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A Model for Estimating the Tourism Carrying Capacity (TCC) of a Serial Cultural Heritage: The Case of the "Via Appia. *Regina Viarum*"

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Abstract

The phenomenon of tourism is becoming increasingly central and integrated into strategic territorial planning practices, playing a crucial role in guiding development processes and prompting growing reflection on its impacts on places. In the absence of adequate planning, tourism can produce negative effects with significant implications for territorial resources and host communities. In territories characterized by high spatial heterogeneity and dispersed tourist attractions, sustainable tourism management represents a growing challenge. Traditional approaches to estimating tourism carrying capacity (TCC) often focus on individual sites, overlooking the complexity and extent of serial cultural landscapes. This study addresses this gap by proposing an innovative geographic-territorial model for estimating TCC, applied to the serial cultural site "Via Appia. *Regina Viarum*". The model, based on Cifuentes' ecosystem approach, expands the spatial domain of analysis to include 614 municipalities organized into 13 gravitational areas. Through a systemic perspective, multidimensional composite indices reflecting territorial extent and resource endowment have been developed. The simulation of three tourism development scenarios—baseline, UNESCO effect, and stress test—up to 2034 reveals differentiated territorial responses, providing analytical tools for sustainable strategic planning and proactive management of complex cultural territories.

Keywords: tourism carrying capacity; tourism planning; territorial planning; UNESCO World heritage site; Via Appia. Regina Viarum; sustainable tourism; local development; geographical information systems; heritage management; tourism management

1. Introduction

Tourism represents a strategic sector for local development, but it poses significant challenges in terms of sustainability and impact management [1–6]. These impacts underscore the necessity for complex governance processes involving institutional actors and stakeholders across multiple levels, highlighting the importance of increasing integration between tourism planning and territorial planning [5,7–15].

The literature has addressed the topic of tourism carrying capacity (TCC) through diverse perspectives [16–18]. TCC methodologies have been developed, for instance, for urban tourism destinations [19], coastal areas [20], geosites [21], or protected areas [22,23]. Others have formulated cross-cutting TCC methodologies applicable to diverse destinations [24–26]. Additional studies focus on defining targeted indicators for measuring tourism sustainability [14,27–30] and for managing criticalities

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related to overtourism [4,31]. However, diffuse cultural destinations, characterized by heterogeneous attractors distributed over extensive geographic areas, require innovative methodological approaches, particularly considering the need to integrate various levels of territorial governance.

The present study introduces assessing carrying capacity in tourism destinations, with particular reference to diffused cultural contexts. From this perspective, the study develops a model to measure the TCC of a complex cultural destination based on the presence of heterogeneous attractors distributed over an extensive geographic area. The estimation model is applied to the "Via Appia. *Regina Viarum*", a serial site inscribed in 2024 on UNESCO's World Heritage List. UNESCO serial sites comprise two or more elements, monuments, and geographically distinct places (located in one or more Member States) that, taken together, contribute to the Outstanding Universal Value of the inscribed site [32,33].

A substantial corpus of research has contributed over time to better defining the concept of TCC and its applicative evolution. Over the years, various definitions of TCC have been proposed, including that of UNWTO [34], which describes it as "the maximum number of people that may visit a tourist destination at the same time, without causing destruction of the physical, economic and sociocultural environment and an unacceptable decrease in the quality of visitors' satisfaction." Despite advances in this field, although there are several studies focused on UNESCO sites, to our knowledge, those dedicated to estimating tourism carrying capacity in relation to extensive serial sites remain limited.

TCC is a holistic and multi-objective concept for which no universally recognized measure or univocal methodological approach exists. Both in theoretical studies and in applied contexts, TCC has followed the evolution of sustainability analysis dimensions, thus incorporating various load components: ecological [35,36], economic [37,38], socio-anthropic [39–41], cultural and behavioral [42].

In theory, TCC estimation should result from the combination of both quantitative descriptive elements and qualitative elements oriented toward achieving a balance between tourism growth, territory, and local community. Simultaneously, quantitative elements are based on the construction of complex indicator sets capable of operating, in time and space, within a systemic framework that encompasses, for a specific context, tourism aspects and territorial dimensions [25]. Authors such as Wagar [43], Lime [44], Mathieson, Wall [39], and Getz [45] have led to consideration of the existence of different carrying capacities for different subsystems of a destination. For example, Getz [45] identifies thresholds for physical, economic, ecological, socio-cultural, political-administrative, and perceptual carrying capacity.

