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Review

Tourism under a life cycle thinking approach: A review of perspectives and new challenges for the tourism sector in the last decades

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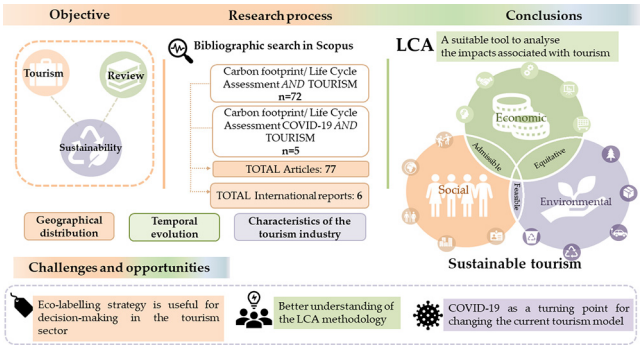
HIGHLIGHTS

- The review dissects 77 articles about tourism, 94 % of them over the last decade and 21 % concerning sustainable tourism.
- Mapping, time evolution, and characterization of the studies is assessed.
- Life Cycle Assessment (LCA) is key to climate change mitigation, tourism sustainability and resilience post-pandemic.
- The most common environmental indicator in the LCA methodology is the Carbon Footprint (CF).
- Ecolabels and digitalisation strategies are useful for decision-making in the sustainable tourism.

GRAPHICAL ABSTRACT



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ABSTRACT

Sustainable tourism should be promoted as a new system for the sustainable management of resources from a socio-economic and environmental point of view. For this purpose, it is necessary to develop a tool capable of assessing the impacts associated with the sector and to identify which actions are currently being addressed in order to achieve the desired sustainability.

This timely study aims to describe the current framework of Life Cycle Assessment (LCA) and its application to the tourism sector. To address these questions, a total of 83 documents (77 reviews and 6 international reports) were evaluated, assessing the geographical distribution, the temporal evolution of the publications, as well as the most relevant characteristics of the tourism industry articles were evaluated such as, life cycle inventory (LCI), system boundaries, functional unit (FU), methods, environmental indicators and impact categories considered.

The study identifies key recommendations on the progression of LCA in tourism sector. As important results, it stands out that 94 % of articles were from the last decade and 21 % of the articles reviewed cover sustainable tourism term, considering the three dimensions. This review showed that in LCA studies the most common method was CML 2001; the most widely used environmental indicator was the Carbon Footprint (CF) and the Global Warming Potential (GWP) was the impact category used in all the studies. Hence, LCA is a highly effective tool capable of assessing direct and indirect carbon emissions in tourism as well as the socioeconomic and environmental impacts generated in this sector.

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COVID-19 pandemic is also an object of discussion in the framework of the sustainable tourism together with advocating support for the eco-labelling and digitalisation of the tourism experiences as valuable tools to minimize environmental negativities, to promote mechanisms to access green markets and to frame successful synergies.

Contents

1. Introduction

Tourism is one of the most important sectors in the global economy, accounted for 10.4 % of global gross domestic product (GDP), which represents 319 GDP and 319 million jobs, approximately 10 % of total employment in 2018 (World Travel and Tourism Council (WTTC), 2021). This economic activity has been growing steadily over the recent decades and whose pre-COVID forecasts for the coming years predicted a strengthening of this trend (Raggi and Petti, 2006). In fact, international tourist arrivals reached 1.4 billion in 2018 with an increase of 5 % compared to 2016 (UNWTO, 2019b).

However, this growth has been interrupted by the COVID-19 pandemic. Over the past 40 years, the world has experienced a series of major epidemic-pandemics, but none of them has had similar consequences for the global economy as the current sanitary issue. The World Tourism Organization (UNWTO) reported that COVID-19 is the worst shock to international tourism since 1950, and it represents the abrupt end of a 10-year period of continuous growth for the tourism sector (UNWTO, 2021c). Consequently, 2020 and 2021 have been the worst years on record for tourism by the pandemic, facing a decline in international tourist arrivals during 2020 of between 58 % and 78 % regarding 2019, with a drop in direct tourism employment of between 100 and 120 million people. In addition, in 2020 international tourism profits fell by 64 % in real terms (local currencies, constant prices), equivalent to a decrease of more than USD 900 billion, and a total loss of international tourism export earnings of almost US$ 1.1 trillion. Despite all this, one positive outcome of the pandemic crisis was a reduction in emissions and improvements in air quality. The last information of the sector denoted that between 2009 and 2013, the global Carbon Footprint (CF) of tourism increased from 3.9 to 4.5 Gt of CO_2 eq., and this growth accounted for around 8 % of global carbon emissions (Lenzen et al., 2018). Nevertheless, in the COVID period, the global carbon emissions in 2020 are estimated to have fallen by 8 % respect 2019 (International Energy Agency, 2020).

Therefore, the need to reach a sustainable tourism remains indispensable for the sector to continue to grow towards international targets that aim to carbon neutrality by 2050 (World Tourism Organization and International Transport Forum, 2019). According to United Nations Environment Programme (UNEP) and UNWTO, *sustainable tourism* is 'the development of tourism activities with an appropriate balance between environmental, economic and sociocultural dimensions to ensure their long-term sustainability'. Furthermore, it should satisfy the needs of existing tourists and destinations, while providing opportunities for further development in the future, as well as maintaining heritage integrity, ecological integrity, biological diversity and livelihood system. A holistic balance between three dimensions (environmental, economic, socio-cultural) must be considered to achieve globally accepted sustainable tourism, so as to ensure the short and long-term sustainability of the tourism sector in the face of climate change (Pan et al., 2018).

Furthermore, sustainable tourism could play an important role in establishing an integrated approach to policy, regulation and management of tourism development, thus providing ways to ensure positive benefits (Bramwell and Lane, 2012) and to adapt tourism activities to climate change (Weir, 2017). Since the late 1980s and 1990s, efforts have been made to introduce the term sustainability in the field of tourism. At international level, in 1996 UNWTO and the WTTC and the Earth Council (EC) created the Agenda 21 for Tourism and in 2012 the document 'The Future We Want' was developed in the Rio + 20 Conference aimed to show the role of tourism in the transition to a green economy in the context of sustainable development. Currently, the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs) promotes responsible, sustainable and accessible tourism for everyone. Tourism contribute to all of the goals but in particular, it has been included as targets in goals 8, 12 and 14 on inclusive and sustainable economic growth, sustainable consumption and production (SCP) and the sustainable use of oceans and marine resources, respectively (UNWTO, 2021a). Moreover, as recently UNWTO-UNEP-World Meteorological Organization (WMO) claim, the tourism sector has an important place in the framework of the Kyoto Protocol due to its global economic and social value, whose role in sustainable development is linked with the climate (UNWTO, 2008). At European level, the European Union (EU) strategy on sustainable tourism (2020/2038 (INI)) sets out the different measures for the benefit of the tourism sector towards the transition to sustainable, responsible and smart tourism based on local craft activities, agro-tourism, rural tourism and ecotourism (European Parliament, 2021). Finally, the European Commission propose to create a communication campaign focusing on travel and sustainable tourism through an '*EU tourism brand*' that promotes to travel in the EU and to restore citizens' confidence in travel and tourism during the sanitary crisis. There are strategies at national level as well, such as the Spanish Sustainable Tourism Strategy 2030, which aims to transform Spanish tourism into a model of sustained and sustainable growth that will enable to maintain its position as a world leader. It seems that the COVID-19 is accelerating the process of its approval and 850 million euros will be allocated to promote the sustainability

and digitalisation. This strategy will contribute to improve the differential natural and cultural values of destinations (Ministry of Industry, Trade and Tourism, 2019).

The transition to a more sustainable tourism needs the quantification of its environmental performance. Thus, emphasis has been given to existing research on the environmental impacts of tourism (Barget and Gouguet, 2012). Recently, researchers, organizations, policy makers and others are striving to develop concepts and metrics that measure environmental sustainability, in particular, on climate change, which has recently become a key issue on the international tourism policy agenda.

Among these concepts and metrics, Life Cycle Assessment (LCA) is a tool for quantifying the environmental impacts of a product, process, or service over the course of its entire life cycle. This tool could provide a consistent analytical framework and environmental data support for decision-making, allowing for the development of sustainable solutions to global tourism challenges and the promotion of mechanisms that allow different tourism services to access green markets (Puig et al., 2017). LCA has demonstrated its efficacy in identifying opportunities for improving environmental performance and defining sustainability strategies for a variety of industries, including tourism and individual tourism events (Michailidou et al., 2016b). From all the environmental indicators and impact categories, Global Warming Potential (GWP) has been widely analysed, being used as a proxy for the entire set of impact categories. In fact, the analysis of this impact thought the CF indicator, which can be evaluated using the LCA approach, has nowadays its own set of standards, such as ISO 14067: 2013 (ISO 14067, 2013).

In view of the methodological advantages of the LCA concept, which include several impact categories or environmental indicators, there is a clear need for more research on tourism impact assessment, which would be based on life cycle considerations (Filimonau, 2016). Fig. 1 displays the conceptual aspects required for achieving sustainable tourism (and the existing policies and strategies) as well as the carbon emissions associated with tourism before and after the COVID-19 pandemic.

In this context, the main objective of this paper is to review the studies based on LCA in order to determine the main progress and challenges in the application to the tourism sector. We analyse the main stages of LCA proposed by the ISO 14040 that includes: i) definition of the goal and scope; ii) life cycle inventory (LCI); iii) life cycle impact assessment (LCIA); and iv) interpretation. This study allows the evaluation of the main problems in LCA modelling and the identification those tourism studies that despite of conducting an environmental analysis employ other tools or do not specify clearly the procedure.

Additionally, as tourism has an important contribution to global carbon emissions, the review has included a search of studies that use the global warming indicator or the Carbon Footprint. However, as COVID-19 has reduced the GHG emissions of the sector, we have reviewed the scientific literature that analyse the influence of the pandemic on tourism. Moreover, as sustainable tourism should consider the economic, social and environmental issues, we have evaluated which papers provide a complete view of sustainability. This includes a review of the application of mono and multi-criteria methods.

Finally, the paper seeks to help to LCA practitioners in the use of this tool, providing the guidelines to conduct an environmental analysis of the main activities of tourism. In this context, different tools such as ecolabels and environmental certifications are shown in order to understand better the implementation of these environmental measures in tourism.

2. Materials and methods

2.1. Literature search strategy and inclusion criteria

This review seeks to address the most relevant studies in the last two decades (2004–2022) based on LCA with the purpose of assessing environmental impacts and achieving global sustainable tourism. Searches of different sources of scientific literature, books and reports were included. This includes Scopus database and Google Scholar and other tourism sector specific databases such as the UNWTO. The review excluded studies that did not address tourism and that did not apply LCA. Also, they were excluded those articles dealing with social issues, as tourism hospitality (Chan and Hsu, 2016), sustainability of cities (Eluwole et al., 2020) or studies focused exclusively on tourist data (Pan et al., 2018). In the same way, they were discarded studies that used LCA but they are focused on other sectors such as transport or buildings (König et al., 2007), or on other aspects like the use of plastic bottles in different cities (Foolmaun and Ramjeeawon, 2012).

