio-economic progress. Tourism is the third largest socio-economic activity in the European Union (EU), and contributes significantly to the EU's gross national product and employment (Santos and Trillo-Santamaría, 2017). Europe is also the world's number one tourist destination (Eurostat, 2023). Spain was the preferred destination for international tourists, with 22 % of the EU total, and it received 83 million visitors in 2019 (UNWTO, 2019). In Spain, this industry contributed a total of 154,000 million euros annually, representing 12.4 % of the gross domestic product (GDP), as well as generating 12.9 % of jobs in 2019 (Solunion Spain, 2022).

In particular, Galicia, located in the northwestern part of Spain, stands out as one of the 17 regions in the country. Its economic structure is characterized by a specialization in the production of primary goods (fish, farming and food, among others) and with a relatively low weight in foreign tourism. Nevertheless, according to the latest Galician tourism studies, in 2019 tourism accounted for about 10 % of the region's GDP, generating 120,000 direct jobs and therefore, it is a sector of great relevance. With its 724 beaches, Galicia is very important for beach tourism (Galicia Tourism, 2016). Two coastal areas, Rías Altas and Rías Baixas, receive the majority of tourist arrivals (53.7 %) and concentrate the majority of overnight stays (63.2 %) in 2019. Tourism in coastal areas is concentrated in summer (64 %), with the majority of overnight stays in June (9.6 %), July (18.7 %), August (25 %), and September (10.7 %) (Toubes et al., 2017). Therefore, the community of Rias Baixas has become one of the main tourist hotspots, since more and more travelers are requesting this destination thanks, mainly, to its coasts in contact with nature as well as its gastronomy (shellfish and fish), cultural visits, and nautical sports, among others (Galicia Tourism, 2016). Of all visitors who do not reside in Galicia, the main origin of national tourists is coming from the Community of Madrid, accounting for 9.1 % of global visitors (Digital Economy, 2021).

While contributing positively to the economic development of the region, tourism brings with it a significant negative impact on the environment and ecosystems. Tourism activity accounted for 8 % of global greenhouse gas (GHG) emissions between 2009 and 2013 (Lenzen et al., 2018), being the fifth most polluting activity in the world. Due to the high carbon intensity of the activities related to tourism and the continuous increase in demand, it is expected that this sector will continue to increasingly contribute to GHG emissions in the world, mainly due to the increase in air traffic (WTO, WMO and UNEP, 2008).

These advances call for the development of sustainable tourism policies, as well as for the promotion of environmental awareness in society, to develop new strategies for tourism based on concepts of sustainable development. Hand in hand with technological development and innovation, the concept of sustainable tourism arises to reduce damage and preserve the environment in all phases of tourism business activity. The World Tourism Organization (UNWTO) conceptually defined sustainable tourism as 'tourism that takes full account of current and future economic, social and environmental impacts to meet the needs of visitors, industry, the environment, and host communities' (UNWTO, 2013).

The literature review of the results obtained by different scientific papers shows that there are many studies based on the carbon footprint indicator of tourism at the national and regional level or of specific holiday packages. The review conducted by Herrero et al. (2022) found that the most widely used environmental indicator in tourism studies was the carbon footprint and the Climante Change was the LCA impact category used in all the studies. In this sense, it is important to note that a comparison of the obtained results with those from previous studies should be considered with caution because other impact assessment methods, considering different impact categories were used. Only one study has examined a vacation package (transportation, accommodation, and tourist activities) in Italy from a life cycle assessment (LCA) perspective, evaluating more environmental indicators than just the carbon footprint, similar to this work (Candia and Pirlone, 2021). This highlights the need for conducting such studies that provide a more in-depth environmental analysis. In recent years, the adoption of sustainability measurement and certification systems has been studied in numerous academic works. Environmental management systems and eco-labels are tools that allow companies to consciously offer the best practices for products and services, as well as to ensure more sustainable management and consumption in the tourism industry, distinguishing them from those companies that do not comply with the standards. These certifications are used for promotion to the educated public (European Commission, 2017).

The objective of the present study is to quantify the environmental impacts caused by a holiday trip to Rias Baixas, including 4 rias which represents one of the most visited destinations in Galicia (north-west Spain). The baseline case considered a four nights' accommodation during a two-day music festival in the region, taking into account the transportation, accommodation and restaurants in the hotel, and different leisure activities, such as visiting a museum or attending a music festival.

Although the environmental performance of the certain subsectors of tourism and touristic regions have been extensively studied, most of these works use only the carbon footprint indicator instead of a complete set of environmental metrics. One of the novelties of this study is the application of the LCA method that provides a holistic LCA approach with 9 environmental indicators. Moreover, to the best of our knowledge, the assessment of Galician holidays from a holistic LCA approach comparing different scenarios (means of transport and tourist activities) is still not covered. This work will also be a breakthrough for the target stakeholders of this assessment of the environmental impacts of tourism includes the government and local authorities and communities, tourism companies, as well as tourists and consumers themselves. Considering the concerns and interests of these groups is essential to promote sustainable tourism and mitigate negative effects on the environment.

2. Materials and methods

The LCA method has been used following the recommendations provided by the ISO 14040 and 14044 standards (ISO, 2006a, 2006b). This approach enables the analysis of the environmental burdens associated with each stage of the tourism life cycle (transportation, accommodation, leisure activities, and food and beverage). According to these standards, the methodological framework involves the following sections:

2.1. Goal and scope definition

This study aimed to bring forward a thorough quantification of the potential environmental impacts linked to a holiday in Galicia-RiasBaixas. As previously remarked, Rias Baixas represents one of the most visited destinations in Galicia and comprises 4 rias (an area where a freshwater river or estuary): Vigo, Pontevedra, Arousa and Muros-Noia, where regions such as Sanxenxo, Vigo and Pontevedra stand out (Fig. 2). The motivation to discover the environment and regional customs is the main factor for traveling to Galicia, an option chosen by 39.7 % of its visitors, according to data from Galician tourism studies (Galicia Tourism, 2016). This interest is focused on nature, landscape, culture (museums, festivals), customs, and the Way of St. James. The baseline case study is based on an assumption of a four-night stay during a very prominent two-day music festival that takes place in the region. The study includes transportation –from origin to destination and back by road– accommodation and restaurants in the hotel, and activities consisting of a visit to a cultural museum and attendance at the music festival. Madrid has been selected as the place of origin for tourists for our analysis, establishing car transportation as a reference. This means of transportation was chosen since according to the AEITG (Area of tourism research studies in Galicia), in 2019 the car was the most popular means of transportation (60 % of tourists). The case study is proposed for the year 2019, since due to Covid-19 it is considered that the years 2020 and 2021 are not representative of the sector.

