IN SEARCH OF THE DESIRED SUSTAINABLE TOURISM: A REVIEW OF LIFE CYCLE ASSESSMENT (LCA) TOURISM STUDIES

CRISTINA CAMPOS HERRERO[1], JARA LASO[1], PERE FULLANA-I-PALMER[2], JAUME ALBERTÍ[2], MARGALIDA FULLANA[2], ÁNGEL HERRERO[3], MARÍA MARGALLO[1] & RUBÉN ALDACO[1]
[1]Department of Chemical and Biomolecular Engineering, University of Cantabria, Spain
[2]UNESCO Chair in Life Cycle and Climate Change ESCI-UPF, Spain
[3]Department of Business and Administration, University of Cantabria, Spain

ABSTRACT
Sustainable tourism should be promoted as a new system for the sustainable management of resources from a socioeconomic and environmental point of view. For this purpose, it is necessary to develop a tool capable of assessing the impacts associated with each of the stages of the sector and to identify which actions are currently being addressed in the tourism sector in order to achieve the desired sustainability in the sector. 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, 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 the functional unit and system boundaries considered. The study identifies key recommendations on the progression of LCA for this increasingly important sustaining tourism sector. As important results, it stands out that 94% of articles focused on LCA methodology were from the last decade and almost 26% of the articles reviewed cover sustainable tourism term, considering environmental, social and economic aspects. Specifically, LCA is a highly effective tool capable of assessing direct and indirect carbon emissions at all stages of the activity as well as the socioeconomic and environmental impacts generated in the tourism sector. This review showed that the most common environmental indicator in the LCA methodology is the carbon footprint. 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.
Keywords: life cycle assessment, sustainable tourism, eco-labelling, COVID-19, carbon footprint.

1 INTRODUCTION

Tourism is one of the most important sectors in the global economy, which has been growing steadily over the recent decades and whose forecasts for the coming years predict a strengthening of this trend [1]. This competitive and dynamic industry on a global scale, employs millions of people, moves billions of dollars, and generates and induces technological innovation. In fact, in 2019, the tourism industry generated more than USD 236 billion, surpassing oil exports and food production in terms of business turnover) [2]. However, 2020 and 2021 have been the worst years on record for tourism, which has been one of the hardest hit economic sectors by the COVID-19 pandemic, facing a decline in international tourist arrivals during 2020 of between 58% and 78%, 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, cutting the overall value of world exports by more than 4% in 2020. The total loss of international tourism export earnings amounts to almost US$ 1.1 trillion. Asia–Pacific (–70% in real terms) and the Middle East (–69%) recorded the largest revenue declines [3]. Then, in the first quarter of 2021, international arrivals were 83% lower (180 million fewer arrivals).

Indeed, tourism is today's most significant and important industry [4], with the greatest environmental impact. Between 2009 and 2013, the global carbon footprint (CF) of tourism increased from 3.9 to 4.5 gigatonnes of carbon dioxide equivalent and this growth accounted for around 8% of global carbon emissions, with transport, shopping and food being the main contributors [5]. Around 2.4% of global CO_2 emissions come from aviation, being one of the most polluting activities in tourism [6]. Despite all this, one positive outcome of the pandemic crisis was a reduction in emissions and improvements in air quality. Furthermore, global carbon emissions in 2020 are estimated to have fallen by 8% in tourism sector [7]. Therefore, the need to transform the operation of the tourism sector towards sustainable tourism remains indispensable for the sector to continue to grow towards international targets and a great opportunity for the tourism sector [8].

Sustainable tourism is widely recognized as the only solution to large-scale tourism's negative effects [9]. According to United Nations Environment Programme (UNEP) and the United Nations World Tourism Organization (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. In fact, tourism development should refer to sustainable development that aims at continuous improvement of tourist satisfaction [9]. A holistic balance between three dimensions (environmental, economic, socio-cultural) must be considered to try 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 [10]. These three dimensions have key elements such as ecotourism, rural tourism, cultural tourism (heritage), community tourism, as well as policies that implement the circular economy in sustainable tourism [11]. Tourism has been identified by UNEP as one of the ten economic sectors capable of contributing to the transition to a sustainable and inclusive green economy [12].

