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Calculating the Carbon Footprint of Urban Tourism Destinations: A Methodological Approach Based on Tourists' Spatiotemporal Behaviour

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Abstract: This study investigates the influence of urban tourists' behaviour on the environmental performance of a destination, particularly in terms of carbon emissions. Tourist-related emissions are shaped by their choices and behaviours, impacting the overall carbon footprint of the locations they visit. To assess this impact, we introduce a methodology for quantifying greenhouse gas emissions linked to tourists' energy consumption. This approach considers key tourism components—activities, accommodation, and transportation—analysing their roles in emissions across a trip's temporal and spatial dimensions. By integrating tourists' spatiotemporal behaviour with emissions data, our framework offers insights that can support local climate-responsive urban and tourism policies. We empirically apply the proposed model to the destination of Donostia/San Sebastián (Spain), where the primary travel sequences of visitors are analysed. We utilise cartographic techniques to map the environmental footprints of different tourist profiles, such as cultural and nature tourists. The findings indicate that visitors primarily motivated by nature and outdoor recreation constitute the segment with the highest greenhouse gas emissions (with a minimum footprint of 30.69 kg CO_2-equivalent per trip), followed by cultural tourists, and finally, other categories of visitors. The results highlight the practical applications of the proposed model for sustainable tourism management, providing valuable guidance for urban planners and policymakers in mitigating the environmental impacts of tourism.

Keywords: greenhouse gas emissions; carbon footprint; urban tourism destinations; climate change; Donostia/San Sebastián

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1. Introduction

The relationship between cities and tourism is complex. In recent years, tourism has significantly boosted urban economies [1]. Cities attract visitors thanks to their multiple monuments, events, services, and solid transport infrastructure. Increased affordability and easier mobility have popularised short urban trips, making urban tourism a rapidly growing sector. Urban tourism contributes around 10% to local gross domestic product in European cities [2], with leading destinations welcoming 223 million arrivals annually

(36.47% of Europe's total) [3]. Historically, cities have been places of exchange and the point of maximum concentration of a community's power and culture [4]. Cities now face significant climate change issues, as they concentrate more than 76% of global greenhouse gas (GHG) emissions [5]. GHG emissions refer to the release of gases into the atmosphere that trap heat, contributing to the greenhouse effect. Due to their high global warming potential, these include emissions generated by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases [6]. Reducing the carbon footprint of cities is, therefore, one of today's major challenges. This includes assessing and measuring the impact of urban tourism on global GHG emissions to guide spatial and city planning decisions.

Tourism is a multidimensional phenomenon shaped by human, spatial, and temporal aspects, influencing how destinations are conceptualised. Initially defined as geographic areas attracting visitors [7,8], destinations have evolved into dynamic constructs shaped by visitor activities, consumption patterns, and socio–economic interactions [9–11]. Visitors navigate spatial and temporal constraints, making decisions that shape their itinerary, from destination selection to transportation and accommodation choices [12]. Tourist mobility, defined as travellers' continuous actions through space and time [13], has become increasingly complex.

Understanding visitor experiences and travel mobilities is essential for uncovering the underlying characteristics of tourist territories, providing key insights for strategic tourism and urban planning [14]. As destinations are now viewed as adaptive, experience-driven spaces shaped by technological advancements, cultural narratives, and sustainability concerns [15], integrating mobility patterns and visitor behaviours into destination management is crucial for fostering sustainable and resilient tourism systems.

One of the most pressing challenges in mobility and urban tourism is climate change because tourism generates 8.8% of the total global GHG emissions [16]. This figure is even higher in tourist countries like Spain, where tourism emits 14% of the country's CO_2eq [17].

To better face the climate emergency, we need to improve our understanding of visitor experiences and travel mobilities and better identify the functional orientations of these destinations. This calls for effective decision-making and knowledge-based support tools [18] to facilitate the shift towards more sustainable practices [19]. However, change will not occur solely through supply-side efforts (e.g., technological advances, industry restructuring, or public policy). Visitors play a fundamental role, as their consumption patterns significantly influence the ecological transition's pace [20,21]. Throughout the stages of travel planning and the journey experience, visitors possess the autonomy to determine the structure and components of their travel itinerary. The collective decisions made by urban tourists significantly influence the environmental performance of a place, particularly regarding the destination's emissions.

The quantification of energy consumption and the use of emission factors serve as one of the principal methodologies for estimating the carbon footprint of tourism [22–28]. Nevertheless, the literature estimating GHG emissions from tourism using this methodology lacks approaches that integrate the spatial dimension of tourism consumption into their analyses. Therefore, they do not provide sufficient information to destination managers about the composition of the environmental impact of their actions.

This study explores the GHG emissions of diverse visitors' travel behaviour. It looks at the impact of visitor choices on the carbon footprint of urban tourism destinations. To this end, the paper introduces a method for calculating the GHG emissions of tourist destinations based on visitors' consumption and itineraries, linking emissions to their mobilities, activities, and accommodations [25]. This approach combines an analysis of mobility patterns with emissions data, providing valuable insights at the local level. These insights can help inform urban policies essential for adapting to climate change [29].

The following section of this paper outlines the theoretical foundations supporting this research (i.e., time geography theories, tourist decision-making, and tourism carbon footprint calculation). Subsequently, we present the model for calculating and graphically representing tourism carbon footprint based on tourism decisions and travel sequences. This is followed by an empirical application of the model to the urban destination of Donostia/San Sebastián (Spain). This city is considered an exemplary case for implementing the proposed model, attributable to its compact urban structure that provides a balanced variety of accommodation types and transport options. Furthermore, its coastal location attracts diverse tourists, drawn by the natural environment and rich cultural heritage, including its cuisine and distinctive local character. Finally, this model's benefits and practical implications for tourism and destination management are discussed.

2. Theoretical Background

This paper builds on three theoretical frameworks. First, time geography-based models of spatial tourist interactions [30–32] serve as a foundation for understanding the dynamics of tourist movements. Second, recognising that visitor spatiality is shaped by a series of decisions, this research also draws on consumer behaviour theories [9,12] to explore the underlying determinants of these patterns. Third, the different methodological approaches used to quantify the GHG emissions generated by the different tourist itineraries of visitors are presented.

2.1. Tourist Itineraries and Spatial Behaviour Models

Time geography asserts that human activities are bound by space and time. Understanding visitors' economic and tourism consumption behaviours is essential, as their allocation of temporal and spatial resources shapes their overall experience [33,34]. Tourism activities occur through a time-space exchange, where specific locations or events act as stations [35], such as attractions, accommodations, or leisure areas. These activities can be fixed or flexible, forming a temporal path known as a tourist itinerary.

Research on tourism, space and mobility emerged in the late 20th century, recognising tourism as inherently involving travel [36–38]. Tourist spatial behaviour influences destination management, planning, and experience design [7,39].

Spatial behaviour in tourism reflects movement patterns tied to consumption activities [40]. Tourist itineraries comprise selected origin points, points of interest (POIs), and spatial connections, analysed at macro (home to destinations) and micro (intra-destination) levels [12,41]. Beritelli et al. [42] further classify itineraries into sequences and trajectories, where trajectories are movement units, and sequences combine these movements, revealing broader spatial behaviour patterns [9] (Figure 1).

2.2. The Role of Motivation and Other Visitor Behaviour Theories

Understanding tourist profiles is crucial for tourism stakeholders, as they reveal visitors' socio-demographic, geographical, and behavioural traits. These characteristics—such as travel motivation, preferences, and decision-making patterns—inform tailored experiences, destination management, and marketing strategies [43].

Motivation is central to visitor behaviour, influencing decision-making by addressing psychological and biological needs [44–47]. However, individual and contextual factors, including destination characteristics, also shape itinerary configurations [7,48,49]. Behaviour-based segmentation provides deeper insights into visitor preferences and motivations [14,50].

Tourist decision-making is dynamic and often uncertain, leading individuals to break it down into manageable steps, known as the 'microstructure of the trip.' This results in a 'portfolio of decisions', where overarching trip plans (macrostructure) guide subsequent choices [12].

Journey organisation involves interrelated subroutines, such as selecting destinations, arranging transport, securing lodging, planning activities, and preparing contingencies [51]. Hyde and Laesser [12] further identify key trip elements, including accommodations, attractions, dining, and shopping [52].

Decisions occur before, during, or after travel, varying in planning depth. Woodside and King [53] outline a three-tiered hierarchy: primary trip purposes (tier 1) influence accommodation and transport (tier 2), while spontaneous decisions shape experiences (tier 3). Given this study's focus and the carbon intensity of these actions [25], choices regarding destination activities, accommodation, and intra-destination transport are particularly relevant (Figure 2).

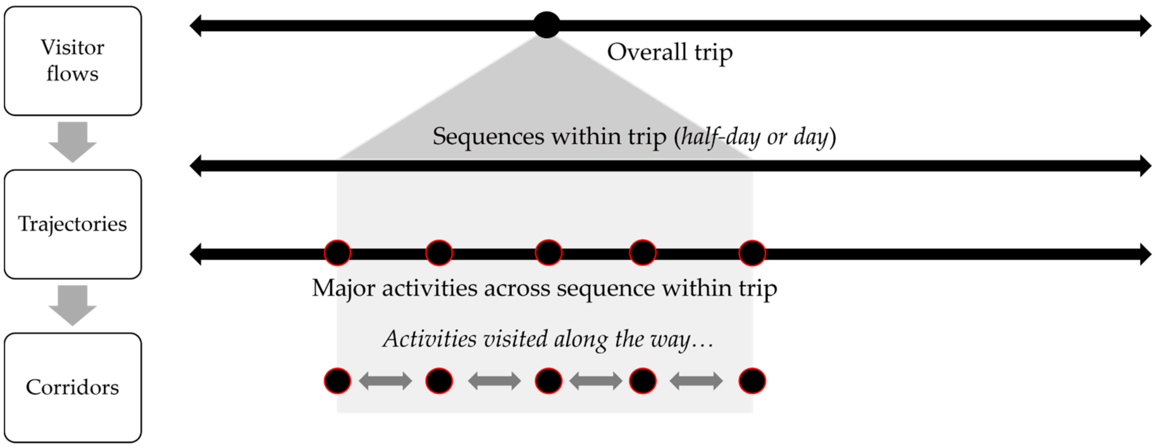

Figure 1. Defining visitor flows, trajectories and corridors of a tourist itinerary. Own elaboration, based on Beritelli et al. [9].