In addition, two alternative scenarios are analyzed for the stage of transportation, evaluating different means of transportation (train and plane) as well as the intermediary transportation from the airport/train station to the hotel of the destination and back again, to find out which is the most sustainable means of transportation. Finally, an alternative case study is proposed by choosing the most sustainable means of transportation (chosen in the sensitivity analysis previously explained) and two other alternative activities to the museum and the festival are analyzed to assess whether they show less environmental impact than the baseline case. These two other leisure activities consist of visits to gardens and hot springs.

The function of the system is a four-night stay in Sanxenxo (Rías Baixas) considering transportation, hotel, food and beverage, and activities (Fig. 1). To measure this function, it is necessary to define a suitable FU, to which all the inputs and outputs will be referred (ISO, 2006a). In this case study, the FU selected is defined as two people traveling to Sanxenxo from Madrid, staying in a hotel for four nights, and participating in two activities.

2.2. System boundaries

The system boundaries of this study comprise the different elements of a trip starting from origin-return transportation and including accommodation and activities at the destination (Fig. 2). Therefore, a 'door-to-door' approach is followed based on the method described by De Camillis et al. (2010). Thus, we divided the system under study into 3 sub-systems (SS) based on the different elements that constitute the holiday package. It is worth mentioning that the system boundaries of the present study do not include the construction of infrastructure and its maintenance due to the low expected influence on the total system impact of the study (Žigart et al., 2018).

2.2.1. Subsystem 1: transportation (SS1)

For the journey from origin to destination and back, the environmental burdens of the different means of transportation are considered, excluding the impacts associated with the displacement at the destination.

2.2.2. Subsystem 2: accommodation (SS2)/subsystem 3: activities (SS3)

For accommodation (SS2) and activities (SS3), the operational use of the establishments is included, i.e. the construction and end-of-life phases are excluded. To calculate the impact linked to the operation

Fig. 1. Simplified graphical representation of the location of the baseline case study by considering the transportation and the other subsectors studied in Rias Baixas (Spain).

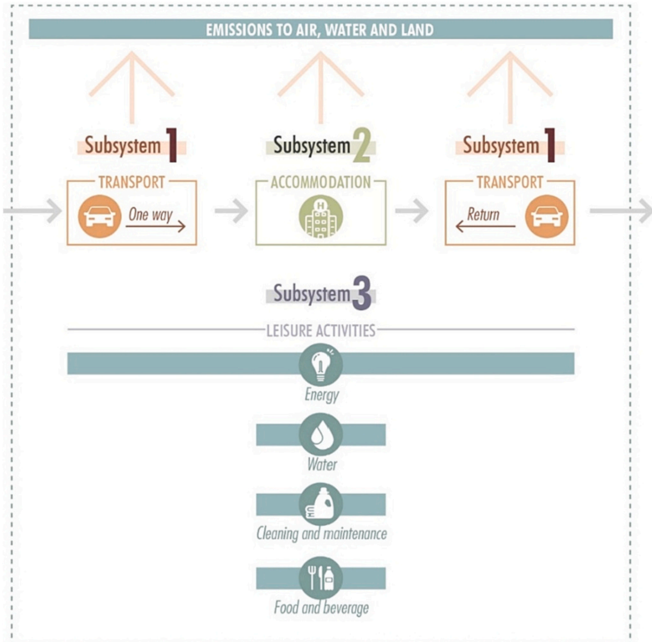


Fig. 2. System boundaries considered in the study: from arrival to departure from the destination.

of each establishment, the inputs to the system include consumption of electricity, fossil fuels and renewable sources, if any, water, as well as materials for the maintenance and cleaning of the establishment for both accommodation and tourist activities. In addition, in the case of accommodation (3 stars hotel) with restaurant service, it is considered the consumption of food and beverage. Three typical meals (breakfast, lunch, and dinner) are assumed to be provided at the hotel per FU. Breakfast was a buffet and was the same for all 4 days while lunch and dinner during the stay. Breakfast included dairy products (milk, yogurt), oil, deli meat, cereals, and confectionery (biscuits, buns, etc.). Lunch included vegetables, legumes, eggs, red and white meat, fruit and drinks. Finally, for dinner, there was fish, seafood, fruit and drinks.

2.3. Data acquisition

Data collection for the study comes from both direct (primary data) and indirect sources (secondary data). Primary information for accommodation, travel and activities, i.e., foreground data, has been obtained through questionnaires completed by managers of the establishments. These include information from the number of customers or overnight stays to more detailed data on operational aspects, such as consumption of electricity, fuels, water, products for cleaning, food, and beverages.

Secondary data, i.e., background processes related to the production of energy or materials (cleaning products, food, beverages), were obtained from life cycle databases such as Ecoinvent (Wernet et al., 2016), which collects process inventory data from different sectors; Agribalyse (Asselin-Balençon et al., 2020), specialized in the agricultural and food sector, and World Food LCA (Bengoa et al., 2020), also specialized in the agri-food sector.

For cases in which the databases do not have all the available data, it has been necessary to model the inventory through information collected via literature reviews of scientific publications or reports by official institutions. This has been the case for cleaners and detergents, where their composition was consulted in the report prepared by the European Commission on the EU Ecolabel Criteria for all-purpose cleaners and sanitary cleaners (Medina et al., 2015); and electricity supply, where the residual energy mix for Spain for the year 2019 has been modeled, i.e. the one resulting from the elimination of energy production from renewable technologies with guaranteed origin (AIB, 2020). As for fuel consumption, both stationary and mobile, direct emissions are estimated using the emissions inventory guide EMEP/CORINAIR (European Environment Agency, 2019).

2.4. Assumptions

In 2019, the Studies and Research Area of Tourism Galicia (SRATG) reported that over one million tourists visited Rías Baixas, with 78.4 % of them being local tourists, namely Spanish residents and Galicians themselves, particularly during the summer. In terms of origin, Madrid is the region of origin of most local travelers to Galicia, followed by Castile and Leon. The international tourist market, Portuguese tourists are the most popular, followed by Germans and French (AEITG, 2020). Table 1 shows the origin of tourists who arrived in Galicia in 2019.

Given its predominance, Madrid has been selected as the place of origin for tourists for our analysis, establishing car transportation as a reference. However, two alternative scenarios are analyzed: plane and train, which represented 20.5 % and 4.3 % of the selected transportation by tourists in Galicia, respectively (AEITG, 2020).