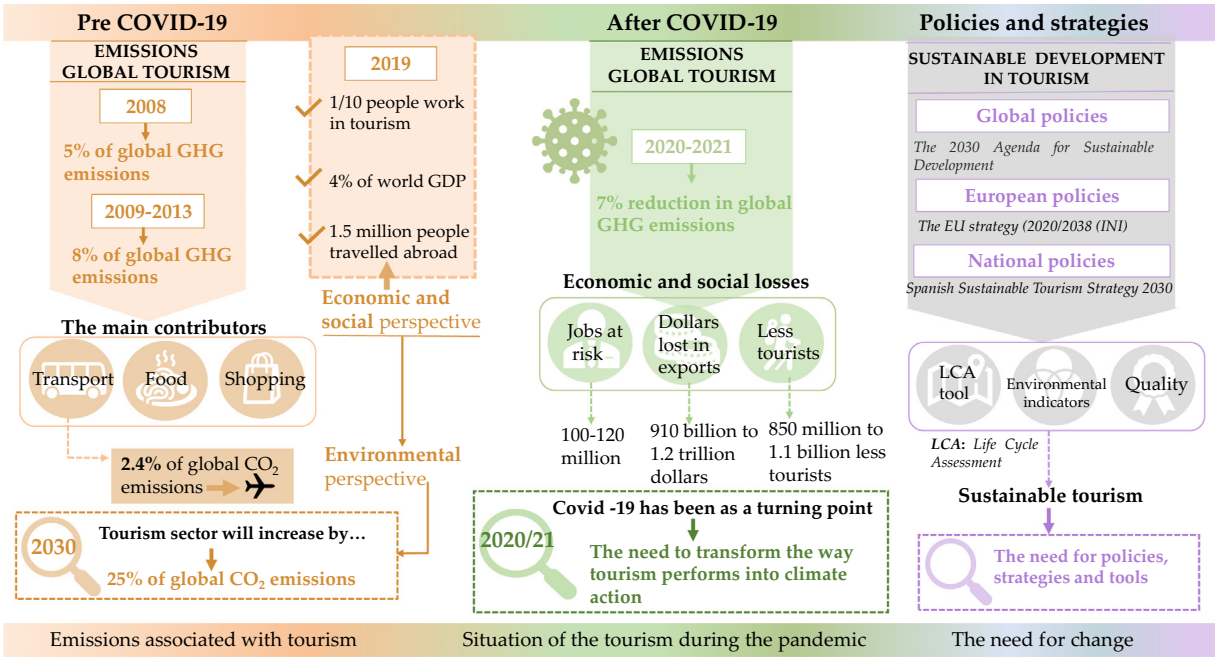

Fig. 1. Conceptual aspects for sustainable tourism. GHG emissions associated with tourism before and after the pandemic and policies and strategies for achieving sustainable tourism.

For the bibliographic search, a classification of the documents was made by considering the LCA approach in the tourism sector. Furthermore, the CF was considered as an environmental indicator due to its wide use in this field, as well as, the influence of COVID-19. Fig. 2 shows an overview of the steps to identify and classify the studies.

Firstly, a global search using both LCA and CF associated with tourism was carried out and 142 articles were found, but only 24 of them were considered. The rest were excluded because they covered tourism-related topics, but with other types of methodologies such as the DIM (Diagnosis-Implementation-Monitoring Model). Subsequently, articles focusing only on LCA associated with tourism were evaluated. A limited number of LCA case studies in the tourism sector have been found in the literature. For this purpose, it was chosen those articles that included the terms 'LCA' or 'Life Cycle Assessment' in the abstract, keywords or title. A total of 31 papers were found in the Scopus database, but only 15 were included, as the rest of the articles were not within the defined scope or they presented other objectives than assessing the impacts associated with tourism. The same procedure was then followed for the CF and definitely, 115 articles were obtained. However, only 33 of them were considered since the rest of the articles were focused more on financial and social issues in the tourism sector and not on CF. In summary, a total of 72 (22 + 15 + 33) papers related to the LCA and CF of tourism were evaluated. The next step was to make a search of the tourism sector and both terms, LCA and CF, used in association with COVID-19, in order to find out the current state of the sector from an environmental point of view. In this case, reports from international governmental organizations, such as UWTO and the UN, were analysed. A total of 6 documents were included in the review, 5 of them conducted in Europe, and the other one in Latin America. Also, 19 articles were found but only 4 of them were included because the rest were focused on economic or social losses due to the health crisis and not on environmental issues. Therefore, based on the LCA, CF and COVID-19 issues, a total of 83 documents (77 articles and 6 reports) have been studied in the review.

2.2. Analysis of LCA study findings

Each article of this review was assessed independently to identify the objective, the methodology and the conclusions. The following characteristics were analysed in each article: scope of the study that includes the life cycle inventory, functional unit (FU) and the system boundaries which leads to a delimitation of the different processes of the system under examination (ISO 14044, 2006). Also, it was considered the tools and the impact method used and impact categories and environmental indicators studied. According to De Camillis et al. (2010a), these characteristics should be considered when developing this type of studies (Fig. 3).

Fig. 3 details the 6 characteristics analysed:

i) LCI includes primary or foreground data, and secondary or background data. Primary information was obtained in the most studies through implementing questionnaires (Puig et al., 2017). Secondary data come from publications, open literature, databases such as Ecoinvent, LCA libraries and tourism statistics office (Candia and Pirlone, 2022).
ii) The choice of system boundaries so as to determine which process units will be included in the LCA study (ISO 14044, 2006). There are three options in this case: a) to consider stages from raw material extraction to transport use, accommodation, restaurants and leisure activities (Sharp et al., 2016), b) apart from the above, to examine the final disposal of waste (Hu et al., 2015) and c) separate systems such as air transport used in tourism, hotels as an example of accommodation, restaurants or sport tourism as a leisure activities. The first two options consider a complete travel package while the third one examines only one of the sectors.
iii) The selection of the FU, which is the reference unit on which all inputs and outputs of the system are based (ISO 14044, 2006). The FU for transport in tourism and tourism activities are well established and they can be defined as '1 passenger per kilometre driven' and '1 visitor activity performed' (Filimonau et al., 2013). However, for a hotel stay, no consensus has yet been reached.
iv) The tools analysed in the articles were the LCA, LCEA (life cycle energy analysis) and LCA-IO (input-output life-cycle assessment), since the aim of the study was to examine studies using the LCA tool in tourism. Each of these tools has an impact method.
v) The fourth point consider the impact method applied. There are several methods for the IO-LCA, LCEA and LCA of tourism. For the first one, the method used was the Inputs-Ouputs Tables (IOTs), for the second tool, the CML 2001 was the most used and finally, for the LCA, CML-2001 and ReCiPe developed by the University of Leiden stand out. Both method groups life cycle inventory (LCI) results into midpoint categories by themes (e.g. climate change or ecological toxicity). The second one considers 18 midpoint indicators and 3 endpoint indicators (Chaiyat et al., 2020). Other important methods are the Eco-Indicator

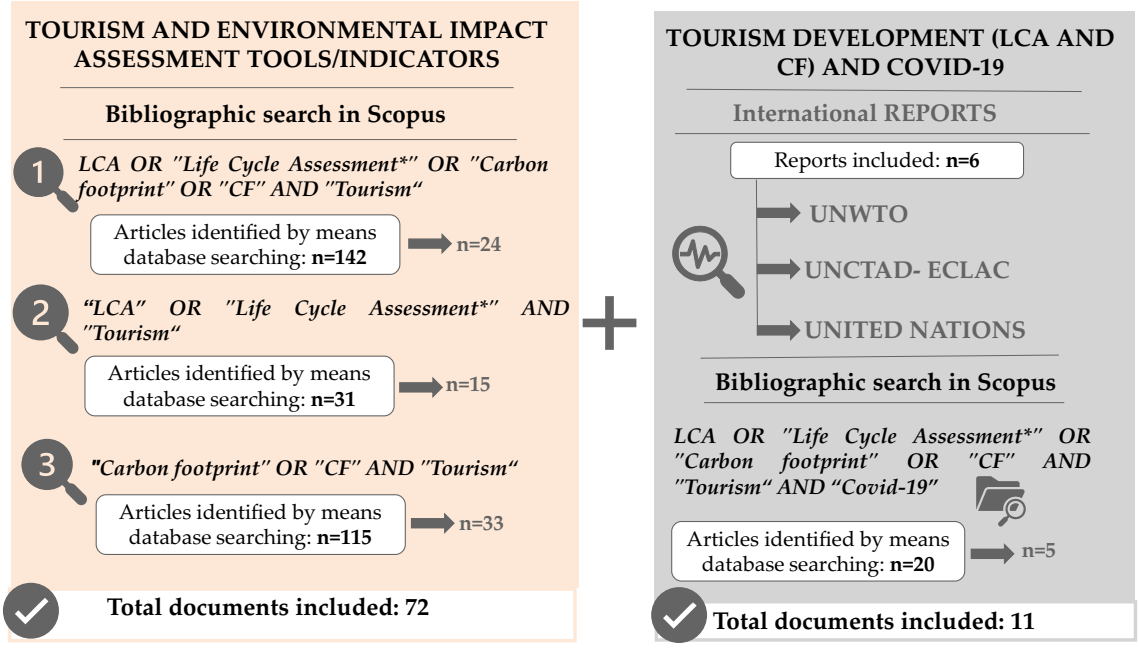

Fig. 2. Schematic diagram of the steps followed in the bibliographic search.