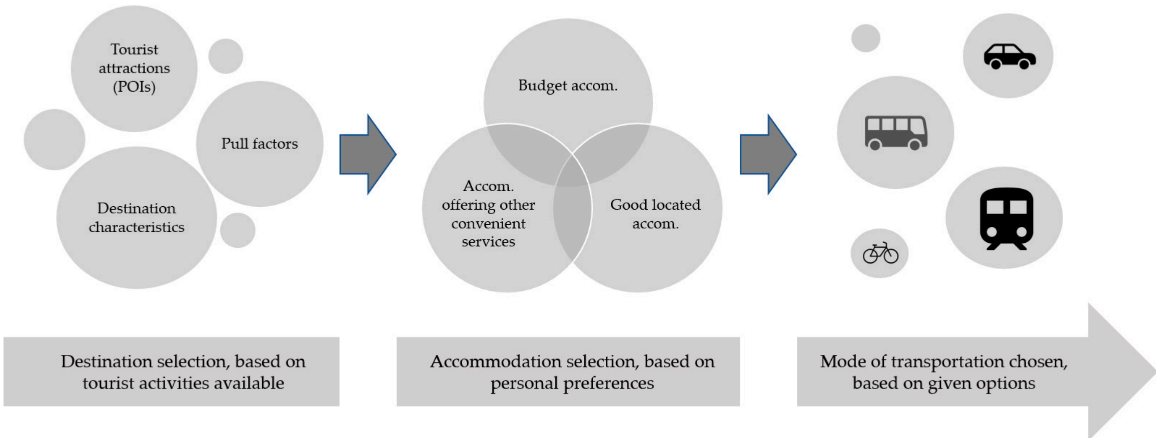

Figure 2. Tourists' key decision chain. Own elaboration.

2.3. Tourism GHG Emissions Estimation Approach

This section elucidates the foremost scholarly contributions to quantifying the tourism carbon footprint, emphasising the diverse scopes, scales, and methodologies employed by researchers to date. Research conducted on a local scale is of paramount importance for this study. As can be observed in the analysed literature, despite considerable variations in results and measurement units across these studies, attention is paid to parameters such as data inputs, methodological processes, and studied destinations, reflecting the varied approaches to tourism carbon footprint estimation (Appendix A).

Data collection strategies vary, encompassing bottom-up processes like visitor consumption surveys [54,55] and macroeconomic studies [23], each tailored to the specific requirements of the calculation method employed. The guidelines provided by the Intergovernmental Panel for Climate Change (IPCC) are a primary reference for these calculations [56], although some studies derive multipliers and standards from alternative sources [57]. Across these studies, emissions are calculated from door to door, encompassing all emissions generated by tourists from origin to destination and back [58], with most articles covering both direct and indirect emissions [59] and some delving into emissions throughout the supply chain [60].

There is a notable research gap in combining carbon footprint calculations with spatial interaction models in tourism. Few studies have examined visitors' itineraries and the emissions generated during these journeys. This paper addresses this gap by improving our understanding of the spatiotemporal distribution of emissions in tourist experiences. It contributes to tourist mobility theory by integrating carbon footprint calculations with potential itineraries for local opportunities.

Therefore, this paper presents a model to calculate and simulate the GHG emissions generated by visitors at specific tourist destinations based on key emission areas identified in past research [25,61,62]. The model is tailored to each destination's unique characteristics, considering accommodation types, transportation options, and visitor motivations.

3. Methodology: A Sequence-Based Carbon Footprint Calculation

3.1. Itinerary-Sequence Definition

Tourist movement can be characterised by its points of origin, the distances traversed, the POIs visited, the trajectories followed, and the frequency of these occurrences [63]. Within a tourist itinerary—as introduced in Figure 1—the ith sequence is composed of a number of activities or intermediate nodes (v) visited by the Travelling Group (TG) in a day—defined as the group of people travelling together, e.g., a couple or a family—which will involve a number of mobilities, and fulfil the constraint that the sequence starts and ends at an accommodation (A) (i.e., origin and destination node).

Spatiotemporal tourist behaviour models are based on several dimensions: territoriality, linearity, intensity, and specificity [7]. Territoriality refers to the spatial extent of tourist movements and their perception of distance, essentially reflecting how tourists consume space [11]. Movements can be limited to areas near the hotel (origin/destination node) or extend throughout the destination. Common indicators of *territoriality* include visited areas, distance travelled, or dispersal from accommodation.

Linearity describes the patterns and directions of tourist movements. Initially studied between destinations, it was later categorised within destinations into point-to-point, circular, and complex patterns [11]. The destination's layout influences these movement patterns, tourists' engagement, and existing tourist activities or POIs [7].

In urban areas, tourists often visit multiple tourist attractions within the same destination, planning sequences that encompass a variety of activities [64]. Therefore, *intensity* refers to the number of activities done in a day [65]. This concept reflects the quantity and quality of interactions with the destination, with daily visit duration as a key measure in urban tourism studies [7].

Lastly, *specificity* involves identifying the POIs visited and their unique characteristics [65]. Studies often use specific attractions to describe visitation patterns. The transitions between activities, their sequence, and the types of activities are key descriptors of tourists' time-space activities [7].

Considering these main dimensions of the spatiotemporal tourism models, the different types of existing sequences are depicted below. These sequences reflect the different potential territorialities, linearities, intensities, and specificities of urban tourists' itinerary sequences (Figure 3).

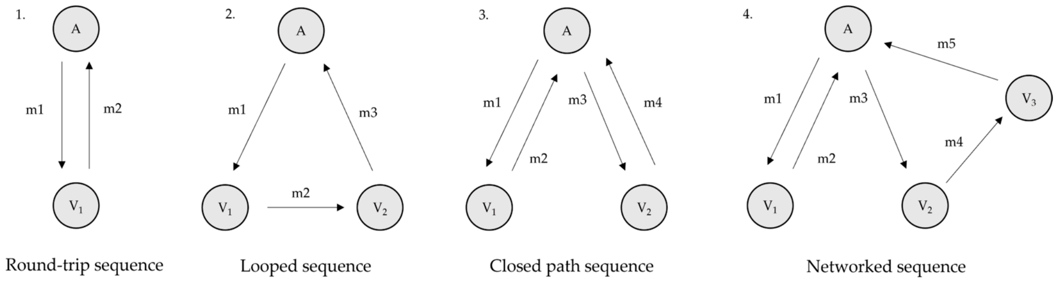

Figure 3. Types of itinerary sequences: single vs. combined (direct and indirect) sequence. Own elaboration.

The number of trips derived from each of the displayed sequence types is defined as follows:

- Round-trip sequence: a path that starts where it began, only stopping at one intermediate node. It is characterised by simple linearity and low intensity.

$$No.mobilities\ (m) = v + 1 \tag{1}$$

- Looped sequence: a multi-attraction (POI) sequence that returns to the origin point after traversing several intermediate nodes (see Equation (1)).
- Closed path sequence: a multi-attraction (POI) sequence that returns to the origin point each time an intermediate node is visited.

$$No.mobilities\ (m) = v \times 2 = (v + 1) + (v + 1) \tag{2}$$

- Networked sequence: a multi-attraction (POI) sequence consisting of at least two of the previously mentioned types of paths. It is regarded as the most intense and linearly complex type of sequence.

$$No.mobilities\ (m) = (v \times 2) + (v + 1) \tag{3}$$

The type of sequence developed by the TG would be dependent on the distance and time required to get between points A (origin/destination nodes) and v (intermediate nodes), the urban-physical characteristics of the site, and the preferences of the visitors themselves. Regarding urban characteristics, notable aspects include the availability of diverse transportation options and the comprehensive services provided by tourist facilities, including dining services within tourist accommodations.

Tourists' decisions often balance time spent travelling and time at POIs, influenced by individual preferences, group dynamics, and available time. 'Outcome-oriented' tourists minimise transit time to maximise their main activities, while 'process-oriented' tourists value the journey, enjoying indirect routes and exploring more areas [11].

However, the cumulative impact of activities, accommodation, and transport determines visitors' final emissions. This suggests that no specific sequence inherently reduces emissions. Instead, environmental impact depends on travel distances, accommodations, and activities. Thus, individual choices, like sustainable lodging, may not always reduce overall emissions.

The sequence of decisions is crucial in shaping the overall itinerary. Visitors first choose activities at the destination, driven by primary attractions (pull factors) [52]. Next, tourists select accommodations based on economic and convenience factors aligned with group preferences [66]. Finally, they choose the most suitable transport, sometimes limited by regional options. This decision structure informs the proposed model.

3.2. Quantification of Carbon Footprint Emissions

The tourism carbon footprint is calculated by estimating energy consumption, fuel usage, and other inputs that release CO_2eq emissions [67]. The proposed model focuses on the assessment of the total emissions of a trip in terms of the different scheduled sequences (E_i). Accordingly, Equation (4) defines the total emissions of tourism activity (E_T) developed by a travelling group (TG) as follows:

$$E_T = \sum_{i=1}^{n} E_i \tag{4}$$

E_i is the total emissions of the ith sequence out of the total number of sequences (n) run by the TG. TG is defined as a group of people travelling together (e.g., people travelling within the same package tour) [68], a condition for the emissions attributable to these visitors. The emissions decomposition of each sequence is calculated using the following equation:

$$E_i = EA_i + ED_i + EV_i \tag{5}$$

where EA_i corresponds to the emissions related to the stay in the accommodation of the ith sequence, ED_i shall be the emissions relative to the total mobilities of the sequence and EV_i gathers the emissions from the visits and activities experienced in the different tourist POIs visited in this sequence.

3.2.1. Emissions Caused by Tourist Activities

Visitors' primary trip motivation drives their destination choice and planned activities [52]. Although these activities do not directly affect accommodation or transportation choices, they significantly influence the trip's itinerary and sequence. Thus, the proposed model initially assesses the GHG emissions from tourism activities.