For transportation by car, a distance of 642 km by road has been assumed, which corresponds to the distance established between the geographical center of both territories. It is also considered that the trip is undertaken in a medium-sized diesel passenger car. For air transportation, a distance between Madrid Airport and Vigo Airport (the closest point to the final destination) of 463 km has been considered. Destination trips to and from the airport are assumed to be made by bus (60 km) and are considered in the further analysis of means of transportation. Likewise, for the training scenario, a distance of 468 km is accounted between the train stations of Madrid and Pontevedra, and then 36 km by bus from the station to the hotel (Distance calculator, 2022).

For the accommodation, it is assumed that the establishment and leisure activities will be fully occupied by tourists. Therefore, the inventory is obtained based on potential customers during 2019 (the reference year of the case study). Finally, the generation of municipal solid waste has been calculated indirectly using the methodology proposed by Fernández and Lazovski (2020), which is specific for modeling tourist flows and seasonal population, based on data available for the Municipality of Sanxenxo for the year 2019, being this the most representative destination for tourists in Rías Baixas.

2.5. Life cycle inventory (LCI)

The LCI has been divided into several sub-systems, following the description in Section 2.2. Firstly, for the transportation subsystem (SS1), the distances from Madrid to Rias Baixas by the different means of transportation are as shown in chapter 2.4. For accommodation, single hotel for the 4 days and for two people was chosen, as it was the only

Table 1
Origin of tourists who visited Galicia in 2019 in percentage terms (AEITG, 2020).

Origin	Visitor percentage (%)
Galicia	41.1
Rest of the Spain	37.3
Madrid	9.1
Castile and Leon	5.4
Catalonia	3.9
Asturias	3.5
Andalusia	3.4
Rest of the country	12
International tourism	21.7
Portugal	6.7
Germany	1.9
France	1.6
Rest of the world	11.4

establishment with relevant and representative data. For activities, the museum is a cultural and art museum where natural gas and refrigerants for air conditioning are analyzed and the festival is a music festival in which different concerts are held, sardines are grilled and drinks and dairy products (milk, yogurt, etc.) are provided. For this reason, the festival presents food data in the inventory as well as the diesel consumption as stationary fuel. Band travel data are excluded as these data are not known. Tables 2 and 3 detail the LCI foreground data for SS2 of accommodation and SS3 of activities, per FU.

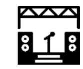
2.6. Life cycle impact assessment (LCIA)

In this study, the EF 3.0 method (European Commission, 2019) was selected to assess the environmental impacts. This distinguishes three levels of robustness for impact categories; level I is recommended and satisfactory, level II is recommended, but needs some improvements; and level III is recommended, but should be applied with caution. In this way, all level I impact categories are included, and for the other two levels, their selection is reinforced with the recommendations for Life Cycle Impact Assessment in a European Context developed by the European Commission - Joint Research Centre (ILCD Handbook, 2011). Thus, the impact categories considered for the study were: Climate change (CC); Ozone layer depletion (ODP); Photochemical ozone formation— human health (POF); Inorganic particles/substances with respiratory effects (Ri); Acidification (AP); Eutrophication—freshwater (FEP); Eutrophication— marine (MEP); Water scarcity (WDP); Resource use —energy carriers (FRD). The software SimaPro v9.3 (PRé Sustainability, 2021) was the program used to implement the inventories computationally.

Table 2
Life cycle inventory for subsystem 2: accommodation per FU.

Categories	Unit	SS2 accommodation
		
Energy sources		
Electricity	kWh	$4.48{\cdot}10^{1}$
Stationary fuels (natural gas)	kWh	$7.94{\cdot}10^{1}$
Refrigerants for air conditioning	kg	$6.00{\cdot}10^{-5}$
Water	m^3	1.30
Maintenance and interior cleaning		
Disinfectants	kg	$2.61{\cdot}10^{-2}$
Cleaners	l	$9.37{\cdot}10^{-1}$
Descaling agents	l	$1.20{\cdot}10^{-3}$
Bleach	l	$9.90{\cdot}10^{-3}$
Detergents	l	3.07
Maintenance and exterior cleaning		
Sodium chloride	kg	$9.02{\cdot}10^{-1}$
Algicides	kg	$7.50{\cdot}10^{-4}$
Food and drink		
Dairy products	kg	$7.01{\cdot}10^{-1}$
Oils and greases	kg	$3.33{\cdot}10^{-1}$
Fruits	kg	2.04
Vegetables	kg	1.44
Cereals	kg	$1.28{\cdot}10^{-1}$
Legumes	kg	$7.45{\cdot}10^{-2}$
Confectionery	kg	$3.04{\cdot}10^{-1}$
Deli meat	kg	$1.94{\cdot}10^{-1}$
Eggs	kg	$8.29{\cdot}10^{-4}$
Red meat	kg	$5.18{\cdot}10^{-1}$
White meat	kg	$7.95{\cdot}10^{-1}$
Bluefish	kg	$7.22{\cdot}10^{-2}$
Whitefish	kg	$4.10{\cdot}10^{-1}$
Shellfish	kg	$2.17{\cdot}10^{-1}$
Drinks	l	7.55
Others		
Office paper	kg	$3.75{\cdot}10^{-3}$
Paper rolls	kg	$3.79{\cdot}10^{-1}$
Waste	kg	8.04

Table 3
Life cycle inventory for subsystem 3: leisure activities per FU.

Inputs/outputs of the SS3	Unit	SS3 activities	
		Museum	Festival
			
Energy sources			
Electricity	kWh	$5.58{\cdot}10^{1}$	–
Mobile fuel (diesel)	kWh	–	1.89
Stationary fuel-museum (natural gas)	kWh	$5.29{\cdot}10^{1}$	–
Stationary fuel-festival (diesel)	l	–	$9.75{\cdot}10^{-2}$
Refrigerants for air conditioning	kg	$3.07{\cdot}10^{-3}$	–
Water	m^3	$5.70{\cdot}10^{-2}$	–
Maintenance and indoor cleaning			
Disinfectants	kg	$5.08{\cdot}10^{-3}$	–
Cleaners	l	$1.10{\cdot}10^{-3}$	–
Descaling agents	l	$5.94{\cdot}10^{-4}$	–
Bleach	l	$8.91{\cdot}10^{-3}$	–
Maintenance and outdoor cleaning			
Fertilizers	kg	$3.71{\cdot}10^{-4}$	–
Pesticides	kg	$1.98{\cdot}10^{-4}$	–
Food and beverage			
Dairy products	l	–	$1.91{\cdot}10^{-2}$
Bluefish	kg	–	$2.54{\cdot}10^{-1}$
Drinks	l	–	4.61
Others			
Office paper	kg	$4.95{\cdot}10^{-3}$	–
Paper rolls	kg	$3.84{\cdot}10^{-3}$	–
Waste	kg	$8.03{\cdot}10^{-1}$	$4.02{\cdot}10^{-3}$

3. Results

This section describes the overall characterization results obtained for the 3 subsystems of study (transportation, accommodation, and tourism activities) as well as the analysis of each of them for the 9 proposed environmental impact categories. Table 4 presents the LCIA results for the system under study per FU and disaggregated by subsystem.

