Journal of Tourism & Development | n.º 39 | 2022 | [475 - 491]
DOI: 10.34624/rtd.v39i0.26494
e-ISSN 2182-1453

Carbon footprint of **tourism** sector in Portugal: Calculator self-validation

Pegada de Carbono do sector de **turismo** em Portugal: Auto-validação duma calculadora

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Abstract | In this work, a Carbon Footprint (CF) calculator developed by authors to the tourism sector in Portugal, was validated. The CF calculator self-validation was based on the comparison of the results obtained with two tools available online (Carbon Footprint Ltd-CFL and Climate Care-CC) and with a Life Cycle Assessment (LCA) performed using the *SimaPro PhD* software. The calculator is based in the CO_2e (carbon dioxide equivalent) emissions of 6 components: electricity, water, laundry, fuels, waste and food. These tools were applied to a 3 stars Hotel, located in Viseu region (Portugal) with 50 guests' rooms and an occupied area of 1500m^2. CF results attained with calculator developed were slightly higher than CFL and lower than CC results, as it has a different emission from electricity component. For LCA two scenarios were considered, Scenario 1 (same assumptions as CF calculator) and Scenario 2 (assumptions based on LCA methodology) a higher emission was obtained of more than 23975.7 kgCO_2e/year and 72680 kgCO_2e/year, respectively. For both scenarios the difference was caused by electricity consumption component and additional by fuel consumption in Scenario 2. The emission factors chosen used for each component were the main responsible for these differences. Self-validation process demonstrated that the CO_2e emissions from the different tools were very similar when the same assumptions were considered, so the calculator is consistent.

Keywords | Accommodation services, carbon footprint, life cycle assessment, self-validation, sustainable tourism

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Resumo | Com o presente trabalho pretendeu-se fazer a validação de uma calculadora da Pegada de Carbono (PC) desenvolvida pelos autores para o sector do turismo em Portugal. A auto-validação baseou-se na comparação dos resultados com duas ferramentas disponíveis online (Carbon Footprint Ltd-CFL e Climate Care –CC) e com a Avaliação do Ciclo de Vida (ACV) recorrendo ao software SimaPro PhD. A calculadora inclui as emissões de CO_2e (dióxido de carbono equivalente) de 6 componentes: eletricidade, água, serviço de lavandaria, combustíveis, resíduos e alimentação. Estas foram aplicadas a um Hotel 3-estrelas com 50 quartos e área ocupada de 1500 m^2 localizado na região de Viseu (Portugal). Os resultados da PC com a calculadora foram ligeiramente superiores aos obtidos pela CFL e inferiores aos da CC, devido à diferença no factor de emissão do consumo de eletricidade. Para a ACV foram considerados dois cenários, Cenário 1 (iguais premissas da calculadora) e Cenário 2 (premissas baseadas na metodologia ACV) em ambos a emissão é superior à da calculadora, mais 23975,7 kgCO_2e/ano e mais 72680 kgCO_2e/ano, respetivamente. Para ambos os cenários, a diferença deve-se ao componente do consumo de eletricidade e ainda aos combustíveis para o cenário 2. Os fatores de emissão escolhidos para cada componente são os principais responsáveis pelas diferenças. O processo de auto-validação demonstrou que as emissões de CO_2e são semelhantes quando as mesmas premissas são consideradas, portanto os resultados da calculadora são consistentes.

Palavras-chave | Auto-validação, avaliação do ciclo de vida, pegada de carbono, serviço de alojamento, turismo sustentável

1. State of Art

Tourism is a very important activity, for the economy of a country and for the the wellbeing of the tourists. Nevertheless, it is responsible for negative impacts in the natural environment in local as well global scale, through transport, accommodation and relevant activities (Gössling, 2002). Boluk and Rasoolimanesh (2022) stated that recent research has suggested tourism is less sustainable now than ever before and critical tourism scholars continue to remind us of this. Kronenberg and Fuchs (2021) corroborated that tourism's role as a demand-driven industry is currently debated, and its potential to achieve the United Nations Sustainable Development Goals is questioned.

On this basis, it is important for the tourism industry to consider its environmental impacts since it is largely dependent on the natural environment (clean water, clean air, pleasant weather, ecosystem quality) (Michailidou et al., 2016). Melissen (2013) considered that this sector, which has the potential to make a positive societal contribution, is currently marked by negative impacts, such as carbon footprint. The tourism would advance towards significantly decoupling growth from emissions in order to grow within the international climate targets (UNFCCC, 2022). The identification of tourism as an important contributor to climate change has become both an important driver for efforts to develop more sustainable forms of tourism.

Over the last years, the scientific community has focused on the impacts of climate change on tourism and the tourism industry response to climate change. In 2018, the carbon footprint of global tourism was estimated for about 8% of all carbon emissions (Lenzen et al., 2018), and the total annual carbon emissions of tourism are nearly 4.3billion metric tons (Huang & Tang, 2021).