The emissions generated by the activities—or visits to POIs—in an ith sequence shall be calculated as the sum of the emissions generated by each of the visits made, following the following equation where EV_k coincides with the emissions for the kth visit, while v will be the total number of visits to the ith sequence.

$$EV_i = \sum_{k=1}^{v} EV_k \tag{6}$$

For this purpose, the average emissions generated by TG in the kth activity are defined with the following equation. Thus, EV_k can be computed as the product of the emissions per visitor and the number of TC components.

$$EV_k = \frac{Annual\ activity\ kg\ CO_2eq}{Annual\ no.visitors} \times N \tag{7}$$

It is noteworthy that the emissions linked to both accommodation and tourist activities are derived from the establishment's annual emissions data. This information is then used to calculate emissions per person, subsequently multiplied by the total number of visitors making up the target group.

To accurately assess the emissions generated by tourism activities within an urban destination, it is imperative to categorise these activities based on their inherent characteristics. Tourists' activities to complete their itinerary can be classified into two principal groups [54]. Firstly, tourist attractions (or POIs) are distinguished by their precise locations. This category encompasses museums and collections, areas of architectural significance, recreational areas, exhibition centres, and other types of urban establishments that could work as tourist attractions: restaurants, shops, or spa centres. Upon visiting these attractions, entering their premises, or utilising their amenities, tourists engage with the facilities provided (Table 1).

Table 1. GHG emissions of different types of urban tourist activities (Scopes 1 and 2).

POIs	POI Definition	kg CO_2eq/Visit	Source
Exhibitions centres	Cinemas, theatres, sporting complexes, or theme parks	1.679	Becken and Simmons [54], Rico et al. [55]
Museums and collections	Art galleries, museums, or visitor centres	1.976	
Recreational areas	Natural attractions (caves, beaches, or mountains)	0.593	
Sites of architectural interest	Historic buildings	0.988	
Other tourist attractions	Restaurant services	0.309 [1]	Özgen et al. [69], Ab Aziz et al. [70], Sha'ari et al. [71], Razali et al. [72], Wongrattanatham et al. [73]
	Shops	0.988	Rico et al. [55]
	Wellness/Spa centres	6.093 [1]	Atalay et al. [74]

[1] An average of 50 visitors per day has been assumed to obtain the disaggregated emission factor. Own elaboration.

Secondly, tourist activities include those endeavours that tourists undertake along tourism corridors or within broader areas of the destination. These activities encompass motorised excursions such as boat trips, as well as other forms of engagement like city tours and guided visits (Table 2).

Table 2. GHG emissions of primary types of urban tourist corridors (Scopes 1 and 2).

Type of Tourist Corridor	Corridor Definition	kg CO_2eq/Visit
City tours	Walking tours that reach the prominent landmarks of the city.	0.0
Special tourist transport	Corridors were travelled on a type of tourist transport, such as boats, trains, or tourist buses.	1.173

Own elaboration based on Rico et al. [55].

Some urban scholars relate the term 'corridor' to a linear system of urban places along with the connecting surface transport media [75]. However, given its complexity, this is not always accurate in the inner city. Yet, the concept of landmarks associated with a path, collectively forming a new area in the city, marks the initial step towards the current use of a tourism corridor. An easily navigable city would be one where its landmarks or pathways are readily recognisable and can be seamlessly integrated into a cohesive overall pattern [76].

> "Paths are the channels along which the observer customarily, occasionally, or potentially moves. [. . .] People observe the city while moving through it, and along these paths the other environmental elements are arranged and related. [. . .] Landmarks are another type of point-reference, but in this case the observer does not enter within them, they are external" [76] (pp. 41–42).

From a tourist point of view, landmarks could be attractions in how the current research is introduced, and pathways around these points could be considered tourist corridors. Thus, in tourism studies, corridor means the concentration of activities that are getting along/making their way in an area [42]. Therefore, these corridors relate to passive or contemplative tourism. This type of tourist activity is quite common among visitors to urban destinations [77], and as they do not directly engage with these landmarks, zero GHG emissions are attributed to them (Table 2).

Recognising that each activity reflects specific traveller profiles and motivations is crucial. For example, museums attract culturally motivated tourists, while recreational activities appeal to nature enthusiasts. Consequently, urban tourist activities shape the visitor profiles they attract.

3.2.2. Emissions Caused by Accommodation Usage

Previous research found that the location of a hotel significantly influences tourist activities, with a substantial portion of their time spent near the hotel [78]. Similarly, these activities individually condition the use of the hotel and the available facilities. In statistical terms and applying the laws of large numbers, we can state that the expected value of emissions caused by TG in the *i*th sequence could be estimated with the following equation:

$$EA_i = E_{aT} \times D \times N \times 1/n \tag{8}$$

where E_{aT} represents the expected value of emissions per person per day according to Equation (9), N is the number of people in the TC, D is the number of days of the hotel stay, and n is the total number of sequences in the trip.

$$E_{aT} = \frac{Annual\ hotel\ T\ CO_2/365}{Annual\ occupation\ rate} \tag{9}$$

Well-established global frameworks systematically collect detailed data on GHG emissions generated by the tourism accommodation sector, following specific calculation methodologies. The Hotel Carbon Measurement Initiative (HCMI) is recognised as the leading international approach for tracking the carbon footprint of tourist accommodations, specifically regarding Scopes 1 and 2 emissions. The Cornell Hotel Sustainability Benchmarking (CHSB) Index 2023 includes registrations from over 25,000 accommodations. Specifically, 'Rooms' footprint per occupied room in kg CO_2eq' and 'Hotel energy usage per occupied room in kWh' serve as the key parameters to consider when deriving the E_{aT} [79,80] (Table 3).

Table 3. HCMI hotel emissions by country.

Country	Rooms Footprint per Occupied Hotel Room (kg CO_2)
Austria	22.00
Belgium	25.27
Canada	19.37
China	62.80
France	12.17
India	58.88
Japan	72.30
Mexico	34.96
Poland	57.39
Spain	16.22
Turkey	53.20
United Kingdom	14.34
United States	18.25

Own elaboration based on HCMI [79].

Scholars have broadened their examination of GHG emissions beyond hotels [81], including the annual energy consumption of tourist accommodations. Rico et al. [55] calculated a range of emission factors that are extensively cited in the literature [82] (Table 4).

Table 4. Tourist accommodation emission factors (Scope 1 and 2).

Type of Accommodation	kg CO_2eq/Overnight Stay
Guesthouse	2.821
Tourist apartment	4.087
Hostels	2.821

Own elaboration based on Rico et al. [55].

A key limitation of existing data sources is their lack of consideration for the spatial distribution of accommodations within a destination—an essential factor for accurately calculating visitors' distances in our model. To address this, our study clusters accommodations based on two primary criteria: location and accommodation type. For this purpose, we employ the K-Prototypes method specifically designed to handle mixed data types.

Unlike clustering techniques such as K-Means, which works exclusively with numerical data, or K-Modes, which are limited to categorical data, K-Prototypes combine the strengths of both methods. It utilises Euclidean distance for numerical data (e.g., spatial coordinates) and Hamming distance for categorical data (e.g., accommodation types), allowing for the creation of clusters that reflect both physical proximity and categorical similarity [83]. This dual capability makes K-Prototypes suitable for clustering accommodations by location and type, yielding spatially relevant and meaningful groupings.

Additionally, the classification within each cluster is enhanced by incorporating emission factors established by the HCMI for hotels [80] and by Rico et al. [55] for other accommodation types. This integration ensures that the clusters are not only spatially coherent but also environmentally informative, aligning with the study's broader goals of sustainability analysis.

3.2.3. Emissions Caused by Transportation Usage

Concerning the concept of locomotion [7,11], which refers to the ability to move from one node to another along the sequence, this section elucidates the methodology for calculating GHG emissions resulting from tourist activities and movements in the ith sequence:

$$ED_{i=}\sum_{z=1}^{v+1} ED_z \tag{10}$$

$$\mathrm{ED_z} = \mathrm{e_z} \times \mathrm{d_z} \tag{11}$$

ED_zbeing the emissions of the zth mobilities of the total that exist in the complete sequence. The value of each ED_z could be calculated by the characteristics of the vehicle used to travel, with the value of e_z, corresponding with the territory's emission factor (gCO_2eq/km) set.

For instance, considering EEA's emission factors [84] for combustion road transportation, the fuel efficiency levels (0.056 L/km and 0.076 L/km for diesel and petrol cars [85,86]; 0.465 L/km for diesel buses [87]; 0.04 for motorcycles and mopeds) [88], and assuming a fuel density of 0.811 kg/L and 0.735 kg/L for diesel and petrol, respectively [88], Table 5 gives the 'gCO_2eq/passenger-km' for Spain.

Similarly, the European Commission [89] estimates an emission factor of 174 g CO_2eq/kWh for electric transport in Spain, which is multiplied by the electricity consumption of these vehicles (cars: 0.15 kWh/km [90]; buses: 1.591 kWh/km [91]; metro: 1.3 kWh/km [92]), allows us to estimate the values shown in Table 5 for electric urban transport such as metro or train in Spain.

Table 5. Spanish urban transportation emissions: gCO_2eq/passenger-km.

Type of Transportation	gCO_2eq/km/Passenger [1]
Passenger cars: diesel	28.885
Passenger cars: petrol	35.080
Electric cars	5.220
Buses	12.647
Electric buses	3.374
Mopeds	47.775
Motorcycles	46.011
Urban train/Metro	0.419

[1] The value per passenger has been calculated assuming full occupancy of the vehicles in their respective capacities (e.g., car: 5 places; bus: 82; electric bus: 56 [93]; mopeds and motorcycles: 2; and urban train/metro: 540 places commonly in Spain [94–96]). Own elaboration, based on Tica et al. [81], EEA [84], Repsol [85], Motor Mapfre [86], EAMA [88], EC [89], AEM [91], MetroMadrid [92] and Endolla Barcelona [95].

These values, multiplied by the corresponding distance travelled d_z (km), provide the value that will be calculated differently depending on the type of transport used for each journey in the sequence. Within a distance matrix formulated with potential origin/destination nodes and intermediate nodes, energy and fuel consumption values are assigned for the various modes of transport available in a specific urban setting. This distance matrix will provide three data outputs: the time taken to travel this distance, kilometres separating the origin/destination node and possible intermediate nodes, and the GHG emissions implied by each of the journeys.