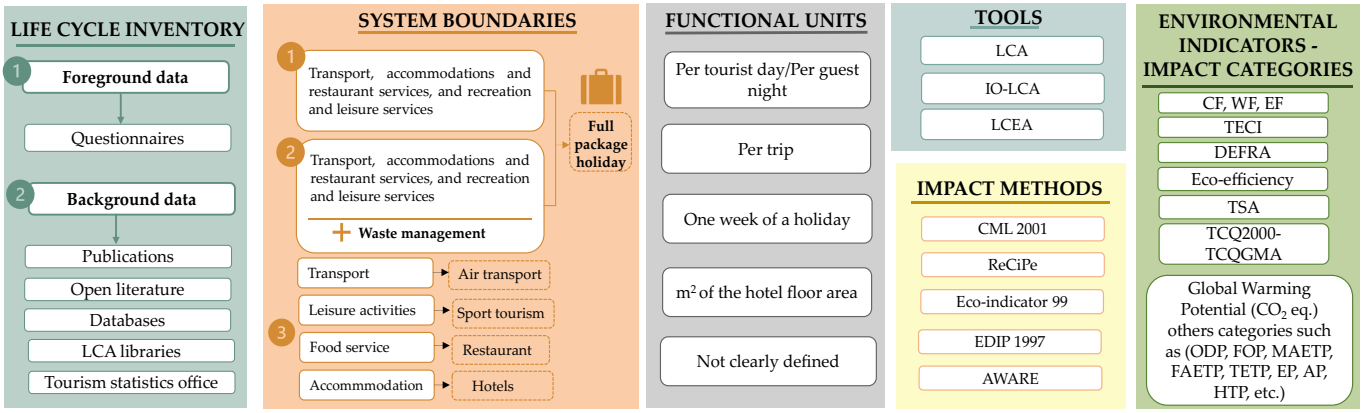

Fig. 3. The main characteristics of the critical analysis of tourism studies. The abbreviations are: Carbon Footprint (CF); Water Footprint (WF); Ecological Footprint (EF); Tourism Environmental Composite Indicator (TECI); Department for Environment, Food and Rural Affairs (DEFRA); Tourism Satellite Account (TSA); Cost Estimates and Technical Conditions (TCQ2000) and Module for Environmental Management (TCQGMA); Terrestrial Ecotoxicity (TETP), Photochemical Ozone Creation (FOP), Ozone Layer Depletion (ODP), Marine Aquatic Ecotoxicity (MAETP), Freshwater Aquatic Ecotoxicity (FAETP), Eutrophication (EP), Acidification (AP), and Human Toxicity (HTP).

99 developed by PRé Consultants that considers the environmental damage in human health, ecosystem quality and resources (Solé et al., 2018); or EDIP 1997 developed by the Institute for Product Development (IPU) at the Technical University of Denmark that uses a midpoint approach. Finally, AWARE is a consensus-based method development to assess water use in LCA, developed by WULCA, a working group of the UNEP SETAC Life Cycle Initiative (Santana et al., 2019).

vi) After the selection of the method, the most appropriate and relevant environmental indicators must be set. A large amount of studies use the CF indicator to measure total GHG; the water footprint (WF) that calculates the volume of fresh water (in litres or cubic metres) used throughout the entire production chain of a consumer item or service, or the ecological footprint (EF), based on resource consumption and waste production (Mancini et al., 2016). There are also other environmental indicators such as the Tourism Environmental Composite Indicator (TECI) that provides the basis for a mathematical comparative analysis (Michailidou et al., 2015); the DEFRA (Food and Rural Affairs) that assesses carbon impact appraisal in the majority of the UK-based carbon calculators (DEFRA, 2008); and the eco-efficiency model, which used for transforming un-sustainable development into sustainable development. Specifically, the eco-efficiency calculation determines the ratio between the value of products and the environmental impacts and gives clear financial results (Gössling et al., 2005). Finally, Tourism Satellite Account (TSA) is an indicator that measures Australian tourism economic activity with data on GHG emissions to enable the footprint to be constructed. These indicators are more specific (in terms of the scope of geographical areas and tourism sub-sectors), so the use of these indicators is more limited in the tourism sector.

Therefore, an LCA can included several impact categories. Impact categories include for instance, Global Warming Potential (GWP), stratospheric ozone depletion, photooxidant formation (smog), EP, AP, water use, noise, etc. The three main groups of categories are based on resource use, human health consequences and ecological consequences (Pennington et al., 2004).

3. Results and discussion

3.1. Mapping of the studies

A total of 83 documents were reviewed; 77 articles related to the tourism sector using LCA tool and/or CF environmental indicator, 5 articles addressing the situation of the tourism sector following these methodologies during the COVID-19 crisis and 6 reports. This section presents the analysis of the studies: i) geographical distribution, ii) temporal evolution, iii) characterisation of the LCA studies and iv) the main conclusions and decisions.

Fig. 4 shows the location of the research institutions of the studies. All articles were included in this figure, except the article by Lenzen et al. (2018) because it refers to large regions rather than specific countries. The reports were also not included in the figure for the same reason. The coloured areas illustrate the territories where LCA and CF studies were conducted. Studies addressing the development of LCA tool focused on Asia (50 %), Europe (43 %) and Oceania (7 %), whereas any study was found in Africa. As a general pattern, the studies were conducted in developed countries, with a low contribution of developing and non-developed countries. Most of the articles were developed by institutions from a particular country, while 4 of them had international collaboration and involved researchers from four or five regions, highlighting the great importance of achieving global sustainable tourism. In the European context, Spain ranks first in the dissemination of studies, producing or collaborating in 10 publications. Italy (6 studies), the United Kingdom (UK) (5) and Greece (4) also played an important role in the evaluation of tourism. However, this is also paradoxical since the environmental impact of tourism is not analysed in the markets with the greatest potential impact, such as France, which is the world's leading tourist destination. Similarly, the United States, which is the third largest tourist destination in the world, does not present any of the studies on LCA in tourism (UNWTO, 2019a).

Regarding publications on the use of LCA tool and/or CF indicator in tourism, almost all regions contributed to a greater or lesser extent to its development. Most of the articles were by authors from the same geographical area (with the exception of De Grosbois and Fennell, 2011; Juvan and Dolnicar, 2014; Lenzen et al., 2018) who conducted studies in an international context. China represented the region with the greatest impact in this field, with 19 studies. In second place was Spain (9 articles), followed by Australia (7), Italy (5) and the UK (5), which contributed significant research in this field. Greece (4) and Japan (4) also presented articles focusing on these tools for assessing tourism impacts. With a minor contribution, the rest of the European countries, largely driven by Germany which participated in 3 studies, and followed by Austria (2), Portugal (2), Bulgaria (2), France (1), the Netherlands (1), Slovenia (1), Norway (1), Iceland (1) and Russia (1) played a role in the study of LCA and CF approaches in order to achieve sustainable tourism. The influence of the Americas was very low, with only the USA presenting 2 CF studies (focusing on air transport and sports tourism) and 1 study in Brazil (also based on transport). The rest of Asia contributed to a lesser extent than China, where Thailand presented 3 studies and Saudi Arabia (2), one of them highlighting pilgrimage as religious tourism. Finally, in Oceania, besides the great influence of Australia, New Zealand also participated in 3 articles focused on the calculation of the LCA. In Africa, no articles have been developed on this topic

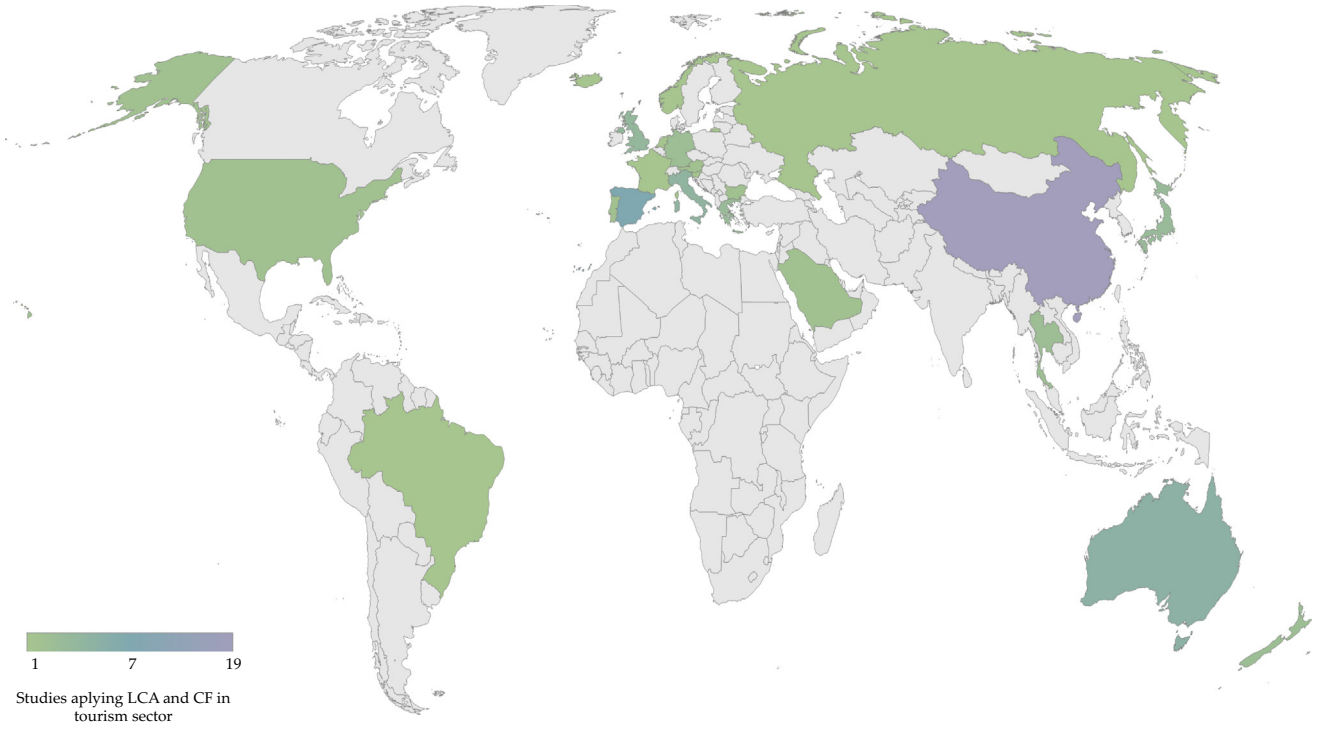

Fig. 4. Geographical distribution of LCA studies included in the review. Reports were excluded from the figure.

and this is because this continent is still in a development stage of using the power of tourism to drive development and opportunities for all (UNWTO, 2021b). Moreover, due to the pandemic suffered in 2020–2022 this inequality has been aggravated in this continent. Therefore, it is expected to cooperate and invest in African tourism so that it can develop this potential in areas of West Africa such as Cape Verde (UNWTO, 2020a). After COVID-19, Africa has suffered a 77 % drop in international arrivals compared to 2020 which was 74 % (UNWTO, 2021c), so the World Tourism Organization is determined to help Africa return stronger, and to make tourism emerge from this crisis as an important pillar of the economy, employment and sustainability (UNWTO, 2020a). Hence, the lack of documents relating to LCA and CF in these African regions may be due to the scarcity of research on minimizing tourism impacts in this continent. In spite of the fact that in developed countries the vision of sustainable tourism marked by the 2030 Agenda and the SDGs is more present than in developing countries, the health crisis affected more negatively than in continents such as Africa: Asia and the Pacific suffered a 95 % drop in international arrivals; the Middle East (82 %), Europe (77 %) and the Americas (68 %). Some small islands in the Caribbean, Africa and Asia-Pacific, along with a few small European destinations performed better in June and July 2021, with arrivals close to or even higher than before the pandemic (Kitamura et al., 2020c). Despite reducing GHG emissions in the post-pandemic tourism sector, governments, non-governmental organizations and the private sector can advise on the development of training programmes and information systems, and help build capacity to manage tourism (Moscardo, 2017), as this industry is expected to grow at exponential levels in the coming years (UNWTO, 2021c). Consequently, it is imperative to include environmental impact assessment methodologies for all stages of this sector in developing countries.