Fig. 3 shows the relative contribution to the impacts of each subsystem considered in the study. It can be seen that SS1 Transportation is the main contributor to impacts in 7 out of 9 categories, more specifically CC (71 %), Ri (75 %), ODP (75 %), POF (72 %), FRD (66 %), AP (57 %) and MEP (51 %). Next, SS2 Accommodation stands out for its contribution to impact for the categories FEP (59 %), WDP (84 %), and MEP (38 %). Finally, the impact contribution of SS3 Activities is important for FEP (39 %), but it is equal to or lower than 16 % for the remaining impact categories.

3.1. Results as regards the transportation subsystem (SS1)

The impact on the transportation subsystem is mainly due to the consumption of diesel and its associated emissions from the origin to the destination and back again. SS1 Transportation will be further discussed in Section 4, where different alternative scenarios are analyzed according to the means of transportation used.

Table 4
Results of life cycle impact characterization for a holiday package in Rías Baixas per functional unit for the selected impact categories.

Impact categories	Units	SS1 transportation	SS2 accommodation	SS3 activities		Total
				Museum	Festival	
CC—climate change	kg CO_2 eq	$2.88{\cdot}10^{2}$	$7.32{\cdot}10^{1}$	$4.02{\cdot}10^{1}$	2.66	$4.04{\cdot}10^{2}$
ODP—ozone layer depletion	kg CFC-11	$6.37{\cdot}10^{-5}$	$1.26{\cdot}10^{-5}$	$8.18{\cdot}10^{-6}$	$4.51{\cdot}10^{-7}$	$8.50{\cdot}10^{-5}$
Ri—inorganic particles/substances with respiratory effects	Disease inc.	$1.07{\cdot}10^{-5}$	$2.93{\cdot}10^{-6}$	$4.50{\cdot}10^{-7}$	$2.13{\cdot}10^{-7}$	$1.43{\cdot}10^{-5}$
AP—acidification	mol H^{+}	$8.54{\cdot}10^{-1}$	$4.64{\cdot}10^{-1}$	$1.58{\cdot}10^{-1}$	$2.50{\cdot}10^{-2}$	1.50
FEP—eutrophication—freshwater	kg P eq.	$4.04{\cdot}10^{-4}$	$9.65{\cdot}10^{-3}$	$4.58{\cdot}10^{-3}$	$1.74{\cdot}10^{-3}$	$1.64{\cdot}10^{-2}$
MEP—eutrophication—marine	kg N eq.	$2.24{\cdot}10^{-1}$	$1.69{\cdot}10^{-1}$	$3.31{\cdot}10^{-2}$	$1.40{\cdot}10^{-2}$	$4.41{\cdot}10^{-1}$
POF—photochemical ozone formation—human health	kg NMVOC eq.	$7.84{\cdot}10^{-1}$	$1.95{\cdot}10^{-1}$	$9.90{\cdot}10^{-2}$	$1.67{\cdot}10^{-2}$	1.09
WDP—water scarcity	m^3 world eq.	$1.79{\cdot}10^{-1}$	$9.42{\cdot}10^{1}$	$1.06{\cdot}10^{1}$	6.84	$1.12{\cdot}10^{2}$
FRD—resource use—energy carriers	MJ	$3.93{\cdot}10^{4}$	$1.09{\cdot}10^{3}$	$8.63{\cdot}10^{2}$	$4.39{\cdot}10^{1}$	$5.93{\cdot}10^{3}$

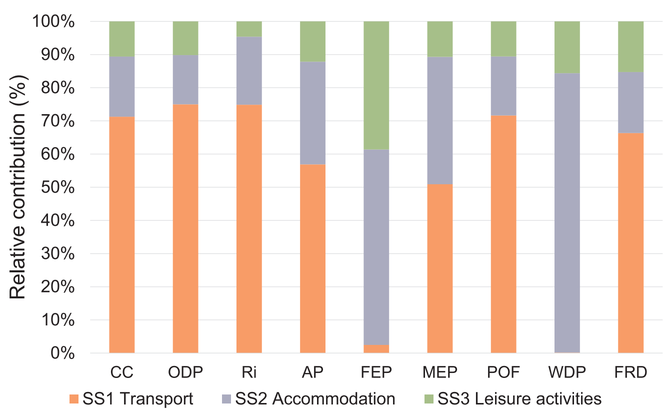


Fig. 3. Relative contribution to the life cycle impact of the sub-systems considered for a holiday package in Rías Baixas.

3.2. Results as regards the accommodation subsystem (SS2)

Fig. 4 shows the contribution of the different flows considered to impacts of SS2 Accommodation. Food and beverage consumption is the main contributor to the impact, with a relative contribution ranging from 32 % to 77 % for the CC and MEP impact categories, respectively. Food and beverage is the main hotspot for ODP (51 %), Ri (75 %), AP (63 %), and MEP (77 %). The main responsible for these impacts is the consumption of meat and deli meat. Although not all meat products contribute equally, beef represents the greatest impact, which in CC is mainly related to the metabolism of livestock and the emission of methane by enteric fermentation in ruminants (Sakamoto et al., 2020). In addition, the cultivation of ingredients to produce animal feed also involves high energy and water consumption (Mannan et al., 2018). The high impact on the ODP indicator is mainly due to the use of refrigerants in the chilling/freezing processes of food and meat (Schmidt et al., 2014). According to the Ri category, fertilizers may contain contaminants/impurities that can impact human health and the environment (Sharma and Singhvi, 2017). In addition to GHG emissions, livestock production has a particularly high ammonia (NH_3) emission factor among livestock species, and the NH_3 emission contributes to AP (Oonincx et al., 2010). Within food and beverage consumption, beef has the highest contribution to MEP due to animal products (like beef) which use chemicals that used in fertilizers, pesticides (Belo et al., 2015), and beef packaging in their production can get into waterways and harm aquatic life, contributing significantly to this indicator (Rivera Huerta et al., 2016). Finally, the production of other food and beverage products of agricultural origin, such as fruit and vegetables, has a relevant impact on AP, MEP, and FEP due to the use of fertilizers and the consumption of water for irrigation.