The proposed calculation methodology employs a bottom-up approach, adhering to the energy/fuel-consumption method and incorporating emission factors derived from the established literature and international standards. This method encompasses emissions within a partial scope, akin to a door-to-door framework, focusing exclusively on the direct emissions generated from the visitor's arrival at the hotel to their departure. These emissions are predominantly within the control of local tourism stakeholders. Given that the model's primary focus is on the on-site part of the trip at the destination level, this methodology pertains to a local geographical scope. It incorporates calculations for both inbound and outbound tourists. In summary, the methodological process outlined in Equation (4) enables the quantification of GHG emissions—expressed in kilograms of CO_2eq emitted by the TG—generated by tourists during their stay in the city. This model comprehensively encompasses both direct and indirect GHG emissions, adhering to the guidelines established for Scopes 1 and 2 by the GHG Protocol [97].

4. Empirical Application of the Model: A Case Study for Donostia/San Sebastián

Once proposed, this model was applied to a real case destination, Donostia, in northern Spain. Donostia/San Sebastián—hereinafter Donostia—is an urban and coastal city in the Basque Country with an area of 61sqkm [98]. This city has 182,892 inhabitants and a population density of 2998 per sqkm [99]. As mountains surround the city and the Cantabrian Sea, its horizontal expansion is limited, which favours a more concentrated and compact urban development (Figure 4).

Its robust public transport network complements the city's solid mobility of pedestrians and cyclists. Developing cycle lanes and pedestrian zones enhances the city's compact nature by prioritising short-distance trips [100].

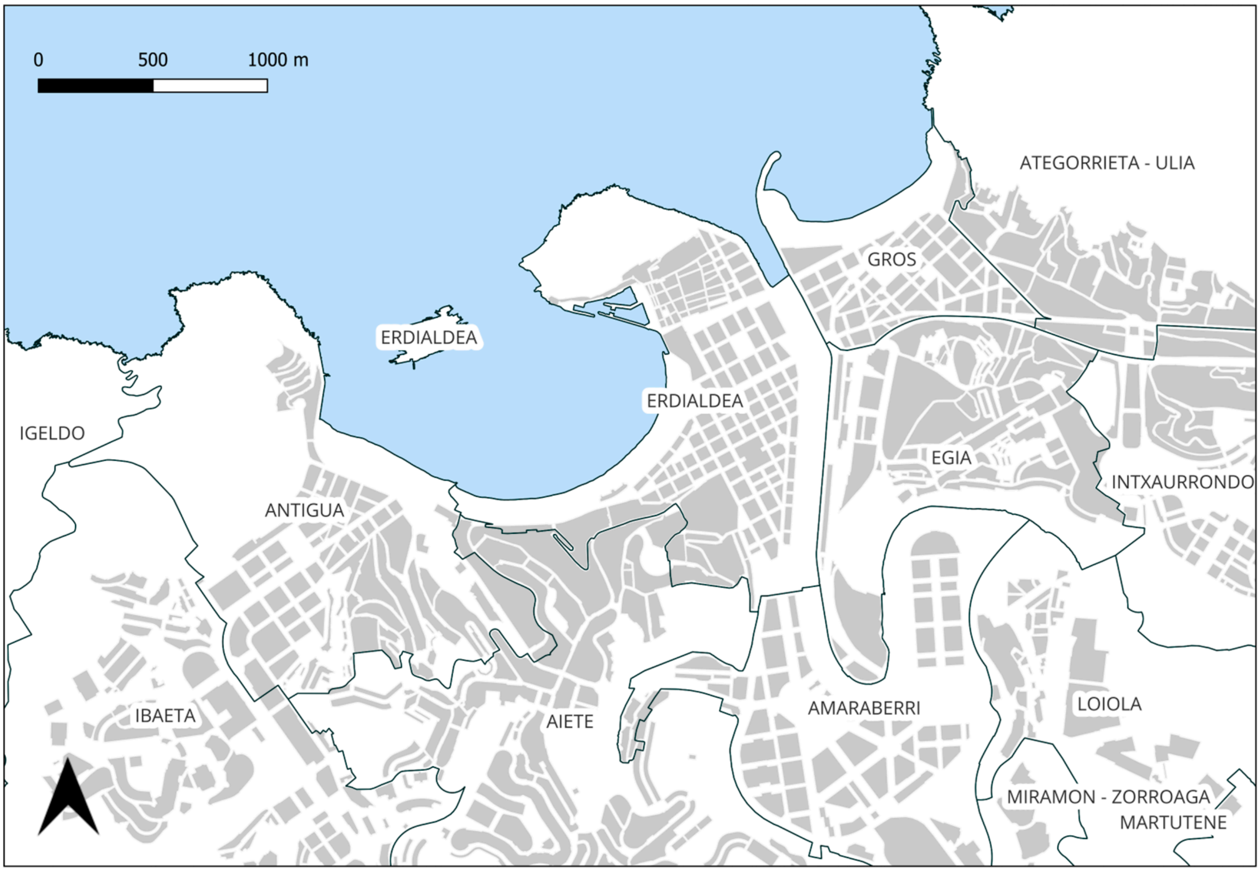

Figure 4. Donostia: neighbourhood delimitation of the city. Own elaboration, based on Donostiako Udala [101].

The city attracts approximately 950,000 visitors per year. It boasts a wide range of socio-economic profiles. It serves as a destination for travellers with diverse motivations [102], which makes it a compelling case for testing the model proposed in this study. Based on the classification provided by the Spanish National Institute of Statistics [103], these visitors can be broadly categorised into three primary groups based on their main travel motivations: (i) culture and heritage, (ii) nature and outdoor recreation, and (iii) others.

A survey was conducted in Donostia to test the proposed model. A market research firm guarantees a diverse participant pool and an appropriate sample size to achieve the research objectives. The data collection, developed between January and April 2024, adhered to ISO 20252 [104] and ICC/ESOMAR [105] guidelines, ensuring ethical research practices.

A total of 301 valid responses were obtained, showing that 50.50% of visitors to the city arrive with cultural and heritage motivations, followed by 13.62% of visitors whose motivation is to enjoy nature and the local environment, and 36.89% attracted by other aspects, such as business tourism.

On average, tourists arriving in Donostia engage in two daily activities. However, relevant variations in this parameter are also perceived depending on the primary motivation of the trip. Table 6 delineates a range of critical attributes relevant to visitor profiling based on average results obtained in the data collection through the survey on their behaviour. The generalisation of the results is acknowledged as a limitation of the proposed model; however, it is considered desirable for the model's scalability to include the total number of visitors to a destination. Acknowledging its inherent biases, we will extrapolate the sequences of the primary itineraries that these visitors typically follow based on these attributes.

Table 6. Urban tourist of Donostia: profiling data.

Average Visitor Profile	Culture and Heritage	Nature and Outdoor Recreation	Others
Number of POIs visited per day	2.16	2.22	1.84
Main intra-destination transport	Cycling or walking Urban bus	Cycling or walking Urban bus Fuel car	Cycling or walking Urban bus
Travelling group (TG) components	2.28	2.05	1.41
Length of stay (nights)	2.07	3.07	3.00
Main type of accommodation	Apartment 4-star-hotel	Apartment 4-star-hotel	Apartment Hostel Guesthouse
Main neighbourhood chosen for accommodation	Erdialdea Gros	Erdialdea Antiguo	Erdialdea Gros

Own elaboration.

Among the primary tourist activities pursued by these groups of visitors are those outlined in Table 7. By the classification of activities provided earlier in this paper, Figure 5 indicates the locations of the city's main attractions (i.e., POIs). For this depiction, gastronomic activity occurs in the Old Part of Donostia—in the Erdialdea neighbourhood, beneath Mount Urgull—due to its high concentration of restaurants offering quintessential 'pintxos' and accounts from visitors to haute cuisine or Michelin-starred establishments specifying these visits.

Table 7. Main activities undertaken by main tourist profiles (motivations) in Donostia.

Tourist Activities and POIs	Culture and Heritage	Nature and Outdoor Recreation	Others
Gastronomy	40.13%	12.20%	25.00%
Walking around the city	39.58%	46.34%	38.90%
Tamborrada (i.e., local festivity)	24.34%	17.07%	22.22%
La Concha beach	16.45%	19.51%	17.59%
Mount Igueldo	10.53%	12.20%	3.70%
Mount Urgull	8.55%	2.44%	1.85%
Churches and cathedrals	6.58%	-	1.85%
Spa/Thalassotherapy	3.94%	4.88%	0.93%
Football/Reale Arena	3.94%	12.20%	-
Museums	3.95%	17.07%	7.41%
Nature/Hiking	1.97%	12.20%	3.70%
Concerts/Theatre	0.66%	-	3.70%
Surf	-	4.88%	0.93%
Cider restaurant	3.29%	-	1.86%
Tourist train	-	2.44%	-

Own elaboration.

4.1. Tourist Activities Emissions in Donostia

Drawing from the survey results of tourists in Donostia, the principal POIs have been categorised according to their respective typologies (Table 8). Figure 6 cartographically delineates the principal tourist corridors within the city, as per the previously articulated definition of corridors.