TCC is intrinsically linked to the notion of sustainability, representing a model that informs about a territory's/tourist site's capacity to sustain a certain level of use over time. A tourism destination can be considered sustainable only when it operates within the limits of its carrying capacity [46,47]. Furthermore, it is not limited to defining a static objective but configures itself as a continuous and adaptive management process capable of responding flexibly to emerging challenges and ensuring constant monitoring of the balance between tourist flows and the territorial system's capacity to absorb and sustain them [8,16].

Over the years, numerous TCC estimation techniques have been proposed involving one or more analysis components. In our case, the carrying capacity methodological framework adopts a phased approach. The estimation of the serial site's TCC is inspired by and adapts the ecosystem model developed by Cifuentes [48,49], originally used for defining TCC in parks and protected areas [50–53], and subsequently experimented with in other fields [24,36,54]. The adaptation follows a geographical-territorial logic capable of capturing the complexity of the case under examination. The proposed model provides the level of interaction between human activities and the physical-ecological environment and is structured, in accordance with the scholar's indications, based on three interconnected indices and the estimation of corrective factors.

The Italian Ministry of Culture (MiC) has identified the designated site in 22 components constituted by a multiplicity of attributes (tangible archaeological evidence), very different from each other in typology and conservation status. The components of the serial site, core zones, are territorially distributed across 4 regions of central-southern Italy (Lazio, Campania, Basilicata, Puglia); the sum of their perimeters covers an area of 9,387.64 ha, while that of their respective protection zones, buffer zones, is 41,354.34 ha. The geographical-territorial model has provided for a recalibration of the route's pertinence areas. To this end, based on a procedure for extending the radius of influence of "Via Appia. *Regina Viarum*", the methodology has integrated two scales of geographical analysis: one with municipal-level analysis units (614 municipalities), the other with territorial-level analysis units (13 gravitational areas). This choice was adopted to overcome the impracticability of a detailed TCC estimate for each component and, simultaneously, to allow its estimation as informed and coherent as possible with the geo-settlement characteristics of the territories involved.

The study provides a replicable methodological framework capable of supporting political decision-makers and heritage managers in defining tourism planning and management strategies, monitoring tourist load, and promoting balanced utilization of territorial resources. Furthermore, it supports public tourism policy choices by identifying areas of greatest tourist exposure and those with potential development opportunities [14]. Since the methodology is developed considering multiple geographical units, it allows model application in other studies to perform detailed estimates, adaptable both to the specificities of different reference contexts and to vaster territories, emphasizing the model's scalability across larger territorial extents.

The document is organized into 5 sections: after the introduction, section 2 explores the theoretical framework and main analytical perspectives on the concept of tourism planning, analyzing the evolution of tourism as a strategic and plannable activity; section 3 identifies the study area and describes the procedure that led to the recalibration of the geographical analysis scope. Subsequently, it presents the geographical-territorial model, illustrating its conceptual structure and analysis dimensions associated with corrective indicators. This approach is further deepened by the construction of scenarios aimed at testing the carrying capacities of individual municipalities and individual areas; section 4 shows the results obtained from applying the model and scenarios, highlighting the temporal evolution of carrying capacities in the municipalities and areas previously derived; finally, section 5 discusses the political and practical implications of the obtained results, proposing recommendations for effective management of tourism destinations in a context of sustainable growth.

2. Theoretical Background

In the context of post-World War II economic growth, the expansion of international travel made mass tourism a global phenomenon, laying the foundations for new challenges in tourism destination management. During this historical phase, mass or conventional tourism activity emerged as a direct application of the fordist approach to the travel industry and destination management, aimed at responding to growing demand from an increasingly broad public [55–58]. Mass tourism has traditionally been associated with intensive resource use, the adoption of unsustainable production models, and increased tourism intensity in many areas, which were in turn reshaped according to strategies markedly oriented by the economic growth paradigm [10,11,59].