Emphasis has been given to existing research on the carbon footprint of tourism, as climate change has recently become a key issue on the international tourism policy agenda [13]. But the question is how to measure and reduce the environmental burdens of this sector. Recently, researchers, organisations and policy makers are striving to develop concepts and metrics that measure environmental sustainability. Among these concepts and metrics, life cycle assessment (LCA) is a methodology for quantifying the environmental impacts of a product, process, or service over the course of its entire life cycle [4]. 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 as well as its efficacy in identifying opportunities for improving environmental performance and defining sustainability strategies for tourism [14]. Currently, very few articles have focused exclusively on LCA methodology and tourism, as most of them are combined with other methods. Some studies such as Maugeri et al. [15] assessed by LCA a trip and overnight stay in a hotel during mid-season with the arrival and departure of the tourist at Fontanarossa Airport in Catania, Sicily. Others like De Camillis et al. [16] use the LCA methodology in order to assess the environmental impacts in a three-star hotel located in Pescara, Italy. In this paper, a quantification of current LCA studies in the tourism sector is given. From all the environmental indicators and impact categories, global warming potential has been widely analyzed, being used as a proxy for the entire set of impact categories [17]. Fig. 1 displays

the conceptual aspects required for achieving sustainable tourism as well as the carbon emissions associated with tourism before and after the COVID-19 pandemic.
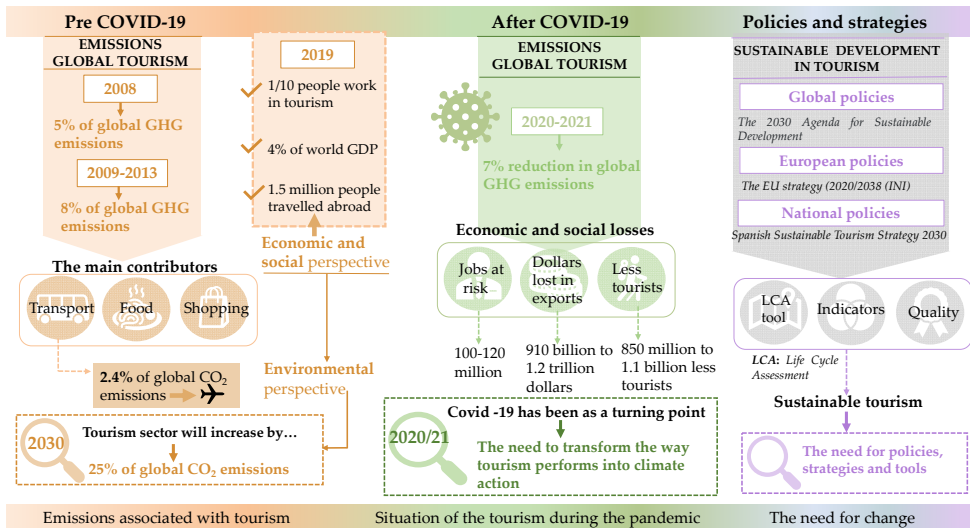

Figure 1:   Conceptual aspects for sustainable tourism. Greenhouse gas (GHG) emissions associated with tourism before and after the pandemic and policies and strategies for achieving sustainable tourism, being GHG and gross domestic product.

In this context, the main objective of this paper is to review the impact assessment methods and impact categories evaluated to the most appropriate combination to evaluate the environmental performance of tourism. As a result of the review of the articles, the most appropriate system is identified, which contributes to and advances the development of future environmental tourism saving the process of studying and selecting the optimum model. Moreover, as a secondary objective, this systematic review intends to contribute to a better understanding of sustainable tourism by compiling articles based not only on environmental but also on socio-economic aspects. To the best of our knowledge, the awareness created by COVID-19 and the climate crises have served as a new opportunity to change the current tourism model towards sustainable tourism.