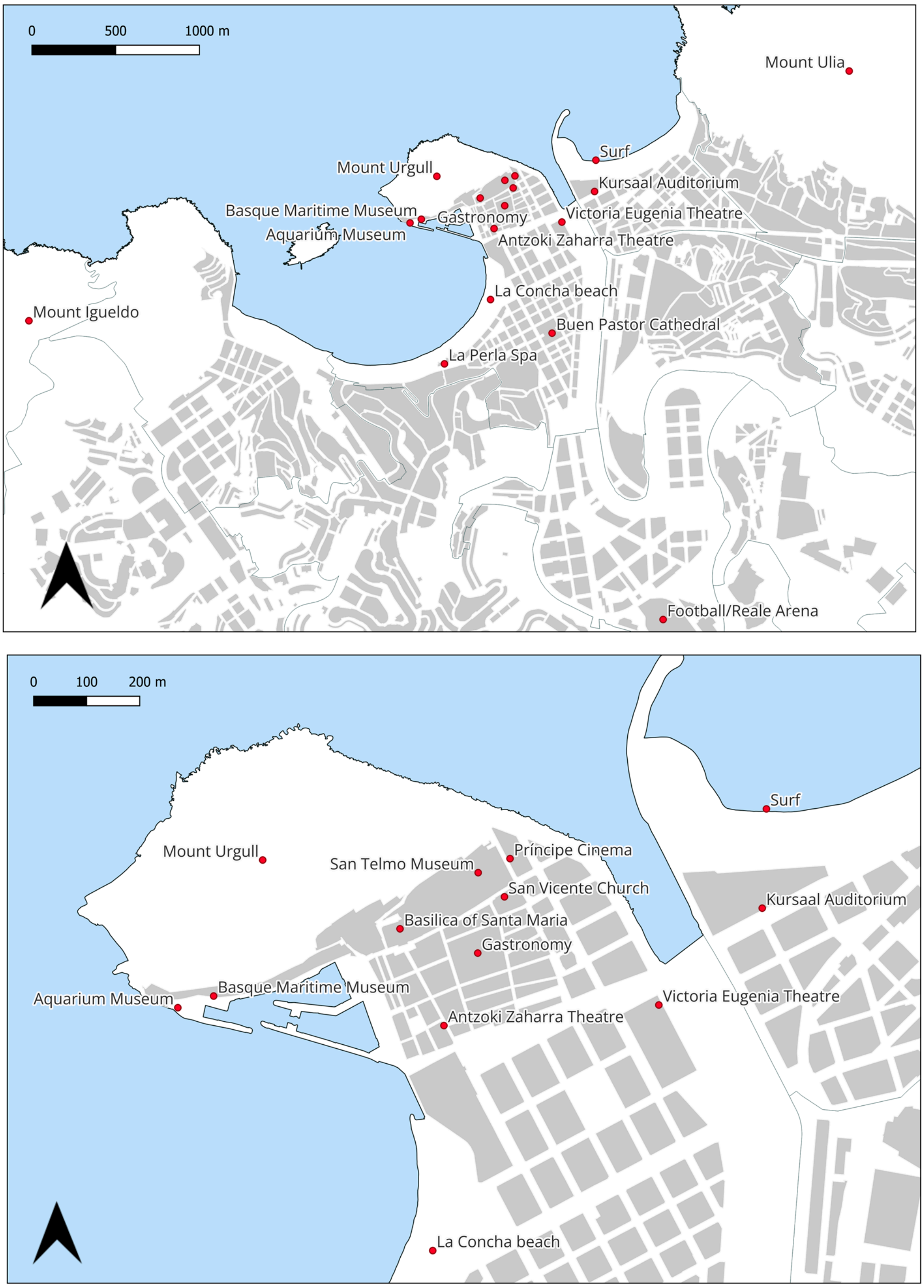

Figure 5. Location of main points of interest (POIs) in Donostia. Own elaboration.

Table 8. Types of points of interest (POIs) in Donostia.

Activity	Type of POIs
Gastronomy	Others: restaurant services
La Concha beach	Recreational area
Mount Igeldo	Recreational area
Mount Urgull	Recreational area
Churches and cathedrals	Sites of architectural interest
Spa/Thalassotherapy	Others: spa centres

Table 8. *Cont.*

Activity	Type of POIs
Football/Reale Arena Stadium	Exhibition centres
Museums	Museums and collections
Nature/Hiking	Recreational area
Concerts/Theatre	Exhibition centres
Surf	Recreational area
Cider restaurant	Others: restaurant services

Own elaboration, based on Rico et al. [55].

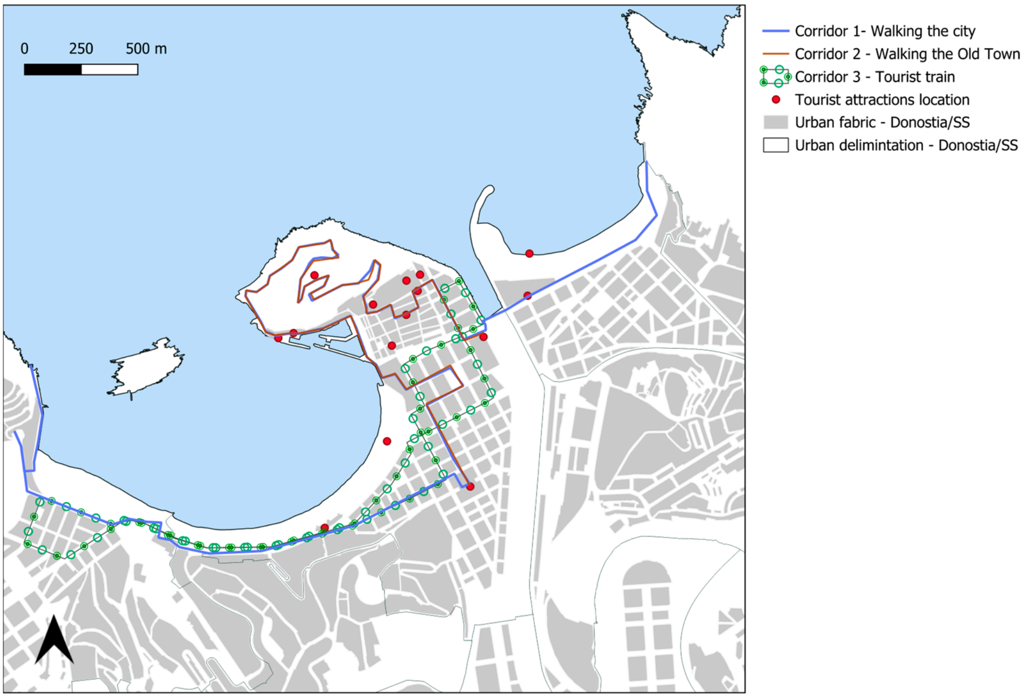

Figure 6. Main tourist corridors in Donostia. Own elaboration based on San Sebastian Turismo [106] and San Sebastian City Tour [107].

Many of these activities are transversal to the trip motivation. However, significant differences in the intensity of the sequences for each visitor segment have been identified. Tourists motivated by nature and the environment engage in more intensive and more territorial sequences. In contrast, tourists with different motivations than those identified in this study engage in less intensive sequences, which may lead to linearly more straightforward outcomes sequences.

In Donostia, most hotel accommodations do not offer restaurant services; 'bed and breakfast' is the predominant accommodation regime. This is significant for defining the sequence, as it reduces the likelihood of tourists returning to their accommodations for meals (e.g., 'closed path sequence' in Figure 3). However, this could be a viable option for tourists with more intensive sequences, such as those motivated by environmental factors.

We aim to calculate the emissions of the two potentially predominant sequences for each visitor profile. Consequently, Table 9 illustrates, alongside the activities designated for each profile, the two distinct types of sequences that exemplify the carbon footprint calculation model proposed in this paper. The local festivity recognised as a principal activity for city visitors (i.e., Tamborrada) is excluded from the design of these sequences. This exclusion is due to its nature as a seasonal event, which does not generally alter the spatial sequences of tourists throughout the remainder of the year.

Table 9. Types of sequences and tourist activities for each tourist profile in Donostia.

Tourist Profile	Type of Sequence	Tourist Activities and POIs
Culture and heritage	Looped sequence ($v = 2,\ m = 3$)	1. Gastronomy; 2. Walking around the city.
	Closed path sequence ($v = 2,\ m = 4$)	1. La Concha Beach; 2. Mount Igeldo.
Nature and outdoor recreation	Looped sequence ($v = 2,\ m = 3$)	1. Walking around the city; 2. La Concha Beach.
	Closed path sequence ($v = 2,\ m = 4$)	1. Football/Reale Arena Stadium; 2. Mount Igeldo.
Others	Looped sequence ($v = 2,\ m = 3$)	1. Walking around the city; 2. Gastronomy.
	Closed path sequence ($v = 2,\ m = 4$)	1. La Concha Beach; 2. Museums.

Own elaboration.

4.2. Tourist Accommodation Emissions in Donostia

The data regarding visitors' preferred types of accommodation is systematically categorised as follows: guesthouses, hostels, tourist apartments, 1-star hotels, 2-star hotels, 3-star hotels, 4-star hotels, and 5-star hotels. The initial phase in calculating the carbon footprint of the accommodations involved clustering them based on their classification and geographical location. Before conducting the cluster analysis, missing values in the dataset were imputed.

Bayesian imputation is ideal for categorical data as it models category probabilities, incorporates prior knowledge, handles uncertainty, accommodates non-normal data, preserves variable relationships, and supports mixed data types, resulting in more accurate and robust outcomes [108]. Consequently, a Bayesian approach was employed for the 24 instances with missing accommodation category data. The mice R package (R Studio 2024.12.0+467) was leveraged to obtain missing data by applying a predictive mean matching (pmm) method in 50 iterations with a seed value of 123.

To complete the variable of accommodation locations, secondary data sources were utilised, including information provided by the Spanish governmental tourism organisation SEGITTUR for hotel and non-hotel accommodations and data from Inside Airbnb© detailing the specific locations of rented rooms and flats. Specifically, data scrapped for the Basque Country (Spain) was used for this case. From the locations gathered in these databases, the spatial distribution of accommodations by neighbourhoods was extracted, and the centroids of these areas were imputed accordingly to address the missing values (n = 153).

Hence, the results derived from the use of the K-Prototypes algorithm in R Studio (2024.12.0+46)—optimally organised into 14 clusters with a predominant type of accommodation—are presented in Table 10 and Figure 7.

Table 10. Accommodation cluster summary in Donostia.

Cluster	n	Average Latitude	Average Longitude	Main Accom. Type	Neighbourhood
C1	46	43.3226108	−1.973160922	Tourist apartment	Gros
C2	2	43.26264784	−2.918452724	4-star-hotel	Bilbao [1]
C3	13	43.30676945	−1.973886586	Guesthouse	Amaraberri
C4	89	43.31744894	−1.983745966	Tourist apartment	Erdialdea
C5	8	43.31937391	−1.866777496	3-star-hotel	Oiartzun [2]

Table 10. *Cont.*

Cluster	n	Average Latitude	Average Longitude	Main Accom. Type	Neighbourhood
C6	14	43.3149228	−2.0058699	Tourist apartment	Antiguo
C7	13	43.31205712	−2.006431724	4-star-hotel	Antiguo
C8	2	43.31413151	−2.009240152	Guesthouse	Antiguo
C9	8	43.3245535	−1.969011814	Guesthouse	Gros
C10	19	43.30425854	−2.022325773	Hostel	Ibaeta
C11	14	43.32324854	−1.983463102	Guesthouse	Erdialdea
C12	41	43.31329499	−1.983249965	4-star-hotel	Erdialdea
C13	14	43.31281488	−1.988889602	3-star-hotel	Aiete
C14	18	43.31628173	−1.983433996	Guesthouse	Erdialdea

[1] Capital city/destination (>100 km from Donostia-SS). [2] Peripheral municipality of Donostia. Own elaboration.