Furthermore, energy requirements are the second largest contributor to impact in terms of their relative contribution, being the main hotspot for the impact categories CC (59 %), FEP (39 %), POF (50 %), and FRD (76 %) and also relevant in ODP (45 %). These impacts are mainly due to the consumption of electricity from the grid and the consumption of natural gas and its derived emissions.

Indoor cleaning and maintenance products make a significant contribution to the impact category FEP (21 %), primarily due to the emission of phosphorous compounds during the production of the consumed cleaning products. Finally, outdoor maintenance and cleaning products, water consumption, waste treatment and management present a negligible contribution (<5 %) for all impact categories, except for the case of water consumption, which presents a relative contribution of 59 % for the WDP impact category.

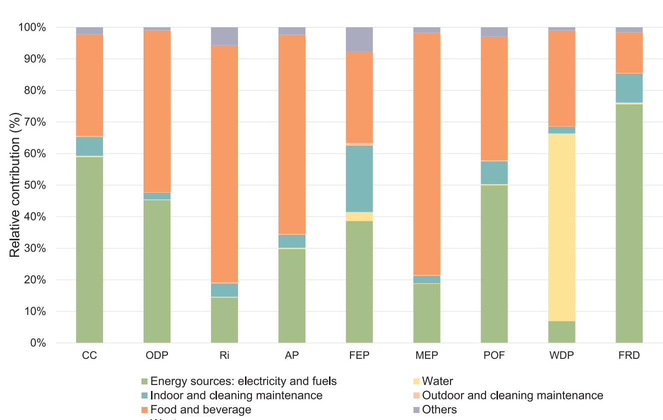


Fig. 4. Relative contribution to life cycle impact of the main flows considered for SS2 of accommodation.

3.3. Results of the activities subsystem (SS3)

Figs. 5 and 6 provide a breakdown of the impact of the museum visit and festival attendance activities, respectively, performed in SS3 Activities. For the case of museum visitation, Fig. 5 shows that energy sources represent the main contribution in all impact categories analyzed, accounting for around 100 % of these impacts, except for the WDP category, where water consumption presents a relative contribution of 23 %. The other flows considered have a negligible relative contribution of <1 %.

In terms of festival attendance, Fig. 6 shows that food and beverage consumption is the main impact driver for all impact categories, especially for the Ri (96 %), FEP (99 %), and WDP (99 %) categories. It is worth mentioning that energy and fuel consumption has a significant impact contribution for the OPD (29 %), CC (21 %), and POF (22 %)

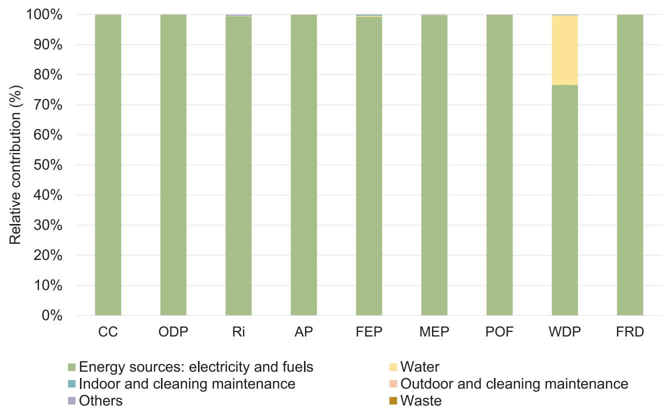


Fig. 5. Relative contribution of the main flows considered for the museum visit activity in SS3.

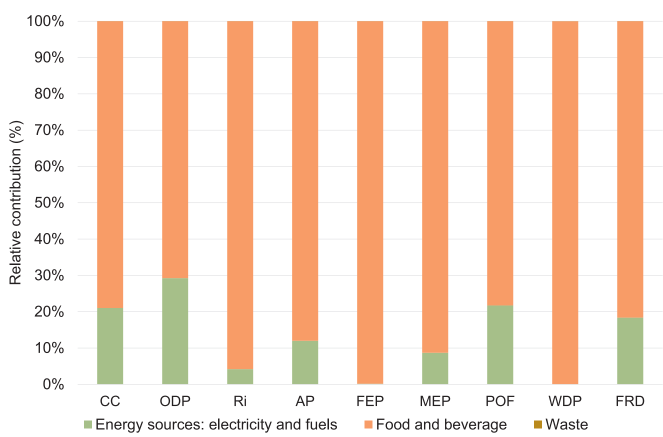


Fig. 6. Relative contribution of the main flows considered for the festival attendance activity in SS3.

impact categories. Ultimately, the environmental impact of waste treatment and management is negligible relative contribution of <0.9 %.

4. Discussion

In the subsystem of accommodation, food and beverages are the major contributors to the negative impact. Therefore, in this case, improvements should focus on more sustainable alternatives for food and beverages. In addition, through awareness campaigns to inform customers about food waste in free buffets and the selection of more sustainable and healthy products. Moreover, establishments could also opt for measures to improve the energy efficiency of facilities (home automation, regulation of cooling and heating systems, installation of efficient lighting systems, etc.), management of spaces considering natural light and contracting electricity with renewable origin guarantee, among others. In the same way, to reduce water consumption, saving equipment could be applied to faucets and sinks and rainwater harvesting measures for reuse. Finally, some practices to improve the traveler experience could focus on the application of environmental certification programs such as eco-labels. In this way, tourists will be involved in environmental improvement practices, thus increasing their positive perception of sustainable activities in tourist destinations.

The results indicate that transportation is by far the main critical system for all impact categories in the overall impact assessment. Therefore, it is necessary to analyze alternative scenarios to car travel, including a comparison between the baseline scenario (car travel), airplane, and train.

Last but not least, applying Life Cycle Assessment methodology to the tourism sector allows for a comprehensive assessment of its environmental impact and provides a solid basis for identifying areas for improvement and taking concrete measures to reduce this impact. This can lead to a more sustainable tourism sector and improved environmental performance in general.

4.1. Comparative analysis of different means of transportation

To analyze the means of transportation and to find the most sustainable one, airplane and train travel have been considered. In addition, transportation from the train station to the hotel (36.5 km) and from Vigo airport to the hotel (70 km) (both round-trip) was also studied (Fig. 7). For this intermediate transportation, the bus was used as it is the most common means of transportation in this type of case (AEITG, 2020).