Between 2009 and 2013, the global carbon footprint of the tourism industry increased from 3.9 to 4.5 $GtCO_2e$, four times the previous estimate, accounting for approximately 8% of global greenhouse gas emissions (Huang & Tang 2021). Tourist transport is recognized as the largest contributor to the carbon footprint of tourism with a range between 70% and 75%. The second largest emitter of Greenhouse Gases (GHGs) are tourist accommodations (21%) whose share in the global carbon footprint is estimated as at least 1% (Filimonau et al., 2014; Rico et al., 2019; WTO & ITF, 2019). Until 2035, the sector of tourist accommodation is expected to generate 25% of all GHG emissions of tourism which is in contrast to transportation whose share is anticipated to decrease (de Grosbois & Fennell, 2011).

Hotels have high energy and material consumption intensity as they hold extensive product and service inventories to satisfy consumer demand (De Camillis et al., 2010). This intensity results in such environmental externalities as GHG emissions. The prime environmental repercussions of hotel operations are attributed to energy consumption that leads to global climate change, water use and solid waste generation (Lai, 2015), water consumption and pollution (Antonova et al., 2021), particulate matter pollution (Chang et al., 2020), ozone layer depletion (Saenz-de-Miera & Rossello, 2013) and solid waste generation (Filimonau & Tochukwu, 2020). Therefore, many experts underlined the importance of accurate quantification of tourism's environmental impacts (Gössling et al., 2005). Moreover, the reduction of the environmental footprint of hotels is critical for more sustainable tourism development (Lenzen et al., 2018). To reduce the environmental footprint of hotels, accurate assessments are required (Castellani & Sala, 2012), that can reveal and quantify the environmental 'hotspots' within a hotel business that should be addressed (Chan et al., 2017).

1.1. Enviromental Impact Assessment Tools

To assess the real impacts of tourism and the level of sustainability achieved requires an in-depth research namely by environmental, economic and social auditing. Existing studies on environmental assessment of tourist accommodations are underpinned by a small number of methods (Filimonau et al., 2011a; Edwards et al., 2016). Some of these methods are: Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), Environmental Indicators (EI), Material Flow Analysis (MFA), Life Cycle Energy Analysis (LCEA), Ecological Footprint Analysis (EFA), Carbon Footprint (CF) and Water Footprint (WF).

Geneletti and Dawa (2009) used the EIA to assess the environmental impact of mountain tourism in Ladakh, Indian Himalaya. They adopted a baseline study on stressors (trail use, waste dumping, camping, pack animal grazing and off-road driving) and receptors (soil, water, wildlife, vegetation) and the environmental impacts were modeled by considering the intensity of the stressors, and the vulnerability and the value of the receptors. The results were spatially aggregated and combined to generate composite impact maps.

De Camillis et al. (2008) analyze the findings of a LCA case study that they carried out on the lodging service provided by an Italian hotel. Kuo and Chen 2009 also used the LCA to explore environmental impacts of an island tourism, and then to find the environmental loads per tourist per trip. Various environmental loads in transportation, accommodation, and recreation activity sector were inventoried and calculated. Hence, the application of multi-impact methods as LCA and MFA to hotels may not necessarily be cost- and/or labour effective. Instead, the use of simpler, cheaper screening methods of environmental assessment that focus on climate change, water use, solid waste generation as a single, most important, environmental impact of hotels is justified.

However, nowadays the majority of these tools are used in an integrate way. For example, to calculate the EI five main categories can be defined for the tractability of the developed composite indicator (Michailidou et al., 2015): (i) Energy-oriented environmental pressures for hotels, (ii) water-oriented environmental pressures for hotels, (iii) waste-oriented environmental pressures for hotels, (iv) carbon footprint-oriented environmental pressures for hotels, and (v) carbon footprint-oriented environmental pressures mainly from air and road transport to the destination and back and from recreation activities.

Some tools related to the footprint evaluation are often used, namely the tourism ecological footprint (EFA), the tourism carbon footprint (CF) and the tourism water footprint (WF). These tools are important for quantitatively assessing the impact of tourism activities on the ecosystem of a tourist destination (Wang et al., 2017). The EFA is popular for measuring the impact of tourism events (Collins & Cooper, 2017) by measuring the total land and sea area needed to support their function (Pandey et al., 2011). Alternatively, the CF model quantitatively approximates the total GHG emissions associated with an event or area over a defined period in terms of weight (Carbon Trust, 2007; Cooper & McCullough, 2021). Therefore, the tourism carbon footprint can be used to obtain the carbon dioxide content consumed by tourism in a certain area during a certain period (Huand & Tang, 2021). The existent models to calculate CF does not exclusively measure carbon emissions but instead measures many GHGs and normalizes the results in carbon units (Pandey et al., 2011). This is a distinct benefit of implementing a carbon footprint (Wicker, 2018) and its ability to account for direct and indirect emissions associated with the target study event or area (Collins & Cooper, 2017).

To assess the CF of tourist accommodations, the screening method of LCEA, alongside its variations, has been proposed and successfully trialled (Puig et al., 2017; Rosselló-Batle et al., 2010; Koiwanit & Filimodau, 2021). For example, Koiwanit and Filimodau (2021) used this method to study the carbon footprint in a case study of home-stays in Thailand and undertook its comparative analysis against other categories of tourist accommodation, globally and in Thailand.