From a scientific perspective, particularly since the 1970s, researchers have repeatedly questioned the effects of intensifying tourism growth and its expansion [39,60–64]. During this years, tourism planning, initially applied only within the tourism industry framework [65] and in the physical-economic evaluation of specific facilities or individual areas [66], began to emerge as a field of study and concept of public interest. This evolution was configured as a response to rapid sector changes and the diseconomies produced by tourism growth, in an attempt to manage its associated effects from environmental, socio-anthropological, and spatial perspectives [10,39].

In his work, Getz (1987) [67] identified four distinct traditions in tourism planning, each representative of a specific vision of tourism development: boosterism; industry-oriented; physical-spatial; community-oriented. These traditions continue to represent an essential reference framework, widely used but also expanded by subsequent literature in analyses of different planning contexts; the traditions do not necessarily exclude each other, nor do they develop in linear sequence. While approaches guided by tourism growth objectives and demand stimulation emerged from the 1960s, reflecting a currently dominant interpretation that tourism would automatically bring positive results in the absence of critical vision – the so-called "boosterism" – more structured attempts at rational planning emerged from the 1970s, aimed at mitigating the diseconomies associated with unregulated or unplanned tourism growth [8]. From this perspective, physical/spatial practices constituted a formulation sensitive to spatial organization, land use planning and associated infrastructure, the search for spatial patterns coherent with the development of specific tourism areas, as well as the ecological absorption capacity of tourism's environmental impacts [64,68,69]. At the same time, such practices were judged less sensitive to socio-cultural aspects. The ecological logic of these models proved coherent with the emergence, beginning in the 1960s, of a growing scientific debate on Tourist Carrying Capacity (TCC), aimed at preventing and monitoring the effects of tourism pressure in spaces designated for recreational uses and tourism places [70]. The TCC concept, although traceable to Sumner [71] in the mid-1930s [72], began to gain consistency later, during the 1970s. These elaborations subsequently gave rise to a broad corpus of empirical research and theoretical reflections, while finding isolated previous contributions [43,73,74], as well as in other seminal works [75,76]. Reflections on TCC remain more central than ever on the conceptual level today, as demonstrated by the overtourism debate and concerns regarding the management of sensitive places [4,18,77–79]. On the operational level, numerous management techniques have been developed, both quantitative and qualitative [80–82], although critical contributions toward attempts to define carrying capacity in purely numerical terms have not been lacking [83].

In the 1980s, in light of problems that emerged in previous decades, attention to the multidimensional and multi-spatial impacts of tourism and carrying capacity gave impetus to a conception of tourism planning as a complex and integrated system. Growing tourism intensification prompted researchers and policymakers to reflect on the impact this expansion had on natural resources and local communities, making tourism planning more attentive to sustainability necessary. The diffusion of the sustainable development concept, promoted by the Our Common Future report [84], found application in tourism beginning in the 1990s, giving rise to an extensive debate on the definition of sustainable tourism [85]. This debate, while having generated relevant contributions, is still marked by persistent conceptual ambiguity, which feeds the gap between theory and practice. Progressively, reflection on tourism sustainability has expanded, including different geographical scales of analysis of implications (for example, as evidenced by studies on tourism water footprint, [86] and interweaving with the development of more sustainable forms of tourism [87–89].

Community-oriented planning frameworks, pioneered in Murphy [66], have proven more sensitive to the diversity of local contexts and coherent with sustainable development principles. In theory, such models support bottom-up participatory practices in line with pre-existing socio-territorial conditions and with a concept of development endogenously conceived on a local basis. This translates into pathways of local community involvement in creating authentic tourism experiences and discovering intangible cultural capital; at the same time, community-oriented planning frameworks aim to improve local living standards and monitor social/perceptual carrying capacity. Hall [90] introduces the concept of "sustainable tourism planning" as an extension of Getz's work [67]. This concept refers to a tourism planning approach that integrates elements of pre-existing traditions and emphasizes holistic practices, management cooperation, and attention to the environmental and social components of development, with a focus on strategic planning.