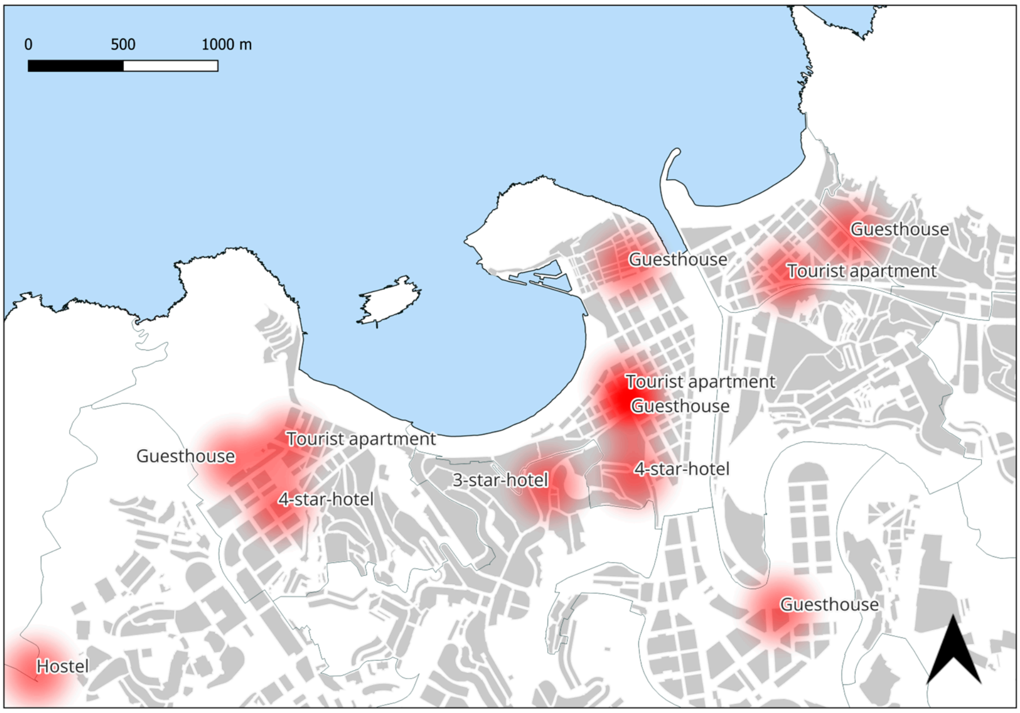

Figure 7. Location of accommodation clusters in Donostia. Own elaboration.

Once the accommodations have been clustered, GHG emissions are allocated to each case. The CHSB Index 2023 methodology allows data filtering based on country or climate zone. Climate zones are key to determining emissions because heating and air conditioning, where applicable, are some of the most important sources in hotels. The CHSB Index includes 646 geographies and 87 climate zones [79,80]. Generally, the climate zone segmentation relies on two classification systems: Köppen–Geiger (temperature and precipitation patterns) and Bailey's Ecoregions (ecological characteristics) [109]. Their combination enhances our understanding of unique environmental conditions. Based on the possibilities offered by CHSB Index 2023, the location of our empirical approximation would be considered a 'forest-meadow of constantly humid eastern oceanic type'. According to the data recorded for 2023, we can estimate an average carbon footprint of 32.69 kg CO_2eq/occupied room for urban hotels located in Donostia. Considering that the double room represents the most prevalent typology across various hotel categories, it is projected that each tourist staying in a hotel in San Sebastián has an individual carbon footprint of 16.35 kg CO_2eq.

For the other categories of accommodation, the emission factors in Table 4 [55] are applied. Table 11 presents the estimated emissions for each of the accommodation clusters identified in Donostia.

Table 11. Emission data for accommodation clusters in Donostia.

Cluster	Most Common Accom. Type	kg CO_2eq/Overnight/Person
C1 C4 C6	Tourist apartment	4.2
C2 C7 C12	4-star-hotel	16.35
C3 C8 C9 C11 C14	Guesthouse	2.9
C5 C13	3-star-hotel	16.35
C10	Hostel	2.9

Own elaboration, based on Rico et al. [55] and HCMI [79].

Combining the preferences of accommodation type and area (Table 6), each visitor profile has been assigned an accommodation cluster from which to start and end each sequence of their journey (Table 12).

Table 12. Transportation emissions for main sequences in Donostia.

Tourist Profile	Type of Sequence	Type of Transport.	Sequence	Dist. and Emissions
Culture and heritage	Looped sequence	Walking	Tourist apartment → Gastronomy → Walking around the city → Tourist apartment	6.3 km 0 g CO_2eq
	Closed path sequence	Urban bus [1]	4-star-hotel → La Concha beach → 4-star-hotel → Mount Igeldo → 4-star-hotel	11.4 km 144 g CO_2eq
Nature and outdoor recreation	Looped sequence	Walking	Tourist apartment → Walking around the city → La Concha beach → Tourist apartment	4.41 km 0 g CO_2eq
	Closed path sequence	Fuel car	4-star-hotel → Football/Reale Arena Stadium → 4-star-hotel→ Mount Igeldo → 4-star-hotel	13.2 km 422 g CO_2eq
Others	Looped sequence	Walking	Tourist apartment → Walking around the city → Gastronomy → Tourist apartment	5.75 km 0 g CO_2eq
	Closed path sequence	Urban bus	Guesthouse → La Concha beach → Guesthouse→ Museums → Guesthouse	4.4 km 55 g CO_2eq

[1] Because less than 16% of the Donostia city bus fleet is electric [94], these sequences have been calculated using the emissions related to fuel buses (i.e., diesel). Own elaboration.

4.3. Tourist Transportation Emissions in Donostia

Finally, Google Maps' data were leveraged to compute tourists' transportation emissions in diverse modes of transport from their anchor points to the existing POIs in the city. To validate the data, journey times from Google Maps were compared with those from the Donostia bus company (DBUS). The differences were minimal: Line 8 took 5 min (DBUS) versus 4 min (Google Maps) from La Concha Beach to the C9 cluster; Line 16 took 23 min for both sources from La Concha Beach to Mount Igeldo; Line 25 took 13 min for both from the gastronomy POI to the C8 cluster [110].

The centroids of clusters derived from the tourist accommodation analysis and main tourist POIs have been employed to construct the distance matrix displayed in the Supplementary Materials File. In those cases where tourist attractions are composed of several POIs, one of the attractions has been taken as a reference for the calculation of distances (e.g., aquarium as a representative POI for museums).

Among the available public transport options, surveyed tourists exhibit a marked preference for walking, cycling, and using city buses. This preference is attributed mainly to the compact size of the destination studied (61 sqkm).

For each visitor profile, urban bus and walking mobility were assigned to each potential sequence for which GHG emissions were calculated. Taking into account that the centroid of the accommodation cluster assigned to each sequence has a location more or less distant from the main concentration of POIs (Figure 5), the urban bus has been assigned as the primary type of transport in those cases where the accommodation was more distant from the frequented POIs.

Combining the emission factors set out in Table 5 with the distances obtained in our matrix, it is concluded that the GHG emissions generated by visitors on journeys occurring during their travel sequences are as shown in Table 12.

Accordingly, Table 13 represents the results of the concatenated model of emissions associated with the tourists' activities, transportation, and accommodation preferences of predominant traveller profiles in the city of Donostia. As an example, Figure 8 illustrates the spatial distribution of the most significant emission sequences identified in the calculations. These sequences pertain to visitors drawn by the city's natural allure, who opt for accommodation types characterised by high emission intensities. Figure 9 presents the cartographic depiction of the predominant sequence type recurrently observed among visitors driven by cultural motivations.

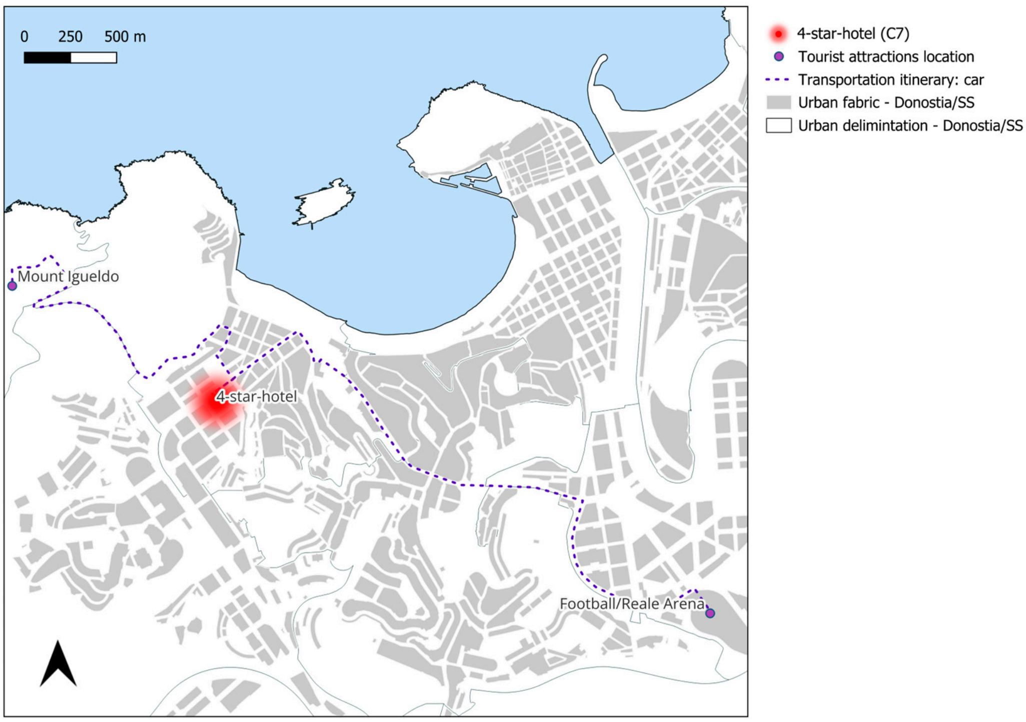

Figure 8. Itinerary sequence representation for nature and outdoor recreation tourists: closed path model. Own elaboration.

Table 13. Carbon footprint emission results for each of most common itinerary sequences in Donostia.