The results of this analysis (Fig. 8) show that air travel by plane has the worst environmental performance in all the impact categories except for the FEP indicator. In this category, travel by train has the largest environmental impact as compared to the alternative scenario. Secondly, the displacement by car presents less impact than an airplane but is greater than a train for the FRD, Ri, ODP, CC, POF, and MEP categories. Finally, it can be observed that train transportation, in general, has the lowest environmental impact of the other two means of transportation studied, except for the FEP and WDP categories (Fig. 8).

The CC results obtained for the comparison between different means of transportation are in line with the conclusions of Sharp et al. (2016), Gössling (2002) and Brand and Boardman (2008), which identified train travel as the most favorable option compared with other modes of transportation. They also identify air travel and car travel as the most unfavorable options. Therefore, it is important to propose different ways to mitigate these impacts. One option would be to promote local tourism as opposed to more distant destinations, a key aspect to reduce travel and make public transportation more attractive.

Similarly, the development of more efficient technologies also plays an important role in reducing emissions, they are gaining popularity such as the use of electric cars or biofuels. In this sense, a study of the impact of a family's trip in Brazil (Pereira et al., 2017) highlights the role of using biofuels in reducing GHG emissions, reporting a reduction of up to 76 % for road transportation using bioethanol. In addition, they indicated that flights powered by bio-based fuels have a considerably lower impact compared to cars using conventional fuels. Along these lines, Filimonau and Högström (2017) explored the public opinion on the use of biofuels in aviation, concluding that the public perception of these technologies — including their safety — is limited and needs to be reinforced. Therefore, the agents involved must accomplish actions to raise awareness among the population.

4.2. Comparative analysis of the other subsystems with other LCA studies

Considering the stay at the destination, i.e. excluding transportation, as seen in previous sections, the accommodation has the highest impact. Thus, Table 5 presents the results of other LCA studies per FU (two tourists per night) for the CC impact category, which allows contextualization of the results obtained for accommodation in this case study. It should be noted that studies have been selected for hotels with similar characteristics to the baseline case study explained in the Section 2.2.2. The selected studies do not include food and beverage consumption.

Comparing the CC results, similar values are found to those obtained by Filimonau et al. (2011) and Michailidou et al. (2016), for two hotels located in the United Kingdom and Greece, respectively. In their studies, they only considered the energy consumption for heating, lighting, laundry, kitchen, etc. Likewise, the results of Díaz Pérez et al. (2019) are presented for a peninsular hotel in which they addressed only electricity and fuel requirements. However, Puig et al. (2017) found a higher

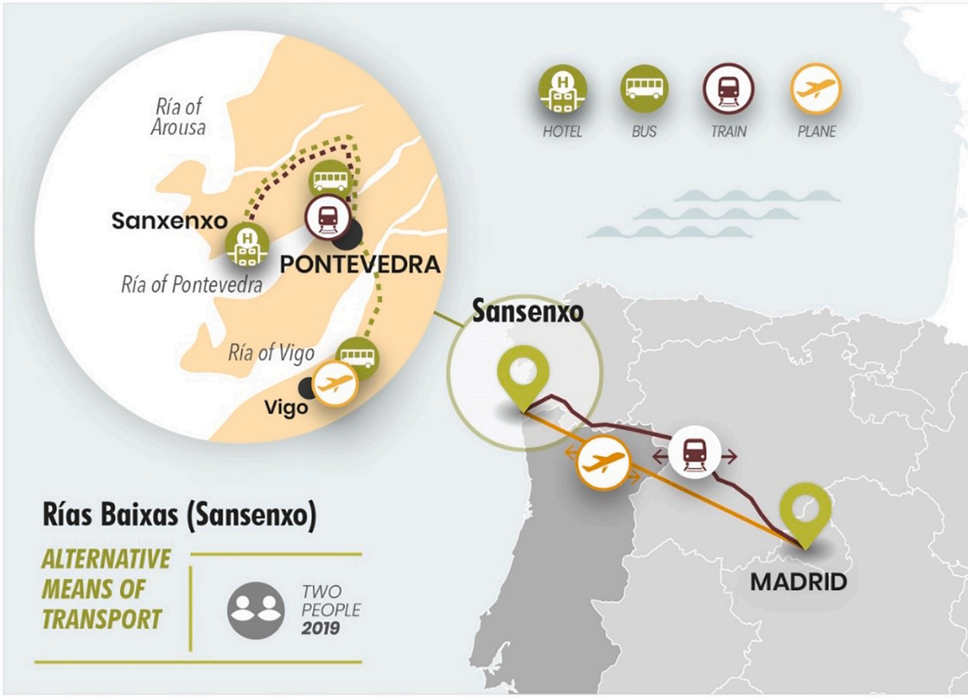


Fig. 7. Graphic map of the alternative transportation considered (plane and train) as well as the intermediate transportation to the hotel by bus in Sansenxo (Rias Baixas).

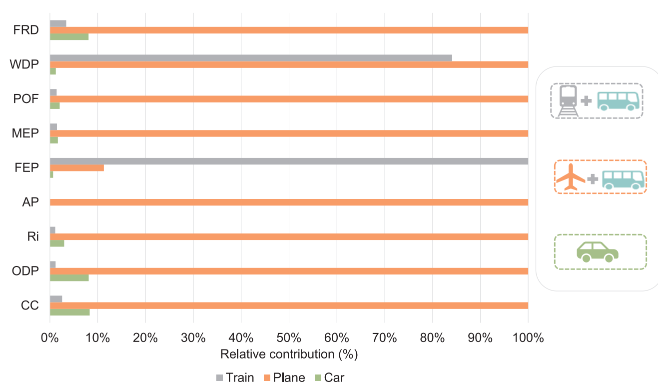


Fig. 8. Comparative analysis of selected transportation scenarios.

Table 5
Comparison of the carbon footprint with LCA studies of tourist accommodations.

References	kg CO_2 eq/FU
Puig et al. (2017) (Majorca, Spain)	24.00
Michailidou et al. (2016) (Chalkidiki, Greece)	12.00
Filmonau et al. (2011) (Dorset, United Kingdom)	15.00
Díaz Pérez et al. (2019) (Aragon, Spain)	11.66
Rico et al. (2019) (Barcelona, Spain)	7.80
Baseline case study	21.66
Baseline case study without food	11.58

impact per tourist per night, with energy being responsible for 48 % of the impact. The rest is due to cleaning products, waste and water consumption. It is worth mentioning that this accommodation had a garden and a swimming pool among its facilities. Likewise, Rico et al. (2019) highlighted the importance of the services included in the accommodations in the city of Barcelona with results varying from 3.90 kg CO_2 eq/FU to 21.90 CO_2 eq/FU depending on the category of the hotel.