Murphy [66] argues that "planning is concerned with anticipating and regulating change in a system, to promote orderly development so as to increase the social, economic, and environmental benefits of the development process." Williams [63] adds that planning requires "an ordered sequence of operations and actions that are designed to realize one single goal or a set of interrelated goals." In this sense, tourism planning can be seen as a process through which to channel broader public interest objectives [67]. Williams [63] identifies some specific objectives of tourism planning, such as the integration of tourism with other economic sectors; the direction and control of physical development

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patterns; the creation of harmonious social and cultural relationships between tourists and local populations. In theory, according to the author, tourism-related planning allows for structuring the spatial allocation of tourism infrastructure and services among different geographical areas; organizing or reorganizing a territorial offering capable of anticipating tourism market dynamics; promoting balanced and monitored tourism development, balancing costs and positively directing spillover effects among different territories [63].Furthermore, as Inskeep [91] emphasizes, it enables the conservation of critical tourism resources, such as natural and cultural ones, preserving them and, when possible, improving them to ensure their future use. As reported by Hall [92], tourism planning contributes to mitigating tourism's negative externalities – environmental, economic, and social. Additionally, it helps produce economic benefits and improve perceptions regarding the relationships between tourists and the local community.

Tourism planning is not necessarily a linear or simple process [90,93]. Planning activity can comprise different key areas of tourism intervention, operate at different geographical scales, involve multiple planning bodies (public or private) and at various levels (starting from the local level), adopt distinct temporal horizons for different development, implementation, and evaluation phases [7]. Conversely, its absence, operational complexity, and the adoption of short-sighted visions can result in negative impacts with different types of implications for territorial resources and host communities [63,68,92]. In a broader vision, it is possible to consider that it aims to achieve, considering different scales, a balance between tourism growth, territorial development, and community [29,68,69]. Tourism planning is a process that highlights the need to consider tourism as a multisector activity, integrating tourism resource management and taking into account both physical and institutional aspects [91]. Previously, the importance of this integration had been emphasized especially by [94] and Getz [67], who proposed an interconnected and systematic perspective of tourism planning [95]. In this sense, it is a dynamic process [65], future-oriented, continuous and participatory [8,63,66,92] and is, above all, constantly informed according to different implementation contexts, which are themselves complex.

Although studies on tourism growth limits and impact management have offered significant contributions, their operational application has often remained limited [35,78,96,97]. This gap between theory and practice is reflected in problems generated by tourism which, in many contexts, has continued – and continues today – to be configured as an unplanned activity [56,69,95]. However, the perpetuation of extreme situations, such as overtourism, has reinforced the urgency of integrating the tourism phenomenon with other functions and levels of planning. It is increasingly clearly recognized that tourism cannot be treated as an uncontrolled economic force, but must be coordinated with territorial dynamics. The heterogeneous nature of tourism, both from spatial and functional perspectives, has indeed intensified interest in its territorial impacts, processes of diffusion or redistribution of effects, and its role in local development [4].

Reading socio-economic and tourism dynamics at the territorial scale is complex and requires being addressed through in-depth analyses, integrated multi-level planning processes, management models, and specific evaluation techniques. Such considerations have contributed to strengthening the role of strategic planning, emphasizing the need to integrate tourism activity within multiple planning frameworks and operate at greater systemic and temporal scales [98]. In the tourism context, strategic planning, borrowed from management studies [99], is seen as a process that "requires some estimated perception of the future" [68] and oriented toward favoring the proactivity of destination places in a systematic way [98].

Strategic planning assumes a higher and guiding role suitable for supporting a more territorially balanced and oriented vision of development [7,66]. Hall [92] emphasizes that the application of sustainability requires a balance between long-term temporal horizons and short-term operational constraints, which can be effectively addressed through strategic planning. Ladeiras et al. [100] affirm that a destination must develop a clear vision and undertake a participatory strategic planning process at multiple levels (national, regional, and local) to ensure sustainable tourism development. The pursuit of sustainability objectives in tourism is indeed linked to a structured planning process that adopts a circular causality perspective [99,101,102]. This goal- and context-oriented process also considers endogenous factors that influence strategy generation, requiring robust coordination mechanisms to support the participation of multiple stakeholders and multi-sectoral and multi-actor coordination [98,102,103]. This approach responds to community needs and integrates conventional planning as part of a continuous and dynamic process [98].

3. Materials and Methods

3.1. Area of Study and Territory Calibration

The analytical process first involved a recalibration of the area of relevance, with an extension of the Via Appia's radius of influence beyond the initial boundaries, in order to include a wide variety of surrounding territories. This approach allowed for the integration of areas not directly connected to the main route but nevertheless relevant in relation to morphological and physical specificities, providing a broader and more representative understanding of the considerable territorial complexity of the study area.