2 MATERIALS AND METHODS

2.1 Literature search strategy and inclusion criteria

This review seeks to address the most relevant studies based on LCA methodology with the purpose of assessing environmental impacts and achieving global sustainable tourism. Searches of different sources of scientific literature, books and reports were included. Also, the Scopus database and other tourism sector specific databases such as the UNWTO were accessed. In addition, Google Scholar was also reviewed as a search engine. The definition of the scope made it possible to eliminate those documents that did not fit the object of the review. The review excluded studies that did not address tourism and that did not apply any type of environmental methodology such as LCA. Also, they were excluded those articles

dealing with social issues, as tourism hospitality [18], sustainability of cities [19] or studies focused exclusively on tourist data [10]. In the same way, we discarded studies that used LCA methodology but they are focused on other sectors such as transport or buildings [20], or on other aspects like the use of plastic bottles in different cities [21].

For the bibliographic search, a classification of the documents was made by considering the LCA approach in the tourism sector. Furthermore, the CF indicator was considered as an environmental indicator due to its wide use in this field. The literature review was performed through a precise search in the Scopus database. Likewise, a bibliographic search was also made of those documents that deal tourism and LCA tool and CF indicator to the health pandemic suffered in 2020. Websites of international governmental organizations such as the UNWTO, the United Nations Conference on Trade and Development (UNCTAD), and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) and United Nations Organization (UN) were also used. Fig. 2 shows an overview of the steps to identify and classify the studies.
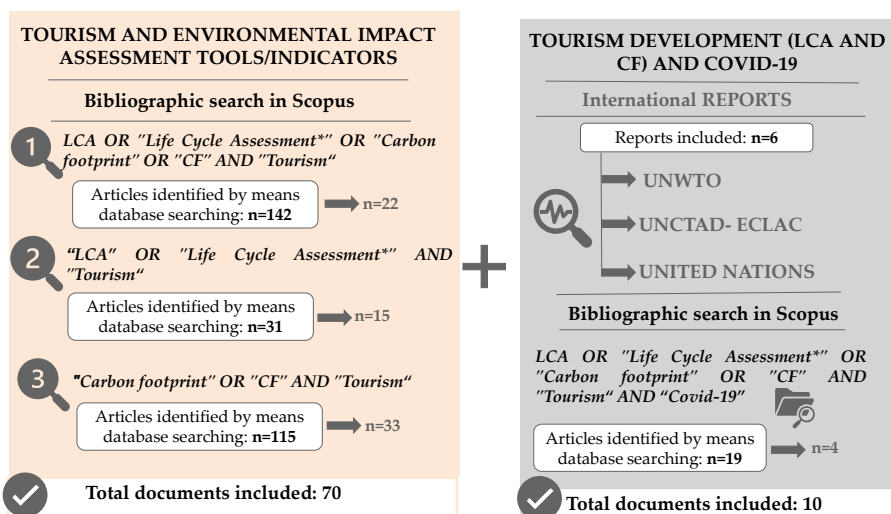

Figure 2: Schematic diagram of the steps followed in the bibliographic search.

2.2 Analysis of study findings

Each article of this review was assessed independently to identify the objective, the methodology followed and the conclusions. The following characteristics were analyzed in each article: phases of the system boundaries which leads to a delimitation of the different processes of the system under examination [22], functional unit (FU), the method used and impact categories studied. According to De Camillis et al. [23], these characteristics should be considered when developing this type of studies. The 4 characteristics analysed were:

(i)   The choice of system boundaries so as to determine which process units will be included in the LCA study [24]. There are three options in this case: (a) *cradle to gate*, which considers stages from raw material extraction to transport use, accommodation, restaurants and leisure activities [25], (b) *cradle to grave*, which also examines the final disposal of waste [26], and (c) separate systems such as air transport used in tourism,

hotels as an example of accommodation, restaurants or sport tourism as a leisure activity. The first two options consider a complete travel package while the third one examines only one of the sectors.

(ii) The second point to take into account is the FU, which is the reference unit on which all inputs and outputs of the system are based [24]. The FU for transport and tourism activities are well established and they can be defined as "1 passenger per kilometre driven" and "1 visitor activity performed" [27]. However, for a hotel stay, no consensus has yet been reached. Some studies use "per guest night" [28] following the PAS 2050:2011 standards. And in this case the carbon intensity of hotel operations is described on a "per capita" or "per user" basis. Another option is to consider the gross floor area of the hotel, such as "m^2 of the floor area" which considers energy and CF analysis [29]. On the other hand, if the whole trip is considered, the most common FU are "per trip" [30] or "one week of a holiday" [31]. In a large number of studies, the FU is not clearly defined and hinders the impact assessment process.