4.3. Alternative scenario with two different leisure activities and travel by train

In this section, an alternative case to the baseline case study has been analyzed to assess more sustainable options for this type of holidays. Regarding tourist activities, gardens (one day) and thermal baths (two days) have been chosen since, according to the Galician tourist office, in 2019 they were among the most common activities performed by tourists due to the nature and climate of this place that allows this type of activities (Pontevedra tourism, 2023). Finally, the transportation used was the train and the bus as it was found to be the means of transportation with the least environmental impact. The duration of the stay was the same, i.e. 4 days for two people traveling from Madrid to Sansenxo (Rias Baixas, Galicia) (Fig. 9).

Fig. 10 presents the LCIA results for the transportation under study per FU. As can be seen, in all impact categories the car is environmentally worse than the other means of transport (train and bus) except in the case of FEP and WDP, where the train presents worse results from an environmental perspective. For FEP, it is due to the consumption of electricity by the train as well as for the manufacture of the train as it uses different minerals such as hard coal and lignite which contribute significantly to the FEP. As might be expected, it would be better to obtain electricity from cleaner, renewable energy sources rather than from fossil fuels that cause these transportations to generate large environmental impacts. A similar situation applies to the WDP, since the train is electric and the car uses diesel, the electricity generation and use requires a large amount of water because electricity comes from hydroelectric dams which cause this huge impact. For that reason, the car in this impact category is more appropriate than the train. The use of the train is more recommendable than the car on this route in terms of environmental impacts, although it is true that it takes more time than the car and it is an expensive means of transportation. It is therefore necessary to strike a balance between these factors to travel as sustainably as possible.

In the case of SS2 Accommodation there are no changes as the same hotel has been chosen. However, for the SS3 activities subsector there

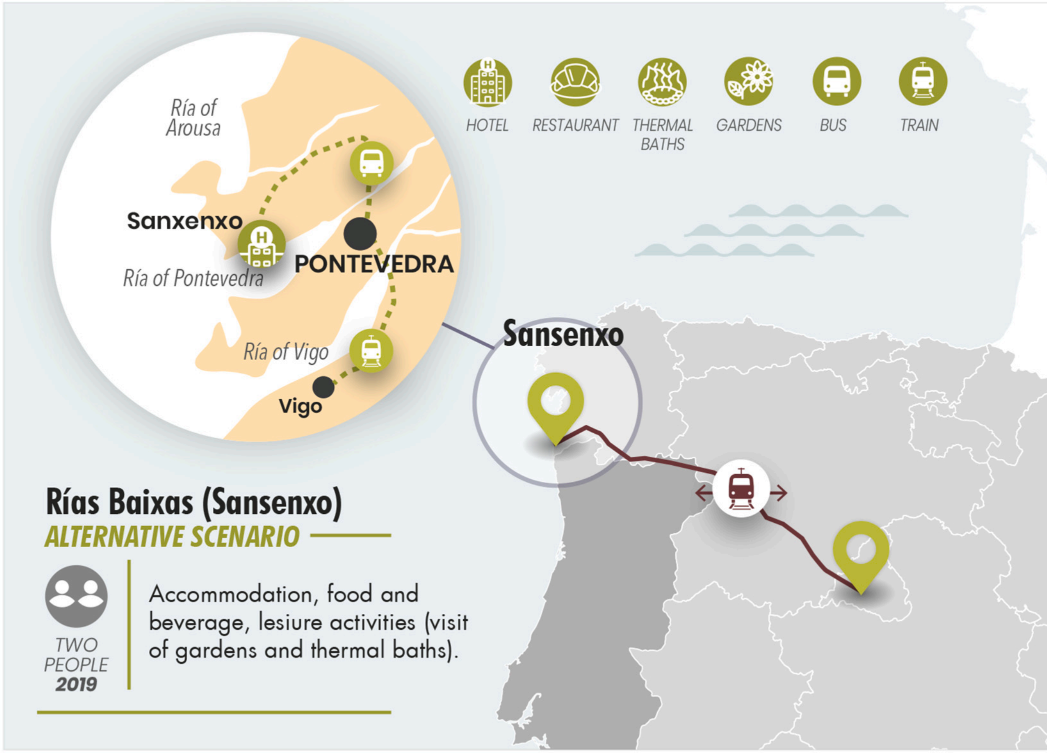


Fig. 9. Simplified graphical representation of the new scenario under study by considering the hotel, transportation (bus and train) and two different leisure activities in Sansexo-Rias Baixas (Galicia, Spain).

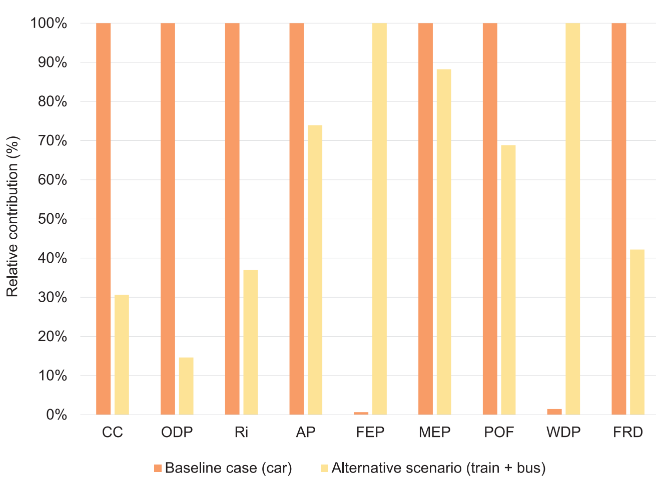


Fig. 10. Relative contribution to the life cycle impact of the SS1 transportation subsector by comparing the baseline case with the use of train and bus.

are very significant differences that are worth analyzing. Fig. 11 shows the relative contribution to the impact of each of the subsystems considered in the study. It can be seen that new activities (garden visits and thermal baths) have a larger impact than the baseline activities in all the impact categories. It is worth noting that in the alternative scenario thermal baths contribute to all impact categories by >99 %, while gardens contribute <0.5 %. The large contribution to the impact of thermal baths is due to the high consumption of electricity used in the facilities, which means that this activity needs to be improved to reduce its environmental impacts. These improvements could include: installing thermostatic devices whenever possible, as they increase comfort and adjust energy consumption to actual demand. In addition, timers are ideal when working with young people and teenagers, as they prevent