Moreover, Michailidau et al. (2016) in their work had combing LCA with EFA, EIs and Multi-criteria analysis (MCA). This methodology was demonstrated for Chalkidiki, an area with considerable tourism activity in Greece and one of the prevalent destinations in the Balkan Peninsula.

The GHG Protocol Initiative (the GHG Protocol) is a carbon footprint assessment, that measure and manage GHG emissions, and is broadly applied worldwide, estimating the footprint for various business sectors, including the service industry (Filimonau et al., 2011b). It addresses six greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (De Grosbois & Fennell, 2011). Lai (2014) calculated the carbon emissions of hotels following the guidelines of the GHG Protocol and other similar documents, like the International Standard on Greenhouse Gases (ISO 14064-1:2018), and had categorised the emissions generated by hotels into three main scopes: scope 1 – direct emissions (e.g., combustion in hotel boilers), scope 2 – energy indirect emissions (e.g., consumption of gas and electricity purchased from a local utility) and scope 3 – other indirect emissions (e.g., overseas business travel by hotel staff).

Others methodological approaches used to calculate CF are PAS 2050 (BSI, 2011) and ISO 14067:2018 (ISO, 2018). PAS 2050 was developed to meet the need for a consistent method to evaluate GHG emissions from the life cycle of goods and services (BSI, 2011). Its main objective is to provide a common basis for the quantification of GHG emissions that will inform and enable significant GHG emission reduction programs (BSI, 2011). According to Garcia and Freire (2014) PAS 2050 shows, for example, how to deal with common methodological issues and how to define and allocate the limits of the system. ISO 14067:2018 arises to complement PAS 2050 and provides specific requirements and guidelines for the quantification and communication of CF products, based on existing ISO standards on life cycle evaluation and environmental labels and declarations.

1.2. Tourism Carbon Footprint Studies

Although the number of carbon footprint assessments of tourism has grown recently, they remain limited in the operational and geographical scope of application (Wang et al., 2017) and most studies dealing with CF of tourist accommodations focus on hotels. In the literature, the majority of studies have a geographical scopus. Geographically, research on CF assessment of tourism has primarily been concerned with either providing a global outlook (Lenzen et al., 2018) or focussed on the 'established' destinations in Europe, North America, Australasia and East Asia (Warren & Becken, 2017). Becken et al. (2001) assessed tourist accommodations in New Zealand; Melissen et al. (2016) who have a more social focus in three Dutch case studies; and Rico et al. (2019) who calculate the CF of tourism across the city of Barcelona attributing the value of 21% of the total GHG emissions to different types of tourist accommodations.

Sharp et al. (2016) used the LCA method to assess the consumption-based carbon footprint of ordinary tourists in Iceland, including direct and indirect emissions, and concluded that the CF of ordinary tourists depends on the distance taken by plane. Koiwanit et al. (2021) used the method of screening LCEA, to study assessed the CF of a sample of home-stays in Thailand. They concluded that the overall annual carbon footprint of home-stays was assessed as low (1.3 tonnes of CO_2-eq. per home-stay on average) which was due to small size and limited guest amenities. Sun (2014) proposed a framework to measure the total domestic carbon effect and the effect of foreign sources, and applied it to Taiwan empirical research that shows that domestic tourism, international aviation and imports account for 47%, 28% and 25% of the CF of the tourism industry, respectively.

Further, this sector is characterised by significant organisational diversity and operational complexity as it is made up by a large number of tourist accommodations that vary substantially in size and extent of services offered (Michailidou et al., 2015). For example, significant differences exist in the business models adopted by so-called full-scale tourist accommodations (i.e. luxury holiday resorts and/or upmarket hotels) in comparison with so-called limited-scale tourist accommodations (i.e. budget hotels and hostels).

Thus, the application of CF assessment of tourist accommodations should be supported by two major considerations. First, a clear boundary should be set up explaining the operational processes of tourist accommodations that have been excluded and included in the assessment (Filimonau et al., 2011b). Here, it is important to carefully and critically evaluate the study's context to ensure that all crucial processes are accounted for (De Camillis et al., 2010). For example, in the context of a hostel, it may be unnecessary to consider food waste as a major contributor to its operational carbon footprint. This is because hostels usualy do not host a restaurant on-site which suggests that the related food wastage is likely to be negligible. In contrast, food waste should be ideally included into the carbon footprint assessment of a full-scale hotel as this type of tourist accommodations, under normal circumstances, offers extensive food services (breakfast, lunch, dinner) implying the likelihood of significant food wastage on-site. In other situations, there are some methodological gaps. Chen and Hsieh (2011) stated that food procurement can add substantially to the environmental loads of hotels but acknowledged methodological difficulties in securing the relevant data.

Second, carbon footprint assessments supported by the screening methods should consider the use of appropriate conversion factors. To enable an accurate conversion of energy consumption in tourist accommodations into GHG emissions, it is necessary to employ factors that are up-to-date and geographically relevant.