3.2. Time evolution of the studies

Fig. 5 illustrates the evolution of the studies over time 2004 to 2022. The starting point is the first year with peer-reviewed articles on tourism and LCA (De Camillis et al., 2010a). It can be seen that very few articles have been developed during the period (2004–2010). However, the development of LCA has progressively increased, presenting a greater constancy and periodicity over the years, highlighting the year 2010 with 6 articles; 2016, with 7 publications and 2020, with 15. The year 2021 presents 5 articles and in 2022 (until May 2022) there were 3 articles but an increase in publications is predicted with respect to 2020 given the growth of the sector and the concern to reduce its negative environmental impact. On the other hand, an increasing number of publications addressing LCA in tourism was observed in the period (2017–2022). Of the 74 articles in total about tourism, the 94 % of them were from the last decade (2010 − 2022).

This is evidence of the great concern and awareness in the sector, with the pandemic serving as a turning point to achieve carbon emission reductions associated with this large industry. In the period 2020–2022 publications have started to increase as the UNWTO began to stand out concerns about emissions associated with the tourism sector. As the number of publications began to increase from 2020 onward, it can be suggested that these initiatives influenced the development of several studies around the world.

3.3. Characterisation of the studies

This section summarizes the main characteristics of the articles on tourism included in the review. For this purpose, a literature review of most relevant articles (27) has been conducted on the LCI, system boundaries, functional unit, environmental methods and impact categories and the influence of the COVID-19 in tourism (Table 1). The rest of the articles (50) were shown in Table S.1 in the Supplementary Material.

According LCI, On the one hand, for all articles, primary information was obtained through the application of questionnaires. On the other hand, in most of the studies (almost 92 %), secondary data came from databases such as Ecoinvent and Agribalyse and tourism statistics offices (Puig et al., 2017).

The system boundaries were quite similar in almost all case studies, although the number of stages included varied depending on the objective of the study: in some articles, only transport was considered (Gühnemann et al., 2021) or more specifically, air transport (Dorta et al., 2021). However, most of the articles analyse transport, accommodation and restaurants together to provide a more global view of the sector (Cadarso et al., 2015). Also, there was a wide variety of studies that take into account the stage of

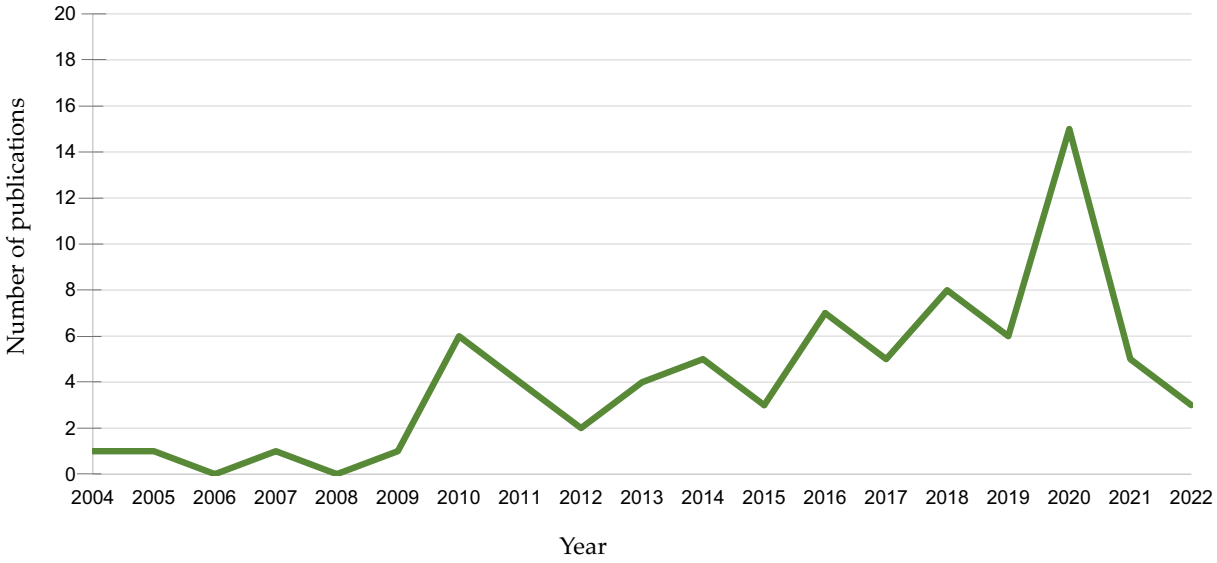

Fig. 5. Temporal evolution of the LCA studies considered in the review from 2004 to May 2022. Reports were excluded from the figure.

waste management (De Camillis et al., 2010b) and leisure tourism activities (Rico et al., 2019).

Regarding the type of FU, in general, it was observed that most authors use 'per guest night' or 'per trip' because accommodation is one of the most common sectors analysed in tourist trips (Baumber et al., 2021). However, this depends on the tourism function performed and the process units considered. Other studies have even used '1 m^2 of the hotel floor area' if the study focuses on the construction materials of a building and the techniques used (König et al., 2007). In other cases, the FU was not clearly specified ('Not clearly defined') even though the function of the system was well defined (Cadarso et al., 2015).

In terms of the type of the methods used, the same trend was generally observed across the studies (Filimonau et al., 2011a). Most of the works are based on the CML 2001 (Puig et al., 2017) method and the Eco-Indicator 99 (Michailidou et al., 2016b), thus demonstrating that these are two of the most common methods in LCA in tourism sector. Others authors use ReCiPe (Chaiyat et al., 2020), EDIP 1997 (Cerutti et al., 2016) and AWARE (Santana et al., 2019) but to a lesser extent.

According to the environmental indicators and impact categories it was observed that the CF indicator (77 % of the studies) (Rico et al., 2019) and the GWP (100 %) (El Hanandeh, 2013) were undoubtedly the most used. This confirms the existing nexus of LCA-CF-GWP in studies that assess the environmental impact of the tourism sector. Other authors have used other methods to evaluate the environmental impacts of tourism such as De Camillis et al. (2012) who used the EF. For instance, WF indicator is not common for tourism studies as only one author has used it to analyse the economic, carbon emission, and water impacts of Chinese visitors to Taiwan (Sun and Pratt, 2014). Filimonau et al. (2013) uses another environmental indicator such as DEFRA, in order to measure the CF of fuel consumption in transport and energy use in buildings, such as tourist accommodation facilities. Similarly, the model of Gössling et al. (2005) studies the eco-efficiency of tourism so as to estimate the CF of tourism transport and hotels. Other case study used the TECI to compare typical all-sized hotel categories in terms of their combined environmental pressure (Michailidou et al., 2015). Finally, from an economic point of view, Rosselló-Batle et al. (2010) used unusual methods such as TCQ2000 (Cost Estimates and Technical Conditions) and TCQGMA (Module for Environmental Management). These models provide the amount of materials, energy consumption, carbon emissions and waste generated, based on information provided by specific measurements. Other authors like Dwyer et al. (2015) used TSA in order to assess the economic impact of an accommodation, transport and leisure activities in an Australian tourist destination. In terms of impact categories, all the studies reviewed used the GWP. Some authors also used more impact categories (TETP, FOP, MAETP, FAETP, HTP, EP, AP, etc.) for a more comprehensive study, such as Michailidou et al. (2015), Maugeri et al. (2017) and Candia and Pirlone (2022), among others.

Finally, it is important to highlight that after the COVID-19 in 2020, tourism has suffered a major change in all three aspects of sustainability (social, economic and environmental). The decline in revenue and the nearly drastic reduction in flights and travel has caused a major socioeconomic loss, which is intended to be recovered from 2022 onwards. However, despite the negative socioeconomic point of view, it has also had a positive impact from an environmental perspective where CO_2 emissions have been reduced by a large percentage (UNWTO, 2021c). Therefore, 5 studies examined the COVID-19 in tourism using LCA and CF indicator, in which a large reduction of CO_2 emissions was observed (Baumber et al., 2021; Dorta et al., 2021; Gühnemann et al., 2021; Kitamura et al., 2020; Candia and Pirlone, 2022).

In summary, most of the articles addressed the stages of accommodation, restaurants and transport in the study phases of the tourism sector. The FU 'Per guest night' or 'per visitor' tends to be the most common, although it changes according to the scope of the study. It should also be noted that the CF environmental indicator is the most common method for assessing the environmental impacts of the tourism sector in LCA studies. This tool is increasingly growing in this field and is expected to be widely used due to its great advantages over the other methods used to date. Likewise, the most studied impact category in tourism is global warming due to its direct influence on the sector. Finally, in the last year, the impact of COVID-19 on tourism is being considered as a turning point for implementing a sustainable tourism system that considers a reduction in CO_2 emissions.

3.4. Monocriteria vs multicriteria approaches in sustainable tourism

Tourism is a human activity that involves the economy, the environment and society. Therefore, the objective will be to find the optimal compromise between environmental, economic and social variables in a defined time and space. Without sustainable tourism, there is a risk of entering a vicious circle in which biodiversity is lost, jobs and wealth are lost and there are demands in other markets (Pan et al., 2018). In the review conducted in this paper, all the studies include the environmental variable but not all of them consider the social and economic variable. For this reason, it has been studied which articles consider the term sustainable tourism when considering the 3 paths, only 2 of them or only the environmental variable.

Table 1
Overview of LCA case studies in the tourism industry: geographic zone, system boundaries, functional unit (FU), impact method, environmental indicators and impact categories are considered. Also, the three dimensions (environmental, economic and socio-cultural) of sustainability are also taken into account.