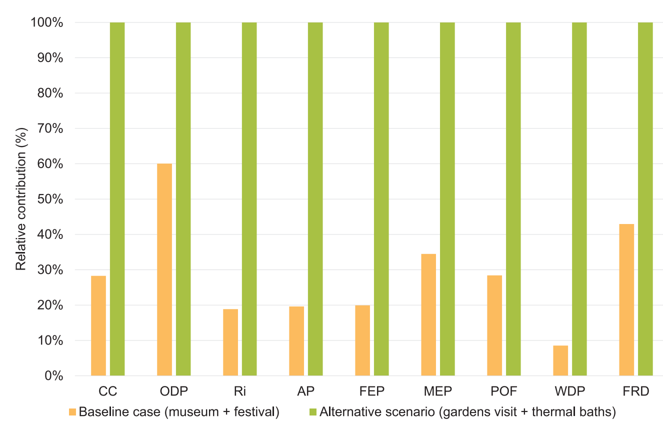


Fig. 11. Relative contribution to the life cycle impact of the SS3 activities subsector by comparing the baseline case with two other new activities.

locking and better withstand possible vandalism. Finally, to install or implement corrective measures to reduce consumption: percolators, ecological shower heads, volumetric reducers, among others.

All in all, it is found that the train and bus would be a better option than using the car for a couple traveling from Madrid to Rias Baixas. Concerning the tourist activities that are so important in this destination, the gardens would be a good option that could replace the museum or festival by reducing the impact by >70 %, while the thermal baths would need to be improved to reduce their environmental impact.

5. Conclusions

Tourism is one of the pillars of the Spanish economy and one of the fastest-growing industries in the world. However, the current tourism model causes a great environmental impact.

This study assesses the environmental impact of two people traveling to Rías Baixas from the Community of Madrid. The results show the high influence of the selected means of transportation. In addition, in contrast to other studies that only focus on transportation mode, the results show that accommodation, meals and activities at the destination also have a relevant contribution, more specifically the energy consumption of the hotel and the food consumption. An alternative scenario has also been evaluated which shows that the train is the most sustainable means of transportation for these holidays and airplane has the largest environmental impacts. In addition, thermal baths are one of the worst activities from an environmental perspective, with electricity being the most critical point. The visit to the gardens or the festival is a sustainable activity while the visit to the museums or the thermal baths needs improvement measures to promote their sustainability in this tourist destination.

It is therefore important to make tourists aware of the effects their decisions have on destinations. Through different communication channels, more sustainable travel habits can be promoted that can have a positive effect on the environmental footprint caused by tourism, for example, traveling to nearby destinations, car-sharing or encouraging the use of public means of transportation.

Based on the results obtained, tourism organizations or establishments could focus their efforts on the hotspots identified in this study, to integrate additional strategies to improve their sustainability. In this sense, the strategies could include: increasing the use of renewable energies, the use of energy and water-saving technologies, and raising awareness for more responsible consumption of food. Finally, these results, in addition to encouraging the improvement of the environment and infrastructures, can also have a positive effect on the promotion of the destination and raise the awareness of the local population with the tourism sector.

The advance of this study is based on the fact that the results can give new information in the tourism sector for transportation and tourism activities in a Spanish destination, support decision-making and give insights into policy-making in terms of the sustainability of the tourism sector. The added value of this study lies in its ability to guide decision-making, promote sustainable practices, highlight the uniqueness of the region and contribute to the development of responsible and environmentally friendly and sustainable tourism. The overall consequences of the study provide insights into the environmental perspective of the Rias Baixas destination, highlighting its critical points (transportation and alternatives to reduce the impact), as well as the opportunity to choose different tourist activities that generate fewer environmental impacts in the destination. This helps tourists to better understand the environmental aspects of Rias Baixas and guides them towards the best option from this perspective. Among the limitations found in this study are the availability of reliable data on the tourist activities of this destination, as well as the scope of the study and the definition of the system boundaries. The included subsectors in the study have been the following: accommodation and its associated services (food, beverage, cleaning), round-trip transportation, and tourist activities (along with the services provided by each activity). However, it has been a significant limitation in the study as finding high-quality data for these system boundaries has not been easy. Clearly defining the scope of the study has been a challenge due to the interconnection and complexity of supply chains and tourist services. Despite these limitations, LCA studies continue to be a valuable tool for assessing and comparing the environmental impacts of different activities and making informed decisions to reduce the environmental footprint.

In this regard, the use of an inventory, allocations, or impact assessment and impact method selections, should be used as a springboard for additional, more comprehensive studies in the future. Furthermore, although embracing the sustainable development goal of the tourism seems a distant view that requires the commitment of all the stakeholders involved, the inclusion of more sustainable strategies, such as in tourist transportation as a step towards the circular economy, could help to achieve tourism environmental sustainability.

CRediT authorship contribution statement

Cristina Campos: Methodology, Investigation, Software, Validation, Formal analysis, Data curation, Writing – original draft, Visualization. **María Gallego:** Conceptualization, Software, Formal analysis, Methodology, Data curation, Investigation, Visualization, Validation, Writing – review & editing. **Pedro Villanueva:** Software, Formal analysis, Methodology, Data curation, Investigation, Visualization, Validation, Writing – review & editing. **Jara Laso:** Methodology, Visualization, Writing – review & editing. **Ana Cláudia Dias:** Software, Formal analysis, Methodology, Data curation, Investigation, Validation. **Paula Quinteiro:** Data curation, Writing – review & editing. **Sara Oliveira:** Visualization, Writing – review & editing. **Jaume Albertí:** Data curation, Writing – review & editing. **Pere Fullana-i-Palmer:** Funding acquisition, Project administration. **Lela Mélon:** Project administration. **Ilija Sazdovski:** Project administration. **Mercè Roca:** Formal analysis. **Ramon Xifré:** Formal analysis. **María Margallo:** Data curation, Writing – review & editing, Supervision, Visualization, Validation. **Rubén Aldaco:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration.

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

No data was used for the research described in the article.

Acknowledgments

This research was funded by the INTERREG SUDOE Programme, grant number GREENTOUR: Circular Economy and Sustainable Tourism in Destinations of the SUDOE space (SOE4/P5/E1089).

The authors of CESAM acknowledge the Portuguese Foundation for Science and Technology (FCT)/MCTES for the contracts CEECIND/02174/2017 and CEECIND/00143/2017, and for the financial support to CESAM (UIDB/50017/2020+UIDP/50017/2020+LA/P/0094/2020), through national funds.

The author of the Galician Water Research Foundation (Cetaqua Galicia) belongs to the Galician Competitive Research Group GRC (IN845A-2), program co-funded by FEDER.

The authors at the UNESCO Chair want to hereby state that the authors are responsible for the choice and presentation of information contained in this paper, as well as for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

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