In summary, the baseline calculation of destination-related emissions would thus, for a given country, include travel to and from the destination (international tourists), as well as accommodation and leisure activities (from domestic and international tourists), including local travel. The impact of the tourist activity, namely the accomodation, measured by the CF, cannot be widespread for all the geographies and tourism markets (Filimonau et al., 2014). This situation arises from the different accessibilities, geographical limitation, energetic production profiles or buildings characteritics (UN, 2017). Thus, it is important that CF calculation can integrate these different geographic and accommodation characteritics.

1.3. Methodological Gaps

The primary data availability is a major problem in environmental impact assessment research (Filimonau et al., 2011b) namely in hotels, and with particular focus in the collection of information in non-operational processes (De Camillis et al., 2010). Routine energy audits are carried out only by a few hoteliers and not by the ‘emerging’ destinations where energy management is rarely assigned an operational priority by hotel’s administration (Oluseyi et al., 2016). The lack of atualization of data and the conversion indices by the well-established IPCC emissions factor database (GHG Protocol) is a drawback in its widespread usage (Filimonau, 2016).

To calculate the CF it were developed calculators by several entities. However, Mulrow et al. (2019) compared 31 carbon footprint calculators available online to identify the most important emission sources and environmental indicators, concluding that most emissions focus on electricity and fossil fuel consumption. However, none of the calculators gives results regarding emissions resulting from water treatment impacts and its relationship with the other components. A variation in the number of indicators chosen make some calculators more comprehensive than others. Other entities such as Green Key, have developed a calculator concerned specifically for accommodation and it can be obtained data on CO_2e emissions from electricity consumption, natural gas consumption, heating oil consumption, gas leakage from air conditioners, laundry and cars fuel consumption (Green Key, 2020).

The above reasons can at least partially explain why research on the assessment of the GHG emissions from the subsector of tourist accommodation must be improved.

1.4. Carbon Footprint Calculation in Portugal

In Portugal, as in many other countries, tourism plays a major economic role. In recent years, it has had important (positive and negative) impacts socially, environmentally and economically. At a national level, actions in this area are scarce, so it is necessary improve the research in this field. There are some national plattaforms who aim to promote sustainable tourism, such as Nøytrall, NEST – T+ and Eco.Economia Alentejo Central. The first, Nøytrall, provides a guest consumption tracking system, which allows hotels and guests to knowledge exactly what they are consuming in terms of water and energy and act to reduce their impact (Nøytrall, n.d.). The Nøytrall system connect equipments that allow the measurment of energy and water consumption, by room, and digital communication of this data in real time. Therefore, it is possible to identify consumption patterns and improvement opportunities, allowing the definition of strategies to increase the business sustainability and good practices.

The NEST - Tourism Innovation Center developed the T+, a sustainability diagnosis tool for small and medium-sized establishments in the tourism industry (accommodation, travel agencies, tourist entertainment agents, event organization, rural tourism and parks of camping, among others) (NEST, 2022). It aims to assess their CF including the energy and water consumption and waste production.

Portugal local projects are also being developed in order to get closer to economic actors. This is the case of Eco.Economia Alentejo Central that developed a simple querry to allow the users to evaluate their ecological footprint (Eco.nomia - Alentejo Central, 2019). The simulator aims to quickly calculate the impacts caused by the footprints of companies as a result of their activities. Specifically, good practices related, for example, to the use of water, electricity and the transport of people and goods are included (Eco.nomia - Alentejo Central, 2019).

The Portuguese Tourism Administration adopted the methodology Hotel Carbon Measurement Initiative (HCMI). This is a free tool for hotels to calculate the carbon footprint of hotel in local stays and meetings (Turismo de Portugal, 2021). The methodology includes all energy used 'on site' (including fuels such as natural gas, oil and other fuels, purchased electricity, and mobile fuels from vehicles and other equipment). It also includes, if applicable, carbon emissions from outsourced operations (e.g. laundry). In order to facilitate the use of this tool, namely not regarding the collection, organization and treatment of the basic data to be used in its completion, this guide has a excel spreadsheet calculator [GEET.xlsx | GEET - Greenhouse Gas Emissions from the Enterprise Tourism] that can be used in conjunction with the HCMI initiative tool.

2. Introduction

The 2007 Davos Declaration on Climate Change and Tourism state that this sector should respond rapidly to climate change and progressively reduce its contribution to GHG emissions and thus grow in a sustainable way (UNWTO, 2007). Sun et al. (2020) stated that exists a bidirectional interconnection among tourism, the environment and sustainable development. The environmental impact of tourism activities has led to the gradual restructuring of the tourist industry to adopt strategies and policies in support of environmental quality, based on the sustainable use of environmental resources. As previous mentioned, CF is a powerful tool to create sustainable products and improve tourism sustainability.

The online CF calculators already developed by organizations or entities can be applied to several sectors and tourism is one of them. Padgett et al. (2008) concluded that there are significant differences in CF estimates depending of the selected indicators and emission factors. The emission factors database depends from the country in which the calculator is developed, although the formulas used to the CF calculation are the same, involving the multiplication of the environmental indicators quantification by their emission factors. On the other hand, Mulrow et al. (2019) compared 31 calculators and concluded that most of the calculators focus on the emissions of electricity and fossil fuel consumption and none of the calculators gives results regarding emissions resulting from water treatment impacts and its relationship with the other components.