Reference	Geographic zone	Life cycle phases included in the system boundaries	Functional unit	Impact method	Environmental indicator/impact categories	Environmental impact	Economic aspects	Social aspects
Kuo and Chen (2009)	Taiwan (Penghu Island)	Transport, accommodation (hotel) and recreation activities	'Per tourist per trip' or 'per tourist per day'	Not clearly defined	→Ecological Footprint (EF) →Water pollution (BOD) Air pollution (CO_2, CO, HC, NO_x)	☑	☒	☒
Filimonau et al. (2013)	United Kingdom	Air transport, Accommodation (hotel), energy consumption in the hotel, leisure activities	'Per guest night' (for energy consumption) and 'Per passenger-km' (for air transport)	CML 2001	→DEFRA →GWP (CO_2 eq.)	☑	☒	☒
Rico et al. (2019)	Spain	Arrival and departure transport, intra-urban transport, accommodation (hotel), leisure and professional activities	'Per tourist day'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☒	☒
Michailidou et al. (2016b)	Greece	Water and energy consumption, accommodation (hotel) and the transport of tourists from their original place to the hotel and their return	'The environmental loads of all tourists visited one hotel in its seasonal operation'	Eco-indicator 99 and CML2001	→GWP (CO_2 eq.)	☑	☒	☒
Cerutti et al. (2016)	Italy	Accommodation (holiday farm), food, beverages, chemicals	'1 Guest night', 'Earnings of the owner' or 'The whole farm'	EDIP 1997	→GWP (CO_2 eq.)	☑	☑	☒
Puig et al. (2017)	Spain	Water, electricity and thermal energy consumption and cleaning products; accommodation services (hotel) and municipal waste	'A guest per overnight stay'	CML 2001	→GWP (CO_2 eq.)	☑	☒	☒
Michailidou et al. (2015)	Greece	Departure, stay in the tourist destination and return. Transport to the hotel, accommodation services and transport back home, water consumption, waste water and other wastes (aluminum, cardboard, glass, Polyethylene terephthalate (PET), Polypropylene (PP), other plastics)	'An overnight stay of one guest with breakfast and car-parking services included'	CML 2001	→TECI →GWP, TETP, FOP, ODP, MAETP, HTP, FAETP, EP, AP, Abiotic Depletion, Radioactive radiation	☑	☑	☒
De Camillis et al. (2010b)	Italy	Service provision (check-in, stay-room use, check-out) and end of service (external laundry, waste treatment, transport)	'One night's hotel stay in a standard room'	CML 2001	→GWP (CO_2 eq.)	☑	☒	☒
El Hanandeh (2013)	Saudi Arabia (La Mecca)	Transport, meals, hotel stay and waste management	'1 pilgrim day'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☒	☒
Hu et al. (2015)	Taiwan	Service provision (check-in, stay-room use, check-out) and end of service (external laundry, waste treatment, transport)	'One night's hotel stay in a standard room'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☒	☒
König et al. (2007)	Portugal	Building material: Outside walls, windows and doors, inside walls and doors, ceilings and staircases, roofs	'1 m^2 of outside wall'	Not clearly defined	→LEGEP →GWP (CO_2 eq.), AP (SO_2 eq.)	☑	☒	☒
Kitamura et al. (2020c)	Japan	Transport, accommodation (hotel), food and beverage (restaurant services), leisure activities (souvenirs, tour operators and shopping)	'Per traveler per year'	Input-Output Tables	→GWP (CO_2 eq.)	☑	☑	☑
Rosselló-Batle et al. (2010)	Spain	Construction materials, electricity, propane gas and gas oil consumption and waste	'Per m^2' or 'Per kWh'	Not clearly defined	→TCQ2000 and TCQGMA →GWP (CO_2 eq.)	☑	☒	☒

Pereira et al. (2017)	Brazil	Road and air transport (car, inter-city bus, airplane, rail)	'A return weekend journey between Rio de Janeiro and São Paulo made by one traveler with tourism and leisure purposes'	Not clearly defined	→EF →GWP (CO_2 eq.)	☑	☒	☒
Filimonau et al. (2011b)	United Kingdom	Laundry, breakfast, hotel construction, energy production and distribution	'1 m^2 of the hotel floor area'	CML 2001	→GWP (CO_2 eq.)	☑	☒	☒
Díaz et al. (2019)	Spain	Electricity and water consumption of the hotels	'Person night' or 'For hotels with external water distribution'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☒	☒
Dorta et al. (2021)	Spain	Air transport	'Per capita per air route'	Not clearly defined	→GWP (CO_2 eq.)	☑	☑	☑
Gühnemann et al. (2021)	Austria	Transport (car, plane)	Not clearly defined	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☑	☑
Baumber et al. (2021)	Australia	Electricity consumption, gas use, life cycle emissions from Sydney water's water supply and treatment, and methane and other emissions from waste sent to landfill	'Per-customer', 'Per guest-night'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☑	☑
Maugeri et al. (2017)	Italy (Sicily)	Transfer to the hotel (gasoline, oil and tire), consumption of methane gas, consumption of energy (during the stay at the hotel-accommodation), consumption related to the toilet breakfast and air emissions, water emissions and solid waste	'Trip and overnight stay in a hotel during mid-season with the arrival and departure of the tourist at Fontanarossa Airport in Catania, Sicily'	Not clearly defined	→GWP (CO_2 eq.), Natural Resources (habitat, water, fossil fuels, minerals, biological resources), Smog ODP, ADP, EP, HTP, TETP	☑	☑	☒
Cadarso et al. (2015)	Spain	Air transport, accommodation (hotel) and restaurants	Not clearly defined	Input-Output Tables	→GWP (CO_2 eq.)	☑	☑	☑
Michailidou et al. (2016a)	Greece	Accommodation (hotel), transport (especially air one), energy and water consumption and waste	'Per guest night'	Eco-indicator 99 and CML 2001	→EF →GWP (CO_2 eq.), Abiotic depletion,, ODP, HTP, FAETP, MAETP, TETP, ADP, EP, FOP	☑	☒	☒
De Camillis et al. (2012)	Italy	Transport passengers from home to the departure airport and vice versa, airport services, flights, accommodation and other leisure activities	'Per study group per package holiday'	Not clearly defined	→GWP (CO_2 eq.)	☑	☑	☑
Luo et al. (2020).	China	Tourism catering, leisure activities (sightseeing, shopping), ecological toilets and trails, vegetation damage area and solid waste	'Per tourist consumption of food'	Input-Output Tables	→CF →GWP (CO_2 eq.)	☑	☑	☒
Candia and Pirlone (2022)	Italy	Origin-destination Transport, Accomodation, service/resources (local transport water, waste, energy), leisure activities	'One person spending 3 days' holiday inside the Cinque Terre National Park'	Not clearly defined	→GWP (CO_2 eq.), abiotic depletion, fossil fuels, ADP, EP, FOP, ODP	☑	☒	☒
Retno Susilorini et al. (2022)	Indonesia	Rural household- solid waste-inorganic and organic	'Per kg of solid waste produced by visitors, population, and buildings'	Not clearly defined	→CF →GWP (CO_2 eq.)	☑	☒	☒
Rodríguez-Pérez et al. (2022)	Spain	Water-energy consumption and waste in rural houses	'Per year'	Input-Output Tables	→CF →EF →GWP (CO_2 eq.)	☑	☒	☒

Firstly, of the 77 articles based on LCA methodology, 4 % considered the social and environmental variables; 21 % considered all three dimensions; 31 % studied the economic and environmental variables; and 44 % of the studies examined only the environmental variable. Authors such as Hares et al. (2010) and Greiff et al. (2016) explored tourists' awareness of the impacts of travel on climate change (social), they examined the extent to which climate change features in holiday travel decisions (environmental). Moreover, Wicker (2018) who estimated the annual Carbon Footprint of active sport tourists caused by snow-sport-related travel in Germany, and Cadarso et al. (2016) who calculated the CO_2 emissions of an example of the Spanish tourism sector were 2 of the 16 studies that considered the social, economy and environmental aspects of tourism. Other authors as Scheepens et al. (2016); Cerutti et al. (2016) and Sun et al. (2019) considered both economic and environmental perspective. Finally, El Hanandeh (2013); Hu et al. (2015); Santana et al. (2019) and Sharp et al. (2016) were 4 of the 34 studies that considered the social, economy and environmental aspects of tourism. Considering COVID-19 issue, of the 5 articles examined, 4 of them had a sustainable tourism vision (Baumber et al., 2021; Dorta et al., 2021, Gühnemann et al., 2021; Kitamura et al., 2020), while Candia and Pirlone (2022) only studied the tourism sector from an environmental perspective.

In relation to the mono and multi-criteria approach (MCA), of the studies reviewed, 3 articles considered the social and environmental variable together. Furthermore, 24 studies analysed the economic and environmental paths of the tourism sector. 34 articles only evaluated the environmental aspect of tourism and finally, 16 works considered the three areas of sustainable tourism (environmental, socio-cultural and economic), making sense of one of the purposes of this review. All in all, 56 % of the articles apply a MCA compared to 44 %, which use a mono-criteria approach. This denotes the relevance of sustainability in tourism, which is expected to grow in the coming years. Fig. 6 shows this previous description.

4. Implementation of sustainable tourism: eco-labelling initiatives

Environmental initiatives and instruments are currently being implemented to create a new framework for sustainable consumption and production in the travel and tourism sector (De Camillis et al., 2012). '*TravelLife*' is a sustainability management system that includes an ecolabelling system for qualifying tour operators, such as hotels, holiday destinations and restaurants. This system was founded in 2007 and was implemented in the framework of the European LIFE04 project ENV/NL/000661 (TOURLINK, 2004). This initiative aims to demonstrate the effectiveness of coordinating a better common branding of ecotourism products in the supply chains of tour operators in Spain, the Netherlands, the UK, Austria, Denmark and Sweden (TOURLINK, 2004). However, it has limitations as it does not consider the transport stage in the management system, it does not include greenhouse gas accounting and it is not based on LCA. '*Blue flag*' is a voluntary award for tourist destinations such as beaches and marinas founded in 1987. It arose with the project 'The Foundation for Environmental Education in Europe' (FEEE) and so far, many countries and regions worldwide have achieved this certification: Europe, South Africa, Morocco, Tunisia, New Zealand, Brazil, Canada and the Caribbean (FEE, 2011). Despite being a great initiative, the criteria are more related to quality issues and cover few tourism sectors. '*TourBench*' is another free European tool that aims to reduce the environmental impacts and organisational costs of tourist accommodation. It is also part of a European project called LIFE03 ENV/NL/000473 that started in 2003 (TOURBENCH, 2003). The '*Biosphere*' tourism sustainability certificate, which is awarded at both business and destination level, is currently growing in Spain. It is a voluntary certification, for destinations, companies, establishments and tourism products, promoted by the Responsible Tourism Institute (ITR) that recognises and certifies the tourism industry that is committed to sustainable management (Biosphere, 2020).