It is plausible to conceive the "Via Appia. *Regina Viarum*" route as a complex set of tourism destinations, characterized by undefined entry and exit points, where tourists and residents share resources and structures. Inevitably, this set of tourism destinations does not exclusively concern municipalities directly crossed by the route, but extends to a broader territorial dimension. A procedure was executed to extend the radius of influence of the serial site that finds support in the concept of range offered by Christaller's model [104,105]. The 22 sections (components) constitute "central goods," from which a hypothetical maximum range extending in a radius reaching 25 km distance was delineated. At the same time, the "central goods" are reinterpreted in the geographical-territorial model as "gravitational centers" around which areas equipped with a complex of infrastructures and services connected to them by functional relationships tend to gravitate. The polygonal approach of the Thiessen method was used to identify gravitational areas; therefore, through the digital geometric tool, space was distributed into areas of relevance, attributing to each section the area closest to it. The association of municipalities belonging to each of the 22 areas of relevance was then optimized according to territorial morphology and the local road system. In some cases, the existence of contiguous sections resulted in an aggregation of areas.

The result achieves a spatialisation of the range defined in 13 new gravitational areas comprising 614 municipalities, compared to the original 74 (Table 1; Figure 1). The range area reflects both elements of heterogeneity in the spatial distribution of population, infrastructure, and activities, as well as the different degree of tourism exposure of the territories. Overall, it covers an area of 30,634 km² and has a population of 11,461,232 residents, 72.4% of the total residents in the 4 regions [106]. Of the 614 municipalities, 64 are cities or large urban areas with high population intensity, equal to 55% of residents in the entire reference area.

Table 1. Connection between the 22 sections to be enhanced and 13 gravitational areas. Source: Authors' elaboration from MiC direct provision and ISTAT data [106].

The 13 areas	Routes (aggregated)	Routes	Denomination of the 22 routes	Population	N° municipalities	Surface (ha)
Area 1	*1*	*1*	L'Appia a Roma dal I al XIII miglio	3 288 724	**21**	**1 903**
Area 2	*2 e 3*	*2*	L'Appia ai Colli Albani	587 028	28	1 312
		3	L'Appia dal XIX al XXIV miglio, con diramazione per Lanuvium			
Area 3	*4*	*4*	L'Appia nella Pianura Pontina, con diramazione per Norba	314 356	23	1 466
Area 4	*5, 6, 7 e 8*	*5*	Tarracina e il superamento del passo di Lautulae	235 384	28	1 406
		6	L'Appia a Fundi			
		7	L'Appia al valico di Itri			
		8	L'Appia dal miglio LXXXIII a Formiae			
Area 5	*9 e 10*	*9*	Minturnae e il superamento del Garigliano	197 736	33	1 289
		10	L'Appia da Sinuessa al pagus Sarclanuse			
Area 6	*11*	*11*	L'antica Capua	3 144 352	138	2 059
Area 7	*12, 13 e 19*	*12*	Beneventum e l'Arco di Traiano	574 310	175	4 340
		13	L'Appia Traiana da Beneventum a Aequum Tuticum			
		19	L'Appia sul percorso da Beneventum ad Aeclanum			
Area 8	*14*	*14*	L'Appia nell'alta Valle del Bradano	141 825	36	2 957
Area 9	*15*	*15*	L'Appia sul percorso del tratturo tarantino	332 006	15	2 947
Area 10	*16 e 17*	*16*	Tarentum	688 744	39	3 007
		17	L'Appia da Mesochorum a Scamnum			
Area 11	18 e 22	*18*	Brundisium	594 585	29	2 260
		22	L'Appia Traiana lungo la costa adriatica, passando per Egnathia			
Area 12	*20*	*20*	L'Appia Traiana da Aecae a Herdonia	256 035	22	2 425
Area 13	*21*	*21*	L'Appia Traiana a Canusium e il percorso dell'Ofanto	1 106 147	27	3 263
			Total	**11 461 232**	**614**	**30 634**