In order to contribute to improve the CF calculation incluiding all environmental components that are related with the accomodations activities the autors developed a calculator in Microsoft Excel (version 365). This is based on accounting for GHG emissions resulting from electricity, water, fuels and food use, laundry and waste production.

The calculator validation process aims to give credibility to the tool and identify possible existing flaws. CF calculator must be validated, and this validation can be done by a simple self-validation, by third parties or by an accredited validation entity (Kent, 2018; Carbon Trust, 2018). Self-validation is the simplest form of validation; however its credibility may be lowest than that given by validation by third parties or by an accredited independent entity (Carbon Trust, 2018). Third-party validation offers greater impartiality while validation by an accredited validation entity offers much greater credibility (Carbon Trust, 2018). Examples of entities that can provide accredited validation are the TÜV Rheinland and SGS (Société Générale de Surveillance) and evaluate all calculator processes in accordance with standards.

In this work a CF developed calculator developed to the tourism sector in Portugal (Fernandes et al., 2021a) was validated by a self-validation process. It was proposed to compare the CF with different tools, similar calculators available online (Carbon Footprint Ltd-CFL and Climate Care-CC) and with a Life Cycle Assessment (LCA). It was intended to identify possible failures and differences between similar tools and evaluate its viability to be applied to the tourism sector in Portugal, more specifically to the accommodation sub-sector.

3. Methodology

Considering the touristic accommodation services (parking, reception and administration, lodging, and breakfast) it was developed a CF calculator in a previous work (Fernandes et al, 2021a). This CF included 6 components: electricity, water, laundry, fuels, waste and food, which were divided in 10 environmental indicators (Table 1). Briefly, it was analyzed the check-in, room stay or usage, check-out, and clean-up or preparation for the next guest. These activities were focused on the preparation of hotel amenities, including production and transportation from suppliers to the hotel. Also involved the room cleanup, including outsourced laundry, waste treatment, and client's transportation. The CF unit for accounting the GHG emissions was $kgCO_2$ equivalent – $kgCO_2e$.

Table 1 | Components and indicators used in the CF calculation tool (adapted from Fernandes et al., 2021a)

Components	Indicators	Description
Electricity	Electricity consumption	Electricity consumption (purchased from a supplier)
	Electricity supplied (renewable energy)	Electricity produced through renewable energy sources
Water	Water consumption	Volume of water consumption
	Production of wastewater	Volume of wastewater produced
Laundry	Laundry done	Amount of laundry to be done
Fuels	Fuel consumption used for stationary combustion	Amount of fuels used (petrol, diesel, biodiesel, natural gas, butane, propane, mixture and wood)
	Distance travelled by cars	Fuel consumption by car, dependent of distance made
Waste	Production of urban waste	Amount of unsorted waste (organic and undifferentiated
	Waste recycled or reused	Amount of waste recycled (paper, plastic, glass, metal, oil)
Food	Food consumption	Consumption of food (food purchased by the accommodation)

In this study, it was also evaluated the avoided emissions. Emissions avoided derive from sustainable practices. The difference between the emission of a "common practice"(using electricity from the grid and throwing all the waste into the unsorted waste container) and a sustainable practice (using renewable energy and recycling) can be designated as avoided emissions. Recycling or using renewable energy allow to achive avoided emissions that would result from not recycling and using electricity from the grid.

The validation followed the process defined by Kent (2018) and Carbon Trust (2018) as a self-validation. To reach the goal it was compared the results obtained with this CF calculator with two online tools and with a LCA tool. These methodologies were applied to a 3 stars Hotel, located in Viseu region (Portugal) with 50 guests' rooms and with an occupied area of 1500 m2, considering the baseline year of 2018, previously described in Fernandes et al. (2021b). The overnights considered was 20220. Some assumptions were done such as, for laundry component, it was considered the amount of 4kg of towels and sheets per room per night. In the Hotel only natural gas was consumed and it were used two cars for travels. About waste management, it was assumed that all paper, plastic and glass produced were separated for further recycling.

3.1. Comparison with Available Online Calculators

For the calculator validation, two online calculators, Carbon Footprint Ltd (Carbon Footprint, 2021) and Climate Care (Climate Care, 2021), were used with the same data. In this comparability, only two components were attained: consumption electricity and consumption of fuels. The other components were not evaluated as they are not included in these two online calculators. The data used are described in the table 2.

Table 2 | Data accounted in the online calculators

Indicator	Value
Electricity consumption (kWh)	245458
Natural gas consumption (m^3)	14865
Distance travelled by cars (km)	2784

3.2. Comparison with Life Cycle Assessment (LCA)

The LCA methodology applied followed the ISO 14040:2006 (ISO, 2006a) and ISO 14044:2006 (ISO, 2006b) guidelines. The functional unit was defined as an overnight stay of one guest according to PAS 2050 (BSI, 2011). In table 3 are represented the scenarios that were used for this validation. In Scenario 1 the same accommodation service conditions used in the calculator under study were used. For Scenario 2 the principles of a tourist accommodation LCA based (cradle-to-grave) in similar works and standards were considered (Castellani & Sala, 2012; De Camillis et al., 2010; Hu et al., 2015; BSI, 2011). The specific LCA conditions and the data used are describe in tables 3 and 4, respectively.