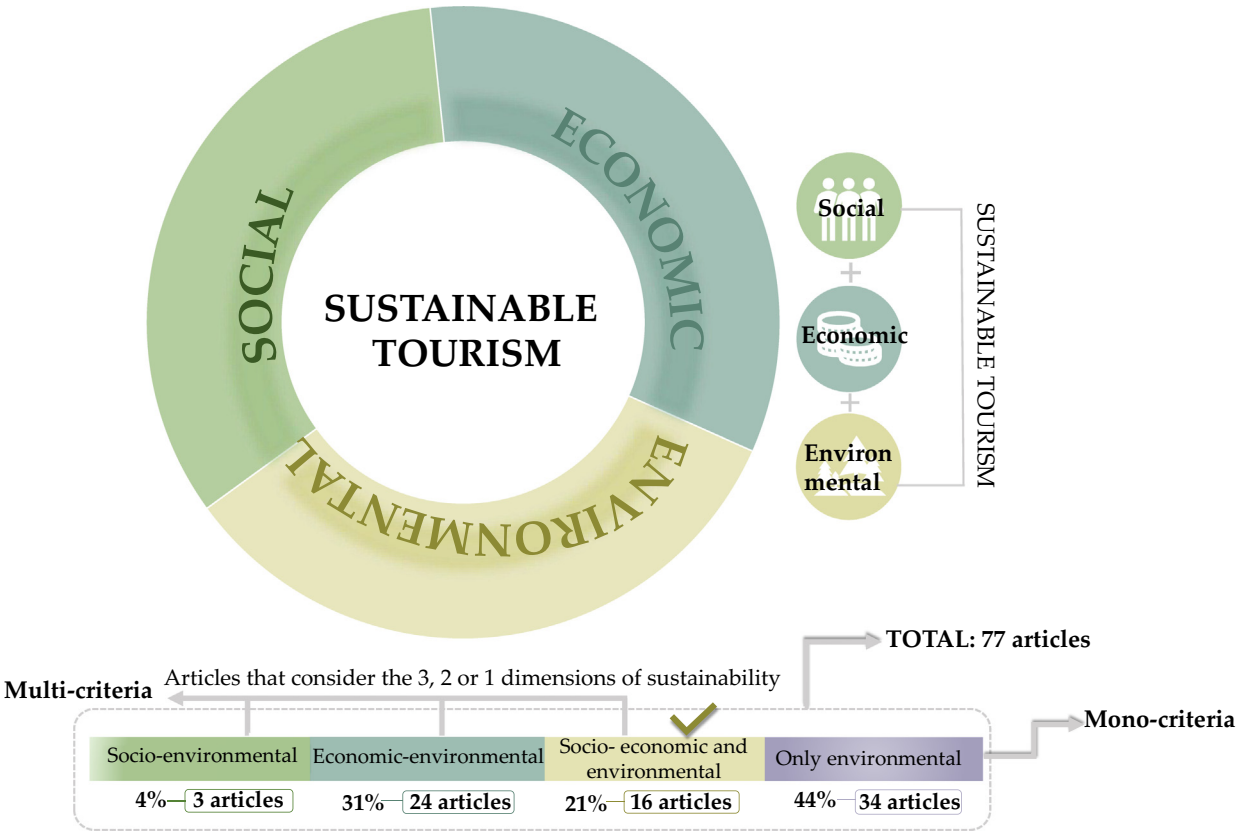

Fig. 6. Degree of implementation of sustainable tourism in the articles studied (77) in terms of the economic, social and environmental variables.

'*EcoPassenger*' is another online tool to compare energy consumption, CO_2 and other atmospheric emissions of means of transport in tourism (planes, cars and trains) for travelling in Europe (Knörr, 2008).

The implementation of ecolabels has a double impact for tourism business and destinations. On the one hand, it has an internal impact by contributing to a more efficient use of energy and resources consumption, waste management system and protection of natural heritage (e.g. biodiversity and landscape). On the other hand, eco-labels serve as a marketing tool by highlighting the values of the destination and acting as a sign of sustainability and quality.

Also, environmental labels and tourism service declarations that consider the LCA of tourism focusing on accommodation are now commonly used. Most of them are 'Type 1' labels are characterised by their regional scale (ISO 14024, 1999). Examples of these labels are '*Viabono*', '*Legambiente Turismo*', '*The Green Key*', '*Milieubarometer*', '*Ibex*', etc. (Sloan et al., 2009). These labels sometimes have some limitations as despite being inspired by LCA principles, no LCA study has yet been carried out to review the mandatory criteria of the eco-labelling scheme. The '*EU Eco Label*' is another example of a 'Type 1' environmental label (ISO 14024, 1999) for accommodation and campsites (European Commission, 2009). In short, all these initiatives can lead to sustainable tourism that makes optimal use of environmental resources, respects the sociocultural authenticity of destinations and ensures viable economic activities in the long term.

5. Challenges and recommendations for the tourism sector

The tourism sector is a very complex system that involves different subsystems: accommodation, restaurants, transport and leisure activities. The LCA tool presents some shortcomings in tourism. On the one hand, it is sometimes difficult to identify the boundaries of the system because of the large number of tourism products. On the other hand, there is no specific database for the tourism sector currently, which makes data collection in the life cycle inventory (LCI) a slow and difficult process. Finally, with the LCA tool there are local and social problems that are not studied in detail, such as landscape disturbances, destruction of flora or fauna habitat or acoustic problems, among others (De Camillis et al., 2010b).

Nevertheless, the current LCA perspective in tourism has also contributed to tackle sustainability challenges from a life-cycle thinking approach that has enabled to improve the environmental profile of the sector (Puig et al., 2017). Hence, in order to consider LCA as an effective method for tourism decision-making, it would be necessary to implement several improvement actions such as: i) tourism-specific databases to support and save time in conducting LCI and ii) taking into account local environmental and sociocultural issues. This integration would allow better planning and management of the environmental performance of tourism destinations and structures and the LCA could become a tool for responsible consumption. Last but not least, LCA could also be used to achieve an environmental improvement through eco-labelling systems, which are so extended in the travel and tourism sector (Buckley, 2002).

Due to the exponential growth of the global tourism sector, its consumption and the level of impact on the environment, it is needed an urgent response to lead tourism towards a sustainable sector (Puig et al., 2017). This transformation requires an interdisciplinary approach to its implementation, such as international, national and local policies, investments in marketing, communication and digitalisation, strong partnerships between governments and tourism businesses, as well as the incorporation of environmental education to increase awareness in society. It would also be important to promote the motivation of green practices (efficient use of energy and water and integrated waste management).

In recent years, it has been observed that neither responsible travel behavior nor technological improvements have been able to curb the increase of the CF of tourism (Lenzen et al., 2018). Therefore, there are major challenges to achieve true sustainable goals. One of them focuses on the assessment of policies and feedback systems that check the behaviors of tourism businesses and tourists by means of generalised rules. Another challenge is focused on the introduction of innovative technologies using hybrid renewable energy systems for tourism and it could also be linked to public transport. In order to achieve sustainable mobility for the tourism sector, it is required to improve existing public transport and to choose electric or hybrid cars. Also, carbon taxes could be imposed on tourists driving their own vehicles to ensure the use of public transport. These taxes could also be applied to aviation services to curb the uncontrolled growth of tourism-related emissions (Pan et al., 2018). However, low-carbon technologies and smart mobility management can improve the environmental performance of tourism travel, but it will not be enough to achieve the climate targets of the Paris Agreement. To reduce significantly the GHG emissions associated with travel, tourism can not only rely on technological solutions (electric or hybrid vehicles) and social trends of vehicle sharing, but must also initiate a switch from air and private road transport to rail and public transport. The awareness created by the COVID-19 crisis and the climate crisis can be considered an opportunity to take these measures (Gühnemann et al., 2021).

Finally, the COVID-19 pandemic has caused unprecedented socioeconomic impacts and at the same time, it has demonstrated the crucial role that sustainability plays in societies. Travel restrictions and a heavy fall in demand for tourism services have caused that tourism-related businesses to face large economic falls and, even, the closure of many of them in the absence of government support (Khalid et al., 2021). Against this background, tourism-dependent countries should establish the necessary conditions for the domestic tourism sector to serve as a buffer for the whole industry, instead of depending as much on international tourism. Furthermore, in the post-COVID-19 period, it is expected that a sustainable recovery of the economy (economic recovery), the health of society and the environment (reduced level of GHG emissions) will be achieved for both tourism stakeholders and society (Kitamura et al., 2020).

After the health crisis, tourism faces the greatest challenge in a generation to improve and recover the sector. The speed of change that the tourism sector is undergoing globally means that the current processes of scientific production and innovation must be accelerated. For this reason, the Smart Destination Platform is being developed, which aims to support the digitalisation of the tourism experience and service integration, connecting tourists, destinations and businesses and serving as a digital ecosystem for "Smart Tourism Destinations" (STD) (Shafiee et al., 2019). In short, the creation of synergies and combined actions under the STD model and the STD Network is needed in order to develop the capacities and opportunities detected after the Post-COVID period. It is also necessary to improve the availability of information in the different areas of tourism R + D + i, so that the innovative nature of the sector and the specific needs of its companies and destinations can be better understood. In this way, LCA could help to implement digitalisation in the tourism sector.

At the same time, the COVID-19 pandemic has made more complex the sustainable use of plastics in many tourism destinations and enterprises. Due to inappropriate disposal and management of plastic waste (gloves, masks and hand sanitizer bottles), an invasion of this waste has already been reported in the natural environments of major tourist destinations, leading to a loss of natural heritage. In the face of this major problem, circular principles such as reuse for single-use products offer credible alternative solutions such as an increased traceability. In this sense, innovation continues to ramp up as the world seeks solutions to plastic pollution where eco-labelling is essential to achieve this.

The implementation of these measures along the life cycle of tourism activities implies significant changes in both companies' processes and consumer behaviors. This requires developing public policies and regulations fostering environmental sustainability, but also communication campaigns aimed to persuade managers and tourists of the need of assuming the costs and drawbacks of environmental measures. In this regards, the post-pandemic context is a great opportunity since consumers are increasingly adopting and supporting pro-environmental services and companies, even though their cost is higher. From the side of companies, the growing environmental consciousness of

consumers can be highlighted as a market reason to undertake the cost and investments needed to offer a more sustainable service. In this context, ecolabels and environmental certifications should become a key tool to launch a signal to the market, highlighting the environmental commitment of the company or destination (Martínez et al., 2019a, 2019b). Finally, the implementation of these environmental measures should lead to an increase of residents' support to tourism development, as they are fundamental for the sustainability of local communities. In conclusion, reactivating tourism in a responsible way requires future actions based on an approach to support governments, enterprises and local communities to achieve sustainable goals in line with hygiene and health protocols (UNWTO, 2020b).

6. Conclusions

The tourism sector faces a major challenge in reducing GHG emissions due to the insatiable demand for travelling and the industry's desire to stimulate that demand. In response, researchers, organisations and policy makers are striving to develop concepts and metrics to measure environmental sustainability. Among those concepts and metrics, LCA is one of the most promising tools that can solve some of the drawbacks of existing environmental approaches and it has become a key target for tourism, as shown by the growing number of studies on tourism in recent years.