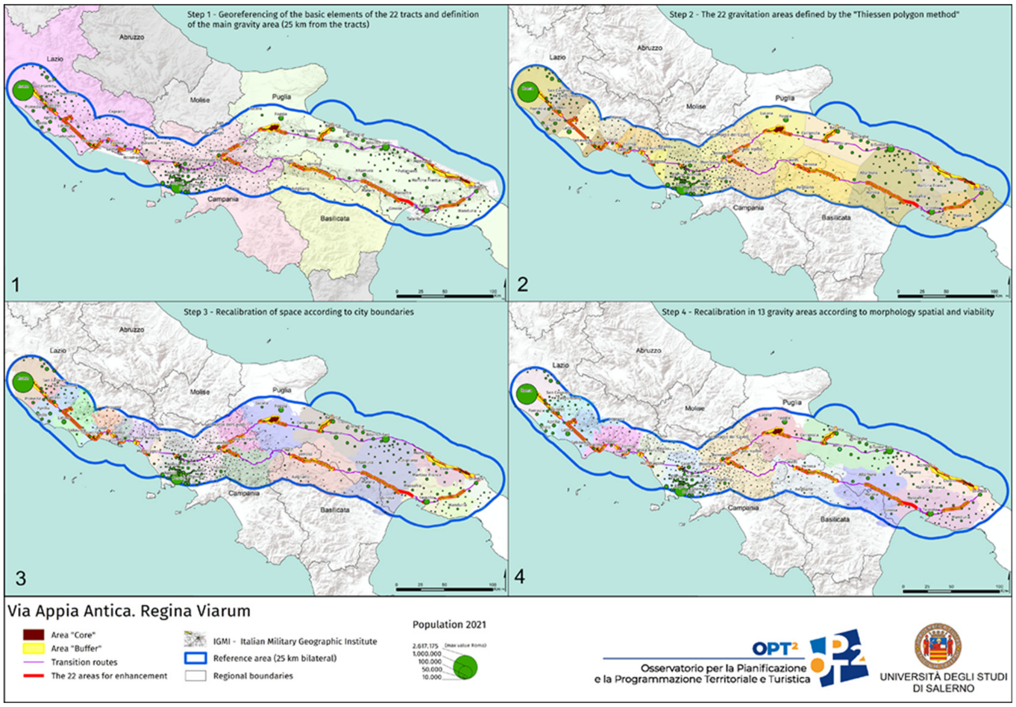

Figure 1. From the 22 sections to be enhanced to the 13 gravitational areas. Source: Authors' elaboration.

The demographic dynamics within the system follow the developments of a space highly conditioned by the existence of different factor endowments. More than half of the municipalities (382 municipalities) included in the system belong to mountain and inland hill areas: these represent 21% of the population considered.

According to the ISTAT [107] parameterized scheme on the degree of urbanization, the range area identifies the territory in three types of municipalities: 1) 64 "Cities" or "Densely populated zones", 2) 227 "Small towns and suburbs" or "zones with intermediate population density", 3) 323 "Rural zones" or "Sparsely populated zones". Respectively, the municipalities thus classified represent 54.6%, 30.5% and 14.9% of the resident population. The cities of Rome and Naples alone (32.5% of total residents) condition the population distribution to such an extent that they bring their respective areas (area 1; area 6) to account for 56.1% of the entire range. Such highly polarized demographics has repeatedly influenced the construction of the analysis model.

3.2. TCC Estimation Model

The development of the methodology is based on the definitions of Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective or Admissible Carrying Capacity (ECC), as proposed by Cifuentes [48]. These definitions are structured in relation to specific correction factors appropriately identified. Within this framework, the estimation model is organized so that each successive level of carrying capacity is determined by correcting the preceding one. In the adapted model, PCC is greater than or equal to RCC, and the latter, in turn, is greater than or equal to ECC (also referred to as TCC). The geographical-territorial model is illustrated in Figure 2, which summarizes the procedural sequence.