SimaPro PhD (Pré consultant, 2021) was the LCA software used in this case study and the data for the background processes were obtained on the Ecoinvent 3.0 database considering the allocation at point of substitution (APOS) approach. The environmental impact category choosen was climate change by measuring the global warming potential for air emissions according with life cycle impact assessment method single issue of IPCC 2013 GWP 100a V1.03. The present data are related with the Hotel conditions in 2018, with 20220 overnights.

Table 3 | Description of the Scenarios took in account for the LCA application.

Component	Scenario 1	Scenario 2
Electricity	The medium voltage value for Portugal was selected	
Water	Emissions in conventional drinking water and wastewater treatment processes	Emissions from the entire drinking water supply process and the conventional wastewater treatment process have been accounted
Laundry	For the laundry, only the consumption of electricity and water and the production of wastewater were considered. The detergents consuption was not considered. The data for this component was introduced together with the electricity and water component	
Fuels	Only CO_2 equivalent emissions are used for fossil fuels burning	Life cycle of fuels including CO_2 eqiuvalent emissions of the burning of fossil fuels
Waste	Emissions from the production of plastic, paper and glass, and the landfilling of undifferentiated waste, which accounts for the use of landfill gas, leachate treatment and the emissions of anaerobic digestion treatment of organic waste	This component accounted for emissions from the entire life cycle of plastic, paper and glass, from landfilling of undifferentiated municipal waste including use of landfill gas and leachate treatment and from the emission of anaerobic digestion treatment of organic waste
Food	CO_2 emissions for the whole life cycle of the food	

Table 4 | Data inserted in the SimaPro PhD software refers to one year (2018) of the hotel activity

Inputs and Outputs		**Value**
Overnights		20220
Electricity consumption (kWh)		245458
Drinking water consumption (m^3)		2642
Wastewater production (m^3)		2299
Laundry (kg of Clothes)		40448
Fuel consumption	Natural Gas (m^3)	14865
	Car 1 (km)	552
	Car 2 (km)	2232
Waste Production	Urban Undifferentiated (kg)	1575
	Organic (kg)	34537
	Paper (kg)	3149
	Plastic (kg)	631
	Glass (kg)	4413
Food and Drink	Bread (kg)	1011
	Cheese (kg)	303
	Pork Ham (kg)	303
	Coffee (kg)	52
	Milk (L)	2023
	Pork meat (kg)	1517
	Rice (kg)	1011
	Potatoes (kg)	1011
	Citrus fruit (kg)	2427

4. Results and Discussion

4.1. Validation using online available calculators

The CF calculator self-validation was based by comparing the results of Carbon Footprint Ltd and Climate Care calculators. The results obtained are described in table 5. In this case only 2 of the 6 components (electricity, water, laundry, fuels, waste and food) were compared: electricity and fuels consumption, because it was the only components considering in these calculators.

Table 5 | GHG emissions obtained for the 3 calculators

	CF Calculator ($kgCO_2e$/year)	**Carbon Footprint Ltd ($kgCO_2e$/year)**	**Climate Care ($kgCO_2e$/year)**
Electricity consumption	62346	62003	77760
Natural gas consumption	32399	29410	29410
Fuel consumption by cars	503	500	500
Total	95248	91913	107670

The results obtained by the developed CF calculator with the online calculators of Carbon Footprint Ltd and Climate Care were similar. The GHG emissions ($kgCO_2e$/year) from electricity consumption of the calculator were similar to the Carbon Footprint Ltd. However, it shows a difference of 15414 $kgCO_2e$ when compared with the results of the Climate Care calculator. The electricity production emission factor used in the developed calculator was more recent than the used by the Climate Car; it was provided by the Portuguese Renewable Energy Association (APREN) for the year 2019 (APREN, 2019). Emissions related to natural gas consumption were equal in the two online calculators and higher than the developed calculator (plus 2989 kgCO_2e). Again, these differences may be caused by the emission factor used. The emission factor used in the present calculator was based on 2006 Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006). The emission resulting from car trips was almost equal in all calculators, with only a slight increase of 3 kgCO_2e in the calculator under study. The total GHG emissions obtained by the calculator is between the two online calculators, but closer to Carbon Footprint Ltd, validating the results achieved by the present study. This process showed that it is essential to account for update emission factors sources in order to reflect the evolution of the several components and environmental indicators included in the calculators.

4.2. Validation with Life Cycle Assessment

The second procedure for self-validation chosen was the comparison with the LCA, executed using the *SimaPro PhD* software. Table 6 shows GHG emissions (kg CO_2e) from Scenarios 1 and 2 and the calculator under study.

Table 6 | GHG emissions results for Scenario 1 and 2 (LCA) and CF Calculator under study.