The review of the 83 papers (77 articles and 6 international reports) showed that, since 2004, there has been an increase in the number of articles using LCA to assess the environmental impact of tourism. Since 2017, there has been an exponential progression until now. In particular, 94 % of the articles focusing on LCA are from the last decade. Furthermore, the regions in which this methodology was considered were limited to developed countries, with a large proportion of studies focusing on Asia, with the vast majority located in China, followed by regions in Europe and Oceania, which gives an idea of the degree of concern and knowledge of sustainable tourism and the LCA tool in these regions. Regarding the characterisation of the systems, most of the articles addressed the accommodation, lunch and transport stages in the study phases of the tourism sector. In addition, the most common UF in the studies was “Per guest night” or “Per visitor”. It should also be noted that the CML 2001 was the most used method and the CF was the most common environmental indicator for assessing the environmental impacts of the tourism sector. Also, GWP was the most studied impact category due to its strong influence and importance in the sector. Moreover, in the last year, the number of studies taking into account the impact of COVID-19 has increased and is considered a turning point for the reduction of carbon emissions for the integration of policies and strategies in the framework of sustainable tourism.

Answering to the broad paradigm of sustainability, this paper quantifies the articles that consider the three dimensions of sustainability. Specifically, 21 % of the articles studied already apply the commitment between environmental, economic and social variables that is optimal in a defined space and time frame in order to achieve sustainable tourism as marked by international institutions such as UNWTO and other governmental entities.

Finally, this review also examines some of the strategies that are currently being implemented to achieve sustainability in tourism, such as the use of eco-labelling, digitalisation and good practices by tourists. These strategies will help both public administration and tourists to make more sustainable tourism choices. Definitely, the awareness created by the COVID-19 crisis and the climate crisis can be considered an opportunity to take these measures.

Further work is recommended and it can be oriented to study in depth the socio-economic variable of the tourism sector in order to have a more detailed knowledge of the models used in these areas of sustainability.

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CRediT authorship contribution statement

Cristina Campos Herrero: Software, Investigation, Writing – original draft. **Jara Laso:** Data curation, Visualization. **Jorge Cristóbal:** Visualization. **Pere Fullana-i-Palmer:** Funding acquisition. **Jaume Albertí:** Formal analysis. **Margalida Fullana:** Formal analysis. **Ángel Herrero:** Data curation, Writing – review & editing. **María Margallo:** Conceptualization, Methodology, Resources, Supervision, Project administration. **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.

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Abbreviations

AP	Acidification
CF	Carbon Footprint
DEFRA	Department for Environment, Food and Rural Affairs
EC	Earth Council
EEIO	Environmentally Extended Input-Output Model
EF	Ecological Footprint
EFA	Ecological Footprint Analysis
EP	Eutrophication
EU	European Union
FAETP	Freshwater Aquatic Ecotoxicity
FOP	Photochemical Ozone Creation
FU	Functional unit
GDP	Gross domestic product
GHG	Greenhouse gases
GTSCM	Green tourism supply chain management
GWP	Global Warming Potential
HTP	Human Toxicity
IOA	Input-output analysis
IOTs	Input-output tables
ISO	International Organisation for Standardization
ITF	International Transport Forum
ITR	Responsible Tourism Institute
LCA	Life Cycle Assessment
LCEA	Life Cycle Energy Analysis
LCI	Life cycle inventory
MAETP	Marine Aquatic Ecotoxicity
PCR	Product category rule
ODP	Ozone Layer Depletion
SDGs	Sustainable Development Goals
TCQ2000	Cost Estimates and Technical Conditions
TCQGMA	Module for Environmental Management
TECI	Tourism Environmental Composite Indicator
TETP	Terrestrial Ecotoxicity
TSA	Tourism Satellite Account
UN	United Nations Organization
UNEP	United Nations Environment Programme
UNWTO	World Tourism Organization
WMO	World Meteorological Organization

WF Water footprint
WTTC World Travel & Tourism Council

References

Baumber, A., Merson, J., Lockhart, C., 2021. Promoting low-carbon tourism through adaptive regional certification. Climate 9 (1), 1–22.

Barget, E., Gouguet, J.J., 2012. The impact on tourism of mega-sporting events: the stakes of foreign spectators. Tour. Rev. Int. 16 (1), 75–81.

Biosphere, 2020. Biosphere Certification: a commitment to sustainable tourism, online. Available on https://www.biospheretourism.com/es/certificacion-biosphere/83. (Accessed 28 January 2022).

Bramwell, B., Lane, B., 2012. Towards innovation in sustainable tourism research? J. Sustain. Tour. 20, 1–7.

Buckley, R., 2002. Tourism ecolabels. Ann. Tour. Res. 29 (1), 183–208.

Cadarso, M.A., Gómez, N., López, L.A., Tobarra, M.A., Zafrilla, J.E., 2015. Quantifying Spanish tourism's carbon footprint: the contributions of residents and visitors. A longitudinal study. J. Sustain. Tour. 23 (6), 922–946.

Cadarso, M., Gómez, N., López, L.A., Tobarra, M., 2016. Calculating tourism's carbon footprint: measuring the impact of investments. J. Clean. Prod. 111, 529–537.

Candia, S., Pirlone, F., 2022. Tourism environmental impacts assessment to guide public authorities towards sustainable choices for the post-COVID era. Sustainability 14, 18.

Cerutti, A.K., Beccaro, Gabriele L., Bruun, S., Donno, D., Bonvegna, L., Bounous, G., 2016. Assessment methods for sustainable tourism declarations: the case of holiday farms. J. Clean. Prod. 111, 511–519.

Chaiyat, N., Chaongew, S., Ondokmai, P., Makarkard, P., 2020. Levelized energy and exergy costings per life cycle assessment of a combined cooling, heating, power and tourism system of the San Kamphaeng hot spring,Thailand. Renew. Energy 146, 828–842.

Chan, E.S.W., Hsu, C.H.C., 2016. Environmental management research in hospitality. Int. J. Hosp. Manag. 28 (5), 886–923.

De Camillis, C., Raggi, A., Petti, L., 2010a. Tourism LCA: state-of-the-art and perspectives. Int. J. Life Cycle Assess. 15 (2), 148–155.

De Camillis, C., Raggi, A., Petti, L., 2010b. Life cycle assessment in the framework of sustainable tourism: a preliminary examination of its effectiveness and challenges. Prog. Ind. Ecol. 7 (3), 205–218.

De Camillis, C., Peeters, P., Petti, L., Raggi, A., 2012. Tourism Life Cycle Assessment (LCA): Proposal of a new methodological framework for sustainable consumption and production in visions for global tourism industry. Creat. Sustain. Compet. 248–268.

Díaz, F.J., Chinarro, D., Guardiola, A., Díaz, R., Pino, M.R., 2019. Comparative study of carbon footprint of energy and water in hotels of Canary Islands regarding mainland Spain. Environ. Dev. Sustain. 21 (4), 1763–1780.

DEFRA, 2008. A Research Report for the Department for Environment, Food and Rural Affairs by the Stockholm Environment Institute and the University of Minnesota. Report. Department for Environment, Food and Rural Affairs.

De Grosbois, D., Fennell, D., 2011. Carbon footprint of the global hotel companies: Comparison of methodologies and results. Tour. Recreat. Res. 36 (3), 231–245.

Dorta, P., Díaz, J., López, A., Bethencourt, C., 2021. Tourism, transport and climate change: the carbon footprint of international air traffic on islands. Sustainability 13 (4), 1795.

Dwyer, L., Spurr, R., Forsyth, P., Hoque, S., 2015. Tourism And the Implications of Climate Change: Issues And Actions. 3, pp. 187–202.

El Hanandeh, A., 2013. Quantifying the carbon footprint of religious tourism: the case of Hajj. J. Clean. Prod. 52, 53–60.

Eluwole, K.K., Akadiri, S.S., Alola, A.A., Etokakpan, M.U., 2020. Does the interaction between growth determinants a drive for global environmental sustainability? Evidence from world top 10 pollutant emissions countries. Sci. Total Environ. 705, 135972.

European Commission, 2009. Commission Decision of 9th July 2009 establishing the ecological criteria for the award of the Community eco-label for tourist accommodation service. Available onOfficial Journal of the European Union. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:208:0021:0038:EN:PDF. (Accessed 11 July 2021).

European Parliament, 2021. EU Strategy for Sustainable Tourism: European Parliament Resolution of 25 March 2021 on Establishing an EU Strategy for Sustainable Tourism (2020/2038(INI)). Report.

FEE, 2011. Blue Flag 2011. Foundation for Environmental Education, Copenhagen, Denmark Available on: https://www.fee.global/ (Accessed on 10 November 2021).

Filimonau, V., Dickinson, J.E., Robbins, D., Reddy, M.V., 2011a. A critical review of methods for tourism climate change appraisal: life cycle assessment as a new approach. J. Sustain. Tour. 19 (3), 301–324.

Filimonau, V., Dickinson, J., Robbins, D., Huijbregts, M.A.J., 2011b. Reviewing the carbon footprint analysis of hotels: Life Cycle Energy Analysis (LCEA) as a holistic method for carbon impact appraisal of tourist accommodation. J. Clean. Prod. 19, 1917–1930.

Filimonau, V., Dickinson, J., Robbins, D., Reddy, M.V., 2013. The role of 'indirect' greenhouse gas emissions in tourism: assessing the hidden carbon impacts from a holiday package tour. Transp. Res. A Policy Pract. 54, 78–91.

Filimonau, V., 2016. Life Cycle Assessment (LCA) And Life Cycle Analysis in Tourism A Critical Review of Applications And Implications. First ed. Springer Faculty of Management Bournemouth University, Poole, UK.

Foolmaun, R.K., Ramjeeawon, T., 2012. Disposal of post-consumer polyethylene terephthalate (PET) bottles: comparison of five disposal alternatives in the small island state of Mauritius using a life cycle assessment tool. Environ. Technol. 33 (5), 563–572.

Gössling, S., Peeters, P., Ceron, J.P., Dubois, G., Patterson, T., Richardson, R.B., 2005. The eco-efficiency of tourism. Ecol. Econ. 54 (4), 417–434.

Greiff, K., Teubler, J., Baedeker, C., Liedtke, C., Rohn, H., 2016. Material and carbon footprint of household activities in living labs: design and assessment of sustainable living, pp. 259–275.

Gühnemann, A., Kurzweil, A., Mailer, M., 2021. Tourism mobility and climate change - a review of the situation in Austria. J. Outdoor Recreat. Tour. 100382.

Hares, A., Dickinson, J., Wilkes, K., 2010. Climate change and the air travel decisions of UK tourists. J. Transp. Geograph. 18 (3), 466–473.

Hu, A.H., Huang, C.Y., Chen, C.F., Kuo, C.H., Hsu, Chia Wei, 2015. Assessing carbon footprint in the life cycle of accommodation services: the case of an international tourist hotel. Int. J. Sustain. Dev. World Ecol. 22 (4), 313–323.

International Energy Agency, 2020. Global Energy Review 2020: The Impacts of the COVID-19 Crisis on Global Energy Demand And CO2 Emissions. Report.

ISO 14044, 2006. Environmental Management - Life Cycle Assessment - Principles And Framework. International Organisation for Standardisation, Geneva, Switzerland.