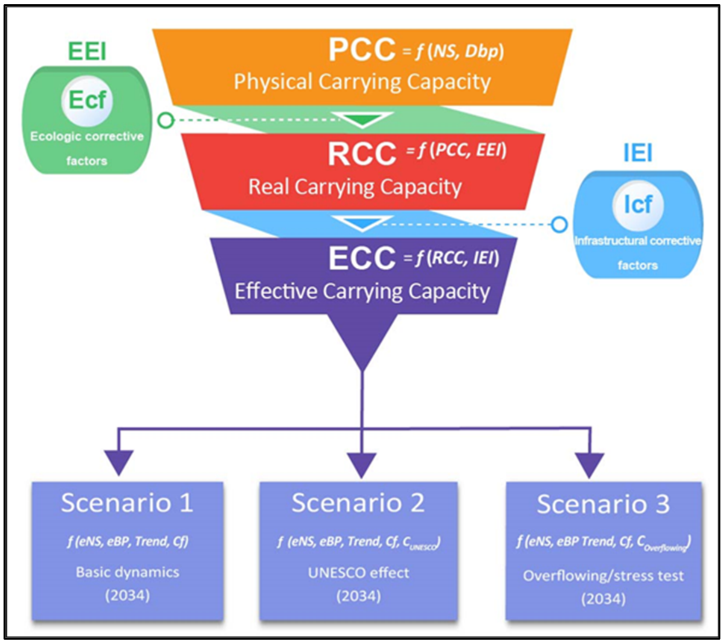

Figure 2. Geographical-territorial model, adaptation of the Cifuentes approach. Source: Authors' elaboration.

The following subsections detail the model, describing the specific phases leading to the estimation of ECC. Intermediate territorial findings are presented, based on the Ecological Endowment composite index (EEI) and the Infrastructure Endowment composite index (IEI), which constitute the correction parameters for the three different levels of carrying capacity. EEI and IEI are considered, in accordance with the geographical scale of reference, as territorial threshold values beyond which tourism pressure results in overcapacity, likely triggering diseconomies. After illustrating the ECC estimation method, the scenario-building method is described, based on the application of specific variation coefficients.

3.2.1. Physical Carrying Capacity (PCC)

Physical Carrying Capacity (PCC) is defined as «the maximum number of visitors who can attend physically in a given place and time» [48] (p. 10). For the case under examination, it is interpreted in terms of receptive capacity; specifically, its determination is based on the Gross

Occupancy Rate (GOr) of tourist accommodation establishments, calculated both at the municipal scale and across gravitational area. The specific calculation is shown in the Formula (1).

$$GOr_t = eNS_t / BPa_t * 100 \quad (1)$$

where GOr is the Gross Occupancy rate in hotels and extra hotels; NS constitutes the number of nights spent in hotels and extra-hotels; BPa the potential number of the bed places on offer by day*365; t is the reference year.

The Physical Carrying Capacity (PCC) is expressed by the Formula (2):

$$PCC = f\,(GOr) \quad (2)$$

The index provides, at specific times and expressed as a percentage, the level of pressure exerted by fluctuations in tourist arrivals on available tourism supply, therefore:

- PCC <20% Very low impact;
- 21% ≤ PCC <40% Low impact;
- 41% ≤ PCC <60% Moderate impact;
- 61% ≤ PCC <80% High impact;
- 81%≤ PCC<100 Very high impact;
- PCC ≥100 Congestion and overuse.

This procedure was developed to calculate the PCC of tourist accommodation (both hotels and extra-hotels).

3.2.2. Real Carrying Capacity (RCC)

Real Carrying Capacity (RCC) is defined as «the maximum limit of visits determined from the PCC of a site, adjusted by correction factors reflecting the specific characteristics of the site» [48] (p.12). For this study, the RCC is derived by applying to the PCC a series of ecological correction factors described through indicators of environmental and anthropic pressure.

Ecological correction factors (Ecf) were normalized and weighted, with their sum constituting the Ecological Endowment composite index (EEI), as shown in Formula (3):

$$\mathrm{EEI} = \sum_{i=1}^{5} \mathrm{Ecf}_i \quad (3)$$

where Ecf_1 is the population density; Ecf_2 is the ecological efficiency; Ecf_3 is the ecological pressure; Ecf_4 is the environmental endowment; Ecf_5 is the unconsumed land. As a result, the Real Carrying Capacity (RCC) is expressed by the Formula (4):

$$RCC = f\,(PCC, EEI) \quad (4)$$

3.2.3. Effective Carrying Capacity (ECC)

Effective Carrying Capacity (ECC) corresponds to «the maximum number of visits that can be allowed, given the capacity to manage and distribute them […] the ECC is determined by comparing the RCC with the management