		Scenario 1		Scenario 2		Calculator	
		Emissions (kgCO_2e)	**kgCO_2e/overnight**	**Emissions (kgCO_2e)**	**kgCO_2e/overnight**	**Emissions (kgCO_2e)**	**kgCO_2e/overnight**
Inputs	Plastic	1737.7		1834.5		1325.4	
	Paper	2943.1		3118.3		3442.4	
	Glass	4250.5		4571.6		3177.3	
	Pork	14797.2		14797.2		18823.6	
	Orange	680.4		680.4		1130.7	
	Rice	1427.4		1427.4		3443.7	
	Milk	3450.3		3450.3		4496.7	
	Bread	1474.9		1474.9		1498.2	
	Wine	-		-		3916.9	
	Eggs	-		-		2554.1	
	Coffee	385.4		385.4		1442.2	
	Potato	324.2		324.2		462.8	
	Cheese	3848.3		3848.3		4836.7	
	Transport (fuel)	Only counts emissions as output		5146.2		Only counts emissions as output	
	Water	678.7		879.5		447.6	
	Electricity	92965.1		92965.1		62346.3	
	Natural Gas	Only counts emissions as output		42725.8		Only counts emissions as output	
Outputs	Fuels CO_2	80.6		80.6		32902.2	
	Fuels CH_4	32806		32806			
	Fuels N_2O	15.4		15.4			
	WasteWater	1237.6		1237.6		2745.7	
	Laundry	23345.3		23383.7		16021.1	
	Undifferentiated municipal waste	1342.7		1342.7		1161.1	
	Organic Waste	3030		3030		618.9	
	Plastic	-1466.9		-1466.9		-504.9	
	Paper	-1212.8		-1212.8		-1259.4	
	Glass	-4448.1		-4448.1		-1765.2	
Total emissions		190 821		239 525		166 794	
Total emissions avoided		-7128		-7127,8		-3529.5	

In general, CO_2e emissions from electricity, laundry and waste components were higher in scenario 1, while water and waste components were higher in the calculator. Only in the fuels emissions similar results were obtained. Globally, Scenario 1 showed a higher emission of 190 821 kgCO_2e compared to the results obtained by the calculator, resulting in a difference per overnight stay of 1.19 kgCO_2e. This variation is mainly due to the difference between the CO_2e/kWh emission factor of the calculator (from 2019) and the *SimaPro* PhD (from 2012), leading to a difference of 30618.8 kgCO_2e in the electricity component. This had a directly influence from the laundry component and consequently in the final emission value. For the waste component, it was emitted an additional 1841.2 kgCO_2e for scenario 1 when compared to the calculator, related with the organic waste emission factor that is about 5 times higher in the LCA. This difference may be related with the emission for the organic waste treatment by anaerobic digestion, that in the LCA is considered the all life cycle of the process, and in the calculator is considered only the emissions from the anaerobic digestion process.

The emissions related to the fuel consumption represent 32902 kgCO_2e in the 3 cases because it accounts to the Intergovernmental Panel on Climate Change emission factors (IPCC, 2006). For the water component, the calculator showed a higher emission since it accounts for all the emissions from the water treatment company (AdP) and the sludge emission, whereas in Scenario 1 only the emission from the treatment process is included. However, the result of the drinking water indicator was higher in Scenario 1. Regarding the food component, the calculator showed a higher emission (+16217.6 kgCO_2e), since it has higher emission factors in all foods (data not show) and because in the SimaPro PhD the emissions of wine and eggs were not considered due to their lack in the database, which contributed 6471 kgCO_2e to the results with the calculator. All components in Scenario 2, except for water and food, have higher emissions than the calculator for the same reasons mentioned above for Scenario 1. Globally, Scenario 2, in comparison with the calculator, has a higher emission of almost 72731.5 kgCO_2e resulting in a difference per overnight stay of 3.6 kgCO_2e. The main variation was in fuels component as their LCA showed that the emission is 80774 kgCO_2e, 47871.8 kgCO_2e more than in the calculator under study probably because in Scenario 2 of the LCA, it was included the whole life cycle of the fuels used by the accommodation. In the calculator, only GHG emissions from fuels combustion are considered.

The GHG avoided emissions, related with the production of electricity from renewable sources and the practices of waste reuse and/or recycling, had a higher estimation in the Scenario 1 than with CF calculator. The main differences registered were due to the emission factors used. Using the most recent emission factor for electricity in the calculator implies a significant decrease in the contribution of this component, once the electricity sector has shown a rapid and very positive evolution in terms of renewable energy sources, which reduces the emission factor and consequently GHG emissions.

Considering the CO_2e emission per guest-night, the data achieved with the CF showed to be 8.3 kgCO_2e/guest-night (Table 6), very similar to the ones reported by Filimonau et al. (2013) that were 8.4 kgCO_2e/guest-night. Slightly lower results were reported by Michailidou et al (2016) that applied LCA to different hotels in Greece, but with different scenarios, and Rico et al. (2019), that presented 7.5 kgCO_2e/guest-night. It must be emphasized that Filimonau et al. (2013) and Rico et al. (2019) only analyzed two components: electricity and fuel. Puig et al. (2017) evaluated the average carbon footprint of an overnight stay in a Spanish coastland hotel, by analyzing 14 two-to-five-stars hotels, and reported an average emission of around 19 kgCO_2e/guest-night, with the main potential components the electricity and fuels consumption, 75% of the impact, depending of the number of stars and unoccupancy rate.