ISO 14024, 1999. Environmental Labels And Declarations — Type I Environmental Labelling — Principles And Procedures. International Organisation for Standardisation, Geneva, Switzerland.

ISO 14067, 2013. Greenhouse Gases — Carbon Footprint of Products — Requirements And Guidelines for Quantification And Communication Report.

Juvan, E., Dolnicar, S., 2014. Can tourists easily choose a low carbon footprint vacation? J. Sustain. Tour. 22 (2), 175–194.

Khalid, U., Okafor, L.E., Burzynska, K., 2021. Does the size of the tourism sector influence the economic policy response to the COVID-19 pandemic? Curr. Issues Tour. 24 (19), 2801–2820.

Kitamura, Y., Karkour, S., Ichisugi, Y., Itsubo, N., 2020c. Evaluation of the economic, environmental, and social impacts of the COVID-19 pandemic on the Japanese tourism industry. Sustainability 12 (24), 1–21.

Knörr, W., 2008. EcoPassenger: Environmental Methodology And Data. Institute for Energy and Environmental Research, Heidelberg, Germany Report.

König, H., Schmidberger, E., De Cristofaro, L., 2007. Life Cycle Assessment of a tourism resort with renewable materials and traditional construction techniques in Portugal. Sustainable Construction, Materials And Practices: Challenge of the Industry for the New Millenium's Conference, p. 8.

Kuo, N.W., Chen, P.H., 2009. Quantifying energy use, carbon dioxide emission, and other environmental loads from island tourism based on a life cycle assessment approach. J. Clean. Prod. 17 (15), 1324–1330.

Lenzen, M., Sun, Y.Y., Faturay, F., Ting, Y.P., Geschke, A., Malik, A., 2018. The carbon footprint of global tourism. Nat. Clim. Chang. 8 (6), 522–528.

Luo, Y., Mou, Y., Wang, Z., Su, Z., Qin, Y., 2020. Scenario-based planning for a dynamic tourism system with carbon footprint analysis: a case study of Xingwen Global Geopark, China. J. Clean Prod. 254, 119999.

Mancini, M.S., Galli, A., Niccolucci, V., Lin, D., Bastianoni, S., Wackernagel, M., Marchettini, N., 2016. Ecological footprint: refining the carbon footprint calculation. Ecol. Indic. 6, 390–403.

Martínez, P., Herrero, A., Gómez, R., 2019a. Corporate images and customer behavioral intentions in an environmentally certified context: promoting environmental sustainability in the hospitality industry. Corp. Soc. Responsib. Environ. Manag. 26 (6), 1382–1391.

Martínez, P., Herrero, A., Gómez, R., 2019b. The role of environmental CSR practices on the formation of behavioral intentions in a certified hotel context: exploring the moderating effect of customer involvement in the buying process. Span. J. Mark. 23 (2), 205–226.

Maugeri, E., Gullo, E., Romano, P., Spedalieri, F., Licciardello, A., 2017. The bioeconomy in Sicily: new green marketing strategies applied to the sustainable tourism sector. Eng. Manag. 4 (3), 133–142.

Michailidou, A.V., Vlachokostas, C., Moussiopoulos, N., 2015. A methodology to assess the overall environmental pressure attributed to tourism areas: a combined approach for typical all-sized hotels in Chalkidiki,Greece. Ecol. Indic. 50, 109–119.

Michailidou, A.V., Vlachokostas, C., Moussiopoulos, N., Maleka, D., 2016a. Life cycle thinking used for assessing the environmental impacts of tourism activity for a Greek tourism destination. J. Clean. Prod. 111, 499–510.

Michailidou, A.V., Vlachokostas, C., Achillas, C., Maleka, D., Moussiopoulos, N., Feleki, E., 2016b. Green tourism supply chain management based on life cycle impact assessment. Environ. Sci. Eur. 6 (1), 30–36.

Ministry of Industry, Trade and Tourism, 2019. Spain's Sustainable Tourism Strategy 2030: General guidelines of the sustainable tourism strategy, Spain 2030. Available on https://turismo.gob.es/es-es/estrategia-turismo-sostenible/Documents/directrices-estrategia-turismo-sostenible.pdf. (Accessed 11 May 2021).

Moscardo, G., 2017. Building excellence in sustainable tourism: 15 years of Building Excellence in Sustainable Tourism Education Network (BEST EN) practice. J. Clean. Prod. 111, 538–539.

Pan, S.Y., Gao, M., Kim, H., Shah, K.J., Pei, S.L., Chiang, P.C., 2018. Advances and challenges in sustainable tourismtoward a green economy. Sci. Total Environ. 635, 452–469.

Pennington, D.W., Potting, J., Finnveden, G., Lindeijer, E., 2004. Life cycle assessment part 2: current impact assessment practice. Environ. Int. 30, 721–739.

Pereira, R.P.T., Ribeiro, G.M., Filimonau, V., 2017. The carbon footprint appraisal of local visitor travel in Brazil: a case of the Rio de Janeiro-São Paulo itinerary. J. Clean. Prod. 141, 256–266.

Puig, R., Kiliç, E., Navarro, A., Albertí, J., Chacón, L., Fullana-i-Palmer, P., 2017. Inventory analysis and carbon footprint of coastland-hotel services: a Spanish case study. Sci. Total Environ. 595, 244–254.

Raggi, A., Petti, L., 2006. A newly developed integrated environment quality approach for the design of hotel services. Prog. Ind. Ecol. 3 (3), 251–271.

Retno Susilorini, Rr.M.I., Ismail, A., Arya Wastunimpuna, B.Y., Wardhani, D.K., Nola Prameswari, L.L., Amasto, A.H., Suryono, A., 2022. Tourism village carbon footprint after COVID-19 pandemic: a challenge to sustainability. Sustainability 14, 2400.

Rico, A., Martínez-Blanco, J., Montlleó, M., Rodríguez, G., Tavares, N., Arias, A., Oliver-Solà, J., 2019. Carbon footprint of tourism in Barcelona. Tour. Manag. 70, 491–504.

Rodríguez-Pérez, M.L., Mendieta-Pino, C.A., Ramos-Martín, A., León-Zerpa, F.A., Déniz-Quintana, F.A., 2022. Inventory of water–energy–waste resources in rural houses in

Gran Canaria Island: application and potential of renewable resources and mitigation of carbon footprint and GHG. Water 14, 1197.
Rosselló-Batle, B., Moià, A., Cladera, A., Martínez, V., 2010. Energy use, CO2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands. Energy Build. 42 (4), 547–558.
Santana, M.V.E., Cornejo, P.K., Rodríguez-Roda, I., Buttiglieri, G., Corominas, L., 2019. Holistic life cycle assessment of water reuse in a tourist-based community. J. Clean. Prod. 233, 743–752.
Shafiee, S., Rajabzadeh Ghatari, A., Hasanzadeh, A., Jahanyan, S., 2019. Developing a model for sustainable smart tourism destinations: a systematic review. Tour. Manag. Perspect. 31, 287–300.
Scheepens, A.E., Vogtländer, J.G., Brezet, J.C., 2016. Two LCA based methods to analyse and design complex (regional) circular economy systems. Case: making water tourism more sustainable. J. Clean. Prod. 114, 257–268.
Sharp, H., Grundius, J., Heinonen, J., 2016. Carbon footprint of inbound tourism to Iceland: a consumption-based life-cycle assessment including direct and indirect emissions. Sustainability 8 (11), 1147.
Sloan, P., Legrand, W., Tooman, H., Fendt, J., 2009. Best practices in sustainability: German and Estonian hotels, in Chen. Advances in Hospitality And Leisure. 5, pp. 89–107.
Sun, Y.Y., Pratt, S., 2014. The economic, carbon emission, and water impacts of Chinese visitors to Taiwan: eco-efficiency and impact evaluation. J. Travel Res. 53 (6), 733–746.
Sun, R.H., Ye, X.L., Gao, J., Zhu, Z.F., Du, J., 2019. Study on carbon footprint and spatial distribution characteristics of human activities in Jiuzhai Valley scenic area. Appl. Ecol. Environ. Res. 17 (4), 7477–7493.
Solé, A., Miró, L., Cabeza, L.F., 2018. Environmental approach. High-temperature Thermal Storage Systems Using Phase Change Materials, pp. 277–295.
TOURLINK, 2004. Travelife, Sustainability in Tourism: demonstrating how an integrated ecolabeling and tour operating supply chain management strategy can foster sustainability in tourism. Available on https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=2697. (Accessed 5 January 2022).
TOURBENCH, 2003. European monitor and benchmarking initiative for environmental impacts and costs in tourist accommodation. Available on https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=2348. (Accessed 20 May 2022).
UNWTO, 2008. Climate change and tourism. Second International Conference on Climate Change And Tourism. Report.
UNWTO, 2019a. International tourism highlights. Available on https://www.e-unwto.org/doi/pdf/10.18111/9789284421152. (Accessed 27 January 2022).
UNWTO, 2019b. Tourism's carbon emissions measured in landmark report launched at COP25. Available on https://www.unwto.org/news/tourisms-carbon-emissions-measured-in-landmark-report-launched-at-cop25. (Accessed 3 May 2022).
UNWTO, 2020a. UNWTO adapts agenda for Africa to accelerate tourism recovery. Available on https://www.unwto.org/es/news/omt-adapta-la-agenda-para-africa-a-fin-de-acelerar-la-recuperacion-turistica. (Accessed 11 March 2021).
UNWTO, 2020b. Recommendations for the tourism sector to continue taking action on plastic pollution during COVID-19 recovery. Available on https://wedocs.unep.org/bitstream/handle/20.500.11822/33240/PPCOVID.pdf?sequence=1. (Accessed 19 January 2022).
UNWTO, 2021a. Tourism in the 2030 agenda. Available on https://www.unwto.org/tourism-in-2030-agenda. (Accessed 11 September 2021).
UNWTO, 2021b. African tourism leaders identify investment as key to sustainable recovery. Available on https://www.unwto.org/es/news/los-lideres-en-turismo-de-africa-identifican-las-inversiones-como-la-clave-para-una-recuperacion-sostenible. (Accessed 11 May 2021).
UNWTO, 2021c. World Tourism Barometer and Statistical Annex. Vaccines and reopen borders driving tourism's recovery. Available on https://www.unwto.org/taxonomy/term/347. (Accessed 11 July 2021).
Weir, B., 2017. Climate change and tourism – are we forgetting lessons from the past? J. Hosp. Tour. Manag. 32, 108–114.
Wicker, P., 2018. The carbon footprint of active sport tourists: An empirical analysis of skiers and boarders. J. Sport Tour. 22 (2) , 151–171.
World Travel and Tourism Council (WTTC), 2021. Travel And Tourism Economic Impact, Global Economic Impact And Trends 2021. Report.
World Tourism Organization, International Transport Forum, 2019m. Transport-related CO2 Emissions of the Tourism Sector – Modelling Results. Report. Available on.