(iii) The third point is to consider the impact method applied. There are several methods for the LCA of tourism among which the CML-2001 developed by the University of Leiden stands out. This method groups life cycle inventory (LCI) results into midpoint categories by themes (e.g. climate change or ecological toxicity) [32]; the Eco-Indicator 99 developed by PRé Consultants that considers the environmental damage in human health, ecosystem quality and resources [33]; or the EDIP 1997 developed by the Institute for Product Development (IPU) at the Technical University of Denmark that uses a midpoint approach [32]. In other cases, the CF (an environmental indicator that measures total greenhouse gases) or the ecological footprint (EF) (based on resource consumption and waste production) [34] are used as tools to assess the impacts of tourism. There are also other environmental indicators such as Water Footprint (WF), Ecological Footprint (EF), the DEFRA (Food and Rural Affairs) [35], the TECI (Tourism Environmental Composite Indicator) [36] the TCQGMA (Environmental Management Module) [37] and the eco-efficiency model [38]. These indicators are more specific (in terms of the scope of geographical areas and tourism sub-sectors) and not as generic as the CF, so the use of these indicators is more limited in the tourism sector. In addition to these environmental methods, others consider economic and statistical aspects such as Input–Output analysis (IO) and Tourism Satellite Account (TSA) that can be combined with LCA or CF [39].

(iv) Finally, in relation to impact categories, the most frequently selected impact category in tourism LCAs is usually Global Warming Potential (GWP) in units of CO_2 eq. as this impact category is closely associated with the CF indicator, which is one of the important points of study in this review. The GWP impact category is sometimes combined with other impact categories such as acidification, eutrophication or ecotoxicity, depending on the scope of the study [40].

3 RESULTS AND DISCUSSION

3.1 Mapping and time evolution of the studies

A total of 80 documents were reviewed; 70 articles related to the tourism sector using LCA tool and/or CF environmental indicator, four articles addressing the situation of the tourism sector following these methodologies during the COVID-19 crisis and six reports.

Fig. 3 shows the location of the research institutions of the different studies that participated in the evaluated studies. Only the original articles were included in this figure,

except for Lenzen et al. [5] because it refers to many countries and not one or two specific ones The reports were also not included in the figure taking into account they refer to large regions rather than specific countries. The icons represent the countries in which only LCA approach has been developed in the tourism sector, along with the number of studies conducted, while the coloured areas illustrate the territories where CF studies, or LCA and CF combined studies related to their application were conducted. Studies addressing the development of LCA tool focused on Asia (50%), Europe (43%) and Oceania (7%). Most of the articles were developed by institutions from a particular country, while four of them had international collaboration and involved researchers from four or five regions. This highlights the great importance of achieving global sustainable tourism and the need for a tool such as LCA to achieve this. It can be seen from the figure that the objective of using different tools to achieve sustainability in the sector is given for developed countries but not for developing countries, such as Africa. In the European context, Spain ranks first in the dissemination of studies using both LCA and CF approaches, producing or collaborating in nine publications. Italy (five studies), the United Kingdom (UK) (5) and Greece (4) also played an important role in the creation and study of tourism impact assessment tools. 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 [41].
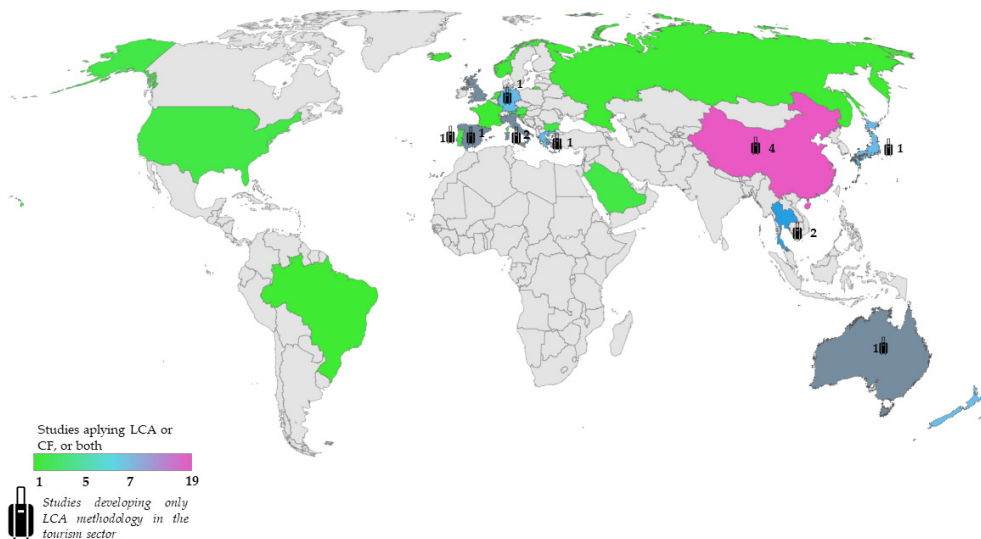