Tourist Profile	Type of Sequence	POIs Visited	Length of Stay	Avg. TG	Accom. Cluster Assigned	Type of Transport.	Daily Tourist Activities Emissions	Daily Accom. Emissions	Daily Transport. Emissions (kg CO_2eq)	Total CO_2eq per Tourist Sequence	Total CO_2eq per Trip [1]
Culture and Heritage	Looped sequence	Gastronomy Walking around the city	2 nights/ 3 days	2.28	C1: tourist apartment	Walking	0.309	4.2	0	4.509	21.266
	Closed path sequence	La Concha Beach Mount Igeldo			C12: 4-star-hotel	Urban bus	1.186	16.35	0.144	17.68	83.653
Nature and outdoor recreation	Looped sequence	Walking around the city La Concha Beach	3 nights/ 4 days	2.05	C4: tourist apartment	Walking	0.593	4.2	0	4.793	30.693
	Closed path sequence	Football/Reale Arena Stadium Mount Igeldo			C7: 4-star-hotel	Fuel car	2.272	16.35	0.422	19.044	122.643
Others	Looped sequence	Walking around the city Gastronomy	3 nights/ 4 days	1.41	C4: tourist apartment	Walking	0.309	4.2	0	4.509	19.509
	Closed path sequence	La Concha Beach Museums			C9: guesthouse	Urban bus	2.569	2.9	0.55	6.019	29.858

[1] This column includes the total emissions of the TG for the entire duration of its trip. Own elaboration.

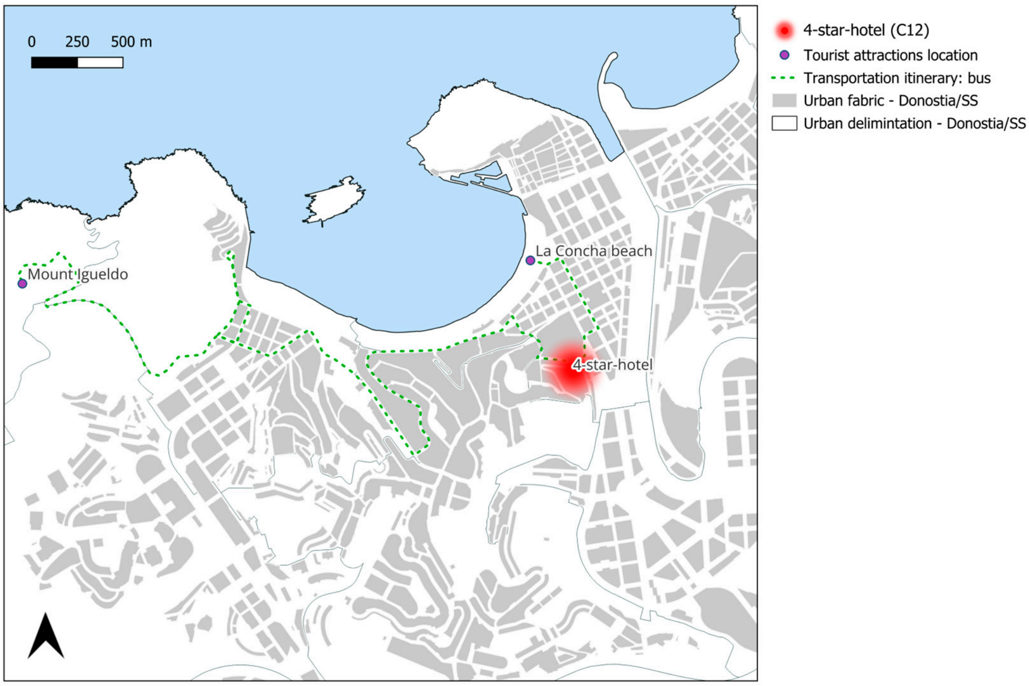

Figure 9. Itinerary sequence representation for culture and heritage tourists: closed path sequence. Own elaboration.

4.4. Discussion of Results

The profiles of visitors driven by the cultural and natural attractiveness of the city, constituting over 64% of the total visitor population, are identified through the application of the proposed carbon footprint calculation model as the tourists exerting the most significant impact on the city. Despite their similar specificity, the two most carbon-intensive sequences (Figures 8 and 9) exhibit varying degrees of territoriality between the sequences of both profiles. While the most prominent sequence of the cultural profile is spatially concentrated in areas proximate to POIs and tourism corridors, the sequence of nature-oriented visitors disperses visitor flows and GHG emissions away from the zones experiencing the highest tourism pressure.

These findings align with the conclusions of other scholars [26], who have similarly determined that segmenting visitors based on their primary travel motivations enables the anticipation of specific consumption patterns indicative of the GHG emissions they will produce. This research underscores the role of visitors motivated by nature and culture as a segment warranting consideration for tourism managers and urban planners.

Likewise, although several authors present results that closely align with those of this study concerning emissions from hotel accommodations—ranging from 5.8 kg CO_2eq/person/overnight to 12 kg CO_2eq/person/overnight [23,111–114]—our research extends beyond these findings. This is achieved through a methodology that allows for assigning diverse accommodation preferences (e.g., tourist apartments or guesthouses, often overlooked in these impact estimates) based on the tourist profile rather than merely the source market.

Moreover, Yang et al. [23] elucidate that, for specific source markets, origin-destination transport can constitute over 95% of their total trip emissions. This underscores the significance of the methodology delineated in this article, as it facilitates a more impartial assessment of the relative impact of each local tourism activity, thereby enabling stakeholders within the tourism system to assume greater responsibility. While large-scale calculations of carbon emissions are instrumental in comprehending the enormity of the issue, localised studies are indispensable in encouraging urban tourism actors to cultivate a heightened sense of agency in pursuing urban decarbonisation [115].

The results presented in Table 13 indicate that the selection of transport and accommodation significantly influences the carbon intensity of the tourist itinerary. While the choice of activities appointed by visitors in the destination—which are generally related to the primary motivation of the trip and therefore less likely to change the tourist's choice—does not demonstrate such a relevant impact, the variation that arises between the emissions related to different types of accommodation is noticeable in the final environmental impact of those visitors.

However, the perceived freedom in choosing modes of transport is illusory, as it is limited mainly by the environmental options available in most cities. In Donostia, where shared transport modes such as electric scooters or bicycles do not meet tourists' needs, some rely on their private cars for intra-urban travel. Destination and city managers should discourage this practice to enhance social cohesion and improve the city's and its residents' environmental quality.

Similarly, the influence of the sequence's linearity on the resultant carbon footprint can be discerned. In this context, the findings for looped and closed path sequences unveil a future research line aimed at comprehending the factors that guide visitors in choosing a specific type of sequence.

Although several authors have studied the GHG emissions of visitors to a destination [25,116] or a specific group of travellers [26,117] by calculating the sum of emissions related to transport, accommodation, and complementary activities, this focus on emissions occurring solely at the destination has not yet been undertaken. Most of these investigations adhere to door-to-door scopes and consider origin-destination transport emissions. While it is acknowledged that these emissions constitute a substantial proportion of the total emissions from tourism activities [16], and therefore, efforts to mitigate them should not be overlooked, it is important to note that these emissions fall outside the purview of local actors. Consequently, the model proposed in this article proves advantageous for tourism stakeholders, as it provides them with activity-specific and spatially disaggregated information. Indeed, a further contribution of this research lies in integrating GHG calculation principles with spatial tourism theories.

Similarly, most research quantifying the tourism carbon footprint relative to travellers comprises non-scalable models [23,58,111], essentially serving as audits of the environmental impact of tourism at a specific, static point in time. This study advances the existing literature by offering destination stakeholders and urban planners a dynamic tool which can be seamlessly integrated into their tourism decision-making and urban planning processes.

5. Conclusions and Model Implications

Urban areas are primary contributors to GHG emissions, with the most substantial rise in energy use and CO_2eq emissions currently occurring in the world's largest cities [67]. Furthermore, the significance of urban tourism within international visitor flows [3,4] underscores the relevance of analysing the evolution of these territories from a tourism perspective.

To mitigate greenhouse gas emissions, it is essential to address their scale [67]. Because the carbon footprint of cities is affected by many citizens' and visitors' decisions, this study investigated how visitors' travel behaviour influences urban tourist GHG emissions, examining the impact of their choices on the carbon footprint of urban tourism destinations. The result is a methodology for calculating the carbon footprint of tourists that integrates information on the environmental impacts of urban tourist activities with the spatial distribution of these emissions. This paper departs from the tourist-itinerary sequence concept and provides an aggregated view of the spatial consumption patterns of a destination's different visitor profiles.

Implementing the model in an urban destination, such as Donostia, has enabled us to validate the model and identify the data input requirements necessary for tourism and urban planners to achieve a spatial understanding of the emissions produced by various visitor profiles.

Nevertheless, scholars or managers of other destinations who aspire to emulate the model delineated in this article must consider numerous considerations. Figure 10 encapsulates the required data for these stakeholders to undertake the estimation process. When integrated with the emission factors posited in this article, these data will yield pertinent insights into the emissions associated with the diverse visitor profiles of the respective tourist destinations.

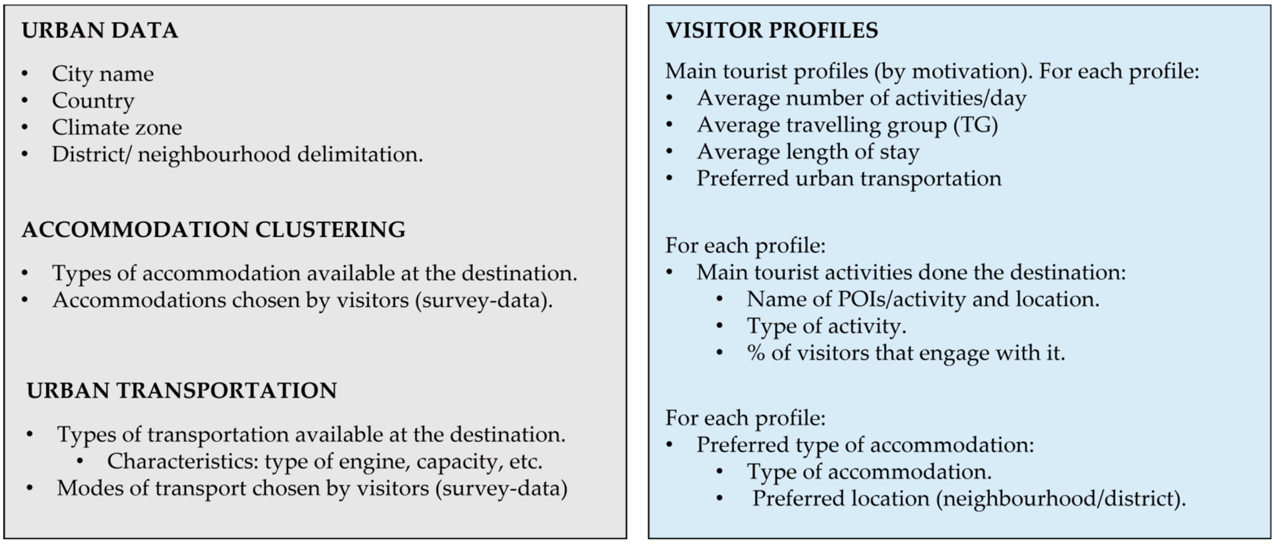

Figure 10. Needed data input for replicating the proposed model in other destinations.