Overall, the CF achieved with the calculator under development, showed higher carbon dioxide emissions related with the water and food components, but less for the electricity, laundry and waste components. Tsai et al. (2014) stated that full-service hotels serving higher level services would contribute higher carbon dioxide emissions per person-night. A full-service hotel will normally provide food and beverage (F&B) services to guests. Using local sources to decrease food miles and selecting more organic food ingredients

(Gössling et al., 2011) can help reduce the carbon footprint from F&B service. Table 7 have a summary of CO_2e emissions of each component for each tool used.

Table 7 | Summary of the CO_2e emissions achieved with the different tools under analysis

	Emissions ($kgCO_2e$)					
Components	**Scenario 1**		**Scenario 2**		**Calculator**	
Electricity	92965	190820	92965	239525	62346	166793
Water	1916		2117		3193	
Laundry	23345		23384		16021	
Fuels	32902		80774		32902	
Waste	13304		13897		9725	
Food	26388		26388		42606	
Avoided Emissions	-7128		-7128		-3529	

The assumptions done in Scenario 2 lead to the highest evaluation of carbon dioxide emissions, with a total emission of 239525 $kgCO_2e$ followed by Scenario 1 and the calculator, with carbon dioxide equivalent emissions of 190820 $kgCO_2e$ and 166793 $kgCO_2e$, respectively. For the avoided emissions, related with the renewable energy and recycling, Scenarios 1 and 2 showed a value that is almost double that obtained by the calculator.

By applying the LCA following the same assumptions as in this study (Scenario 1), the results show a difference of 14.4% in favor of Scenario 1 when compared to the calculator with the electricity component being the main responsible. However, applying the LCA according to the requirements defined in the LCA standards (cradle-to-grave) (Scenario 2) increases the difference to 43.6% in favor of Scenario 2 when compared to the calculator, with the electricity and fuel components responsible for the difference.

Given that energy use is closely linked to GHG emissions, energy conservation will result in a significant reduction in the carbon footprint from hotels (Filimonau et al., 2011b).

Despite this, limited research exists on the environmental assessment of hotels, particularly their contribution to global GHG emissions (Filimonau et al., 2011b). This is corroborated by Rosselló-Batle et al. (2010), that stated that hotels assessments generally concentrate on energy performance. From the self-validation of CF calculator it is inferred that it can be used as an indicator of the CF accommodation, and it is important that it is flexible in order to allow frequent updating of the emission factors of the various components.

The results obtained in the self-validation process were encouraging as they were very similar when the same assumptions were considered. The calculator presented results close to the online calculators differentiating only the emission factor of the electricity consumption indicator being the lowest as it is more recent. As with the online calculators and for the same reason, the major difference between the LCA and the calculator is the emission factor of the electricity consumption indicator (also influencing the difference in the laundry emission). All other slight differences in the emissions of the other components were expected since the emission factors are different. The indicators used in the LCA study are the most similar to those in the calculator as it was not possible to find exactly the same indicators in the software. The important task of an accurate CF calculation is to collect reliably the necessary information from hotel managers and tourists. To find energy, water and food consumption data as well as amounts of wastes generated for all items at all sectors of the tourists' holidays may not be economically and logistically feasible (Michailidou et al., 2016). These data is difficult to collect because most hotels do not have detailed records and hotel managers are often reluctant to share them. However, due to the increasing of GHG emissions, action is needed because catastrophic consequences are expected from the global temperature increase. Therefore, calculating emissions from all sectors, including the tourism sector, is increasingly important for monitoring and further reducing GHG emissions. Thus, the calculator developed allows this calculation to be made on the basis of scientific studies and may become extremely relevant in supporting the achievement of reduction targets up to 2100, since the tourism sector has an important weight in GHG emissions and has direct consequences of global warming.

The results presented herein provide the basis for the identification of environmental "hot spots" in order to highlight processes with considerable environmental impacts and promote the implementation of effective mitigation measures by hoteliers, especially in countries with strong dependence of tourism activities.

5. Conclusion

A self-validation process of a developed CF was done and showed that the GHG emissions results attained were very similar when the same assumptions were considered in the utilization of boarder tools currently used. The calculator under study presented results close to the online calculators. The difference found between the LCA and the calculator CF estimation is related with the electricity consumption indicator emission factor (also influencing the difference in the laundry emission). All other slight differences in the emissions of the other components were expected since the emission factors were different.

Acknowledgements

This work is funded by National Funds through the FCT - Foundation for Science and Technology, I.P., within the scope of the project Refª UIDB/05583/2020. Furthermore, we would like to thank the Research Centre in Digital Services (CISeD) and the Polytechnic of Viseu for their support.

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