Figure 3: Map showing the geographical distribution of studies included in the review.

According to the evolution of time of publications that use LCA and CF tools in the tourism sector, the period of time studied was from 2004 to 2021, i.e. for 17 years. The starting year chosen was 2004 since it is the first year in which there are peer-reviewed articles on tourism and LCA [23]. It can be seen that very few articles have been developed during the period (2004–2010). However, the development of this methodology has progressively increased, presenting a greater constancy and periodicity over the years, highlighting the year 2010 with six articles (three exclusively on LCA); 2016, with seven

publications (two focused only on LCA) and 2020, with 15 (three focused only on LCA). The year 2021 (until June 2021) presents five articles (one exclusively on LCA) so far 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. Ultimately, an increasing number of publications addressing LCA tool in tourism was observed in the period (2017–2021). Of the 74 articles in total about tourism, 37 were LCA or LCA-CF and 94% of them were from the last decade (2010–2021).

3.2 Implementation of 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 [10]. 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 take into account the term sustainable tourism when considering the three areas, only two of them or only the environmental variable (Fig. 4).
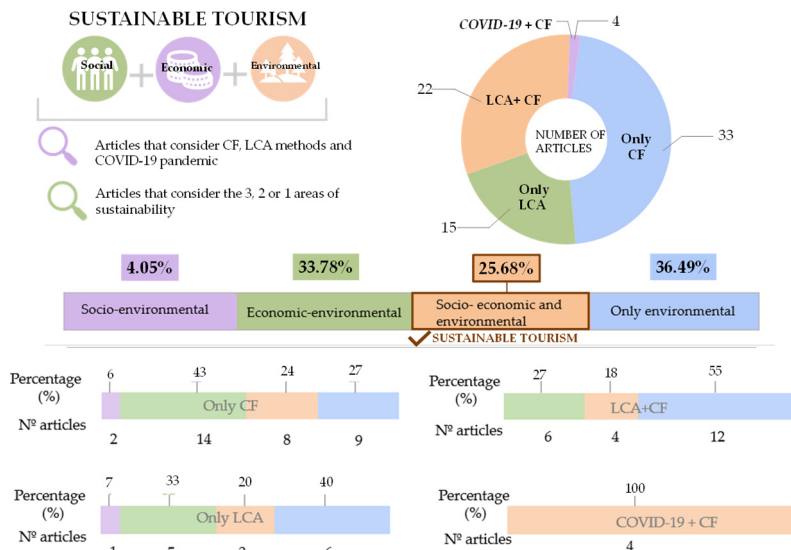

Figure 4:   Degree of implementation of sustainable tourism in the articles studied (74) in terms of the economic, social and environmental variables.