It is also advisable to consider the characteristics inherent to the territory under study, such as urban morphology, predominant tourist activities, or determinant features of the tourist supply. For instance, in Donostia, these specific attributes have guided us to identify certain sequences as the most pertinent. However, the tourism model of other destinations or the diverse modes of transportation available at the destination may influence the types of sequences engaged in by their visitors.

5.1. Practical Implications of the Model

The proposed model represents a significant improvement over existing methods for calculating the carbon footprint of tourism. Unlike traditional approaches that provide only a static figure or the total emissions of a tourist destination, this methodology offers detailed insights into the carbon footprint generated by different visitor groups. Although it requires data on the profiles of the visitors being analysed, the model is highly adaptable and can be applied to various tourist destinations, regardless of their specific facilities or infrastructure.

The developed methodology is a powerful resource for tourism destinations and urban planners. It enables integrating carbon footprint analysis into territorial management strategies, fostering informed decision-making regarding decarbonisation efforts and the transition to sustainability.

On the one hand, the methodology provides destination and urban managers with detailed environmental insights into key components of the urban tourism system, such as emissions from tourist accommodations, points of interest, and available transportation options. On the other hand, it highlights the interconnections among these elements, offering actionable guidance for tourism and urban planning stakeholders to foster more sustainable combinations tailored to potential visitor profiles. This model allows us to identify the profiles of visitors who frequent specific areas of the destination, select particular modes of transport, and choose accommodations with unique characteristics. This information is invaluable for tourism planning, as it aids in developing targeted awareness and promotional campaigns designed specifically for these visitor profiles.

Measuring the carbon footprint is crucial for identifying, during the urban and tourism planning phases, the strategies that can achieve the most significant reductions in GHG emissions, focusing on preventive rather than corrective actions [67]. The calculation method proposed in this paper enables forecasting urban density, including residents and tourists, to plan emissions and decarbonise the city. For instance, public transportation with unlimited stops in tourist corridors, which cannot be efficiently covered on foot, can be planned more effectively. In the case of Donostia, for example, this may encompass enhanced electrification of the public transportation network, particularly the bus lines, which service these more heavily trafficked trip sequences.

Initiatives such as the recent enforcement of the low emission zone in Donostia—similarly implemented in most municipalities with populations exceeding 50,000 inhabitants in Spain—serve as an initial incentive to promote public transport usage. However, to encourage visitors to use public transport for traversing distant destination nodes (e.g., from Mount Igeldo to Cider Restaurants), it is essential to extend these incentives to the economic sphere, as financial considerations are recognised as a key determinant in visitors' decision-making [118,119]. Thus, in Spain, the current national public transport subsidies [120] could be partially extended to encompass single tickets, thereby fostering public transport use among temporary visitors.

Nevertheless, the findings indicate that the choice of accommodation significantly affects the overall emissions of travellers. In light of this, destinations should advocate retrofitting lodging facilities to improve energy efficiency. Additionally, regulating recreational water usage in areas facing water scarcity and implementing incentives for establishments that minimise waste generation are supplementary measures that local policymakers could endorse and apply to the most GHG-intensive types of tourist accommodations.

Understanding the impact of climate change can highlight hidden issues and alleviate pressure on historic environments, enhancing environmental quality and tourism. Despite its significant impact, tourism is often overlooked in urban planning. Current plans encompass cultural and tertiary uses but do not fully acknowledge tourism's role. Given its carbon footprint, tourism should be considered a distinct element, necessitating specific regulation, design, and integration within urban planning for effective management functioning.

An increasing number of tourist destinations are considering implementing tourist taxes, or eco-taxes, on the cost of visitors' accommodation. While there is ongoing debate regarding the efficacy of these taxes [121,122], they can be viewed as valuable instruments for funding specific initiatives to offset carbon footprints tailored to the emissions generated by visitors, as the tool presented in this paper demonstrates.

5.2. Limitations of the Model and Future Research Lines

Our research encountered certain constraints in the model development process. This research aimed to formulate and implement a visitor GHG calculation model. Despite the inherent assumptions within this process, it has not been subjected to any hypothesis testing. This CO_2 emissions calculation method excludes same-day visitors, adhering to the UN

Tourism definition of tourists as overnight visitors [123]. Because tourist accommodation is highly carbon-intensive, the research excludes excursionists.

This research has drawn upon the extant literature, specifically secondary sources, to formulate a concatenated model for calculating the carbon footprint. In certain instances, this could have resulted in a diminution of precision in the findings, attributable to the absence of consensus regarding emission levels, particularly concerning complementary activities carried out by tourists at the destination. This model excludes indirect emissions from the tourism upstream and downstream supply chain (Scope 3 of the GHG Protocol). It is designed for local managers and planners who often lack detailed data [111,124]. Thus, it partially presents both direct and indirect emissions. Due to this paper's limited scope, only the main visitor profile and their decision-making have been given. However, destination managers must evaluate all visitors' territorial consumption patterns using the recommended methodology. The delineation of the sequences is predicated upon the average or most frequently occurring responses obtained from the questionnaire. This approach may result in a deviation from the patterns observed within each visitor profile.

Certain constraints are associated with the selected environment for the model's implementation. For instance, Donostia lacks peer-to-peer transport services like Uber or Bolt. Nonetheless, we recognise that such modes of transport would be significant for tourists in bigger urban destinations, such as Madrid or London. However, this is a minor limitation, given that, from an environmental perspective, these vehicles produce emissions comparable to those of private cars or conventional taxis.

Due to its methodological focus, this paper does not analyse internal factors influencing visitors' behaviour. Nevertheless, further research is essential to ensure the model incorporates suitable cognitive and subjective constructs, taking into account tourism's social and psychological aspects. In line with this, upcoming research should also examine the impact of visitor awareness campaigns on reducing carbon footprints within the tourism sector and further study the role of environmental knowledge in the decision-making processes of destination visitors.

Finally, in light of the considerations delineated in Figure 10, a significant avenue for research emerges, focusing on applying the presented model across various cities and contexts. Emerging research replicating the model presented in this article could integrate necessary survey data with alternative data collection methods—such as Big Data analysis—to further refine estimates and reduce assumptions about visitor profiling and urban consumption patterns.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land14030534/s1.

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Institutional Review Board Statement: Page 13 of the manuscript provides a comprehensive elucidation of the ethical commitments undertaken during the processes of data collection and management. This task was delegated to a specialised consulting firm, Adimen, S.L., which is dedicated to research and data analysis. Adimen, S.L. ensures compliance with ISO 20252 [104] and ICC/ESOMAR [105]

standards in its operations. The company collects fully anonymised data and transmits it to us only after processing.

Data Availability Statement: The dataset containing the primary characteristics and sequences of visitors to Donostia is available upon request. The distance matrix constructed for the case study is available online as Supplementary Materials.

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Abbreviations

The following abbreviations are used in this manuscript:

CHSB	Cornell Hotel Sustainability Benchmarking
CO_2	Carbon dioxide
EEA	European Environment Agency
GDP	Gross domestic product
GHG	Greenhouse gas emissions
HCMI	Hotel Carbon Measurement Initiative
ICC/ESOMAR	International Chamber of Commerce/European Society for Opinion and Marketing Research
I-O/TSA	Input-Output/Tourism Satellite Account
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
POI	Point of interest
TG	Travelling group
UN Tourism	United Nations Tourism, former United National World Tourism Organisation

Appendix A

Table A1. Tourism carbon footprint calculation literature review.

Reference	Location	Scope of Emissions	Data Collection Procedure and Data Source	Calculation Methodology	Standards
[22]	Whistler, Canada	Direct and indirect	Bottom-up: Resort Municipality of Whistler.	Energy/fuel consumption and emission factors.	N.A. [1]
[23]	Shangri-La, China	Direct	Combination: National Bureau of Statistics. Yearbook of China & Yunnan Tourism, Yunnan Tourism Bureau (2000–2006).	Energy/fuel consumption and emission factors.	N.A.
[24]	Chengdu, China	Direct and indirect	Bottom-up: Chengdu Domestic Tourist Expenditure Survey 1999–2004; Chengdu Bureau of Tourism.	Energy/fuel consumption and emission factors. Kaya emission identity, factor decomposition.	IPCC
[55]	Barcelona, Spain	Direct and indirect	Bottom-up: Survey on Tourist Activity in the City of BCN. Survey of Daily Mobility in Catalonia, Annual Survey of Characterisation of Tourist. Cruise Passengers Survey, own survey for transportation uses.	Lifecycle analysis	GHG Protocol, IPCC, ISO.
[125]	Queensland, Australia	Direct and indirect	Top-down: Tourism Research Australia. The previous literature.	I-O/TSA	N.A.
[126]	Shanghai, China	Indirect	Top-down: Statistical Yearbook Shanghai 2012. Shanghai 2013 Energy Statistics Yearbook, National Bureau of Statistics, 2013 Sampling Survey Data of Inbound Tourists, Statistics Bureau of Shanghai, others, e.g., Qunar website.	I-O/TSA	IPCC
[127]	Beijing, China	Direct and indirect	Top-down: IO tables from the Chinese Bureau of Statistics and Provincial Bureau of Statistics, Beijing Statistical Yearbook (years 2008, 2011, and 2012).	I-O/TSA	IPCC

[1] Not applicable. Own elaboration.

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