Firstly, of the 33 articles that study only the CF environmental indicator, 14 articles consider a socio-economic view of tourism, which represents 42% of the CF articles. For example, Sun [42] uses the TSA (Tourism Satellite Account) method that defines tourism expenditure in Taiwan (economic model) and the Environmentally Extended Input–Output Model (EEIO) to assess the CF (environmental indicator). Only 7% of the studies i.e. one article, they include a social and environmental perspective, such as a study in which tourists

are evaluated through different questionnaires on some of the practices they perform [43]. According to the articles that considered both LCA tool and CF environmental indicator, it is noticed that 55% (12 articles) evaluate the studies from a unique environmental perspective [25], [26], [44], [45], 27% of the case studies, i.e. six articles, consider both economic and environmental perspective [46]–[48]. Finally, 18% considered the concept of sustainable tourism, as they study the three strands of sustainability as is the case of Gallucci and Dimitrova [49] who evaluate the CF of a city in Bulgaria, analyse social indicators and marketing strategies are suggested. Also, Cadarso et al. [50] which calculates the CO_2 emissions of an example of the Spanish tourism sector, uses a life cycle assessment input–output (LCA-IO) model and considers the social activity of the destination.

There are 15 articles considered the LCA tool, without combining it with the CF indicator. 40% considered only the environmental area as in the Cerutti et al. [47] and Li et al. [39] studies, among others. 33%, i.e. five articles considered the environmental and economic aspects such as Gössling et al. [38] or König et al. [20] three articles in this group accounted for sustainability in tourism such as the study by Sun et al. [48]. Finally, only one article addressed social and environmental variables together [43].

Finally, the four articles studying the CF of the tourism sector during the health pandemic (CF and COVID-19) can be expected to consider the economics of the sector and how it has affected society and the environment. This is indeed the case, 100% of the articles have a sustainable tourism vision [52]–[55].

4 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 80 studied showed that, since 2004, the increase in the development of articles employing the LCA tool has grown very successfully, with the progression being almost exponential from 2017 until now. Specifically, it stands out that 94% of articles focused on LCA methodology were 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 great majority located in China, followed by territories in Europe and Oceania, giving an insight into the degree of concern and awareness of sustainable tourism and the LCA tool in these regions. In terms of systems characterisation, most of the articles addressed the accommodation, restaurant and transport stages in the study phases of the tourism sector. In addition, the FU most commonly used in the studies was "per guest night" or "per visitor" although this may change depending on the objective and scope of the study. By measuring environmental burdens and providing a reliable assessment of GHG emissions associated with tourist accommodation, a CF-LCA approach could be a scientific supporting tool for environmental communication and education of tourists, as well as an objective instrument for more responsible consumption. Likewise, GWP was the most studied impact category due to its strong influence and importance in the sector. Furthermore, in the last year, there has been an increase in the number of studies that take into account the impact of COVID-19 and it 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, 26% 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, in order to know its acceptable level of environmental impact, 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.

REFERENCES

[1]   Raggi, A. & Petti, L., A newly developed integrated environment quality approach for the design of hotel services. Progress in Industrial Ecology. *An International Journal*, **3**(3), pp. 251–271, 2006.

[2]   UNWTO, Tourism highlights: 2018 edition, 2018. https://www.e-unwto.org/doi/book/10.18111/9789284419876. Accessed on: 20 Apr. 2022.

[3]   UNWTO, World tourism barometer and statistical annex: Vaccines and reopen borders driving tourism's recovery, 2021. https://www.unwto.org/taxonomy/term/347. Accessed on: 19 Apr. 2022.

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

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

[6]   Timperley, J., Should we give up flying for the sake of the climate? 2020. https://www.bbc.com/future/article/20200218-climate-change-how-to-cut-your-carbon-emissions-when-flying. Accessed on: 20 Apr. 2022.

[7]   International Energy Agency, Global energy review 2020: The impacts of the COVID-19 crisis on global energy demand and CO_2 emissions. Report, 2020.

[8]   World Tourism Organization and International Transport Forum, Transport-related CO_2 emissions of the tourism sector: Modelling results. Report, 2019.

[9]   Sharpley, R., Tourism and sustainable development: Exploring the theoretical divide. *J. Sustain. Tour.,* **8**, pp. 1–19, 2000.

[10]   Pan, S.Y., Gao, M., Kim, H., Shah, K.J., Pei, S.L. & Chiang, P.C., Advances and challenges in sustainable tourism toward a green economy. *Sci. Total Environ.* **635**, pp. 452–469, 2018.

[11]   Aall, C., Sustainable tourism in practice: Promoting or perverting the quest for a sustainable development. *Sustain.*, **6**, pp. 2562–2583, 2014.

[12] Park, D.B. & Yoon, Y.S., Segmentation by motivation in rural tourism: A Korean case study. *Tour. Manag.,* **30**, pp. 99–108, 2009.

[13] Barget, E. & Gouguet, J.J., The impact on tourism of mega-sporting events: The stakes of foreign spectators. *Tourism Review International,* **16**(1), pp. 75–81, 2012.

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

[15] Maugeri, E., Gullo, E., Romano, P., Spedalieri, F. & Licciardello, A., The bioeconomy in Sicily: New green marketing strategies applied to the sustainable tourism sector. *Engineering and Management*, **4**(3), pp. 133–142, 2017.

[16] De Camillis, C., Raggi, A. & Petti, L., Life cycle assessment in the framework of sustainable tourism: A preliminary examination of its effectiveness and challenges. *Progress in Industrial Ecology*, **7**(3), pp. 205–218, 2010.

[17] ISO 14067, Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication, 2013. https://www.iso.org/standard/59521.html. Accessed on: 15 Apr. 2022.

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

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

[20] König, H., Schmidberger, E. & De Cristofaro, L., 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, 2007.

[21] Foolmaun, R.K. & Ramjeeawon, T., 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), pp. 563–572, 2012.

[22] ISO 14040, Environmental management – Life cycle assessment – Principles and framework, 2006. https://www.iso.org/standard/37456.html. Accessed on: 15 Apr. 2022.

[23] De Camillis, C., Raggi, A. & Petti, L., Tourism LCA: State-of-the-art and perspectives. *Int. J. Life. Cycle. Assess.,* **15**(2), pp. 148–155, 2010.

[24] ISO 14044, Environmental management – Life cycle assessment – Principles and framework, 2006. https://www.iso.org/standard/38498.html#:~:text=ISO%2014044%3A2006%20specifies%20requirements,and%20critical%20review%20of%20the. Accessed on: 18 Apr. 2022.

[25] Sharp, H., Grundius, J. & Heinonen, J., Carbon footprint of inbound tourism to Iceland: A consumption-based life-cycle assessment including direct and indirect emissions. *Sustainability*, **8**(11), p. 1147, 2016.

[26] Hu, A.H., Huang, C.Y., Chen, C.F., Kuo, C.H. & Hsu, C.W., 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), pp. 313–323, 2015.

[27] Filimonau, V., Dickinson, J., Robbins, D. & Reddy, M.V., The role of 'indirect' greenhouse gas emissions in tourism: Assessing the hidden carbon impacts from a holiday package tour. *Transportation Research Part A: Policy and Practice,* **54**, pp. 78–91, 2013.

[28] Lai, J.H.K., Carbon footprints of hotels: Analysis of three archetypes in Hong Kong. *Sustainable Cities and Society*, **14**, pp. 334–341, 2015.

[29] Priyadarsini, R., Xuchao, W. & Eang, L.S., A study on energy performance of hotel buildings in Singapore. *Energy and Buildings*, **41**, pp. 1319–1324, 2009.

[30] Luo, F., Becken, S. & Zhong, Y., Changing travel patterns in China and 'carbon footprint' implications for a domestic tourist destination. *Tour. Manag.,* **65**, pp. 1–13, 2018.

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

[32] GaBi, Introduction to LCA and modelling using GaBi: Part 1, 2021. https://gabi.sphera.com/international/support/gabi-learning-center/gabi-learning-center/part-1-lca-and-introduction-to-gabi/. Accessed on: 20 Apr. 2022.

[33] Solé, A., Miró, L. & Cabeza, L.F., Environmental approach. *High-Temperature Thermal Storage Systems Using Phase Change Materials,* pp. 277–295, 2018.

[34] Mancini, M.S., Galli, A., Niccolucci, V., Lin, D., Bastianoni, S., Wackernagel, M. & Marchettini, N., Ecological footprint: Refining the carbon footprint calculation. *Ecol. Indic.,* **6**, pp. 390–403, 2016.

[35] Department for Environment, Food and Rural Affairs (DEFRA), A research report for the Department for Environment, Food and Rural Affairs by the Stockholm Environment Institute and the University of Minnesota. Report, 2008.

[36] Michailidou, A.V., Vlachokostas, C. & Moussiopoulos, N., 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**, pp. 109–119, 2015.

[37] Rosselló-Batle, B., Moià, A., Cladera, A. & Martínez, V., Energy use, CO_2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands. *Energy Build.,* **42**(4), pp. 547–558, 2010.

[38] Gössling, S., Peeters, P., Ceron, J.P., Dubois, G., Patterson, T. & Richardson, R.B., The eco-efficiency of tourism. *Ecological Economics*, **54**(4), pp. 417–434, 2005.

[39] Li, L., Li, J., Tang, L. & Wang, S., Balancing tourism's economic benefit and CO_2 emissions: An insight from input–output and tourism satellite account analysis. *Sustainability*, **11**(4), p. 1052, 2019.

[40] UNWTO, Climate change and tourism. *Second International Conference on Climate Change and Tourism*. Report, 2008.

[41] UNWTO, International tourism highlights, 2019. https://www.e-unwto.org/doi/pdf/10.18111/9789284421152. Accessed on: 20 Apr. 2022.

[42] Sun, Y.Y., Decomposition of tourism greenhouse gas emissions: Revealing the dynamics between tourism economic growth, technological efficiency, and carbon emissions. *Tour. Manag.,* **55**, pp. 326–336, 2016.

[43] Greiff, K., Teubler, J., Baedeker, C., Liedtke, C. & Rohn, H., Material and carbon footprint of household activities. Living Labs: Design and Assessment of Sustainable Living, eds D. Keyson, O. Guerra-Santin & D. Lockton, Springer: Cham, pp. 259–275, 2016.

[44] El Hanandeh, A., Quantifying the carbon footprint of religious tourism: The case of Hajj. *J. Clean Prod*., **52**, pp. 53–60, 2013.

[45] Santana, M.V.E., Cornejo, P.K., Rodríguez-Roda, I., Buttiglieri, G. & Corominas, L., Holistic life cycle assessment of water reuse in a tourist-based community. *J. Clean Prod.,* **233**, pp. 743–752, 2019.

[46] Scheepens, A.E., Vogtländer, J.G. & Brezet, J.C., Two LCA based methods to analyse and design complex (regional) circular economy systems. Case: making water tourism more sustainable. *J. Clean Prod.,* **114**, pp. 257–268, 2016.

[47] Cerutti, A.K., Beccaro, G.L., Bruun, S., Donno, D., Bonvegna, L. & Bounous, G., Assessment methods for sustainable tourism declarations: The case of holiday farms. *J. Clean Prod.,* **111**, pp. 511–519, 2016.

[48] Sun, R.H., Ye, X.L., Gao, J., Zhu, Z.F., Du, J., Study on carbon footprint and spatial distribution characteristics of human activities in Jiuzhai Valley scenic area. *Applied Ecology and Environmental Research,* **17**(4), pp. 7477–7493, 2019.

[49] Gallucci, T. & Dimitrova, V., The role of carbon footprint indicator for sustainable implications in tourism industry: Case study of Bulgaria. *Int. J. Sustain. Dev. World Ecol*., **12**(1), p. 61, 2020.

[50] Cadarso, M., Gómez, N., López, L.A. & Tobarra, M., Calculating tourism's carbon footprint: Measuring the impact of investments. *J. Clean Prod*., **111**, pp. 529-537, 2016.

[51] Kitamura, Y., Ichisugi, Y., Karkour, S. & Itsubo, N., Carbon footprint evaluation based on tourist consumption toward sustainable tourism in Japan. *Sustainability*, **12**(6), pp. 1–23, 2020.

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

[53] Dorta, P., Díaz, J., López, A. & Bethencourt, C., Tourism, transport and climate change: The carbon footprint of international air traffic on islands. *Sustainability,* **13**(4), p. 1795, 2021.

[54] Gühnemann, A., Kurzweil, A. & Mailer, M., Tourism mobility and climate change: A review of the situation in Austria. *J. Outdoor Recreat. Tour.,* 100382, 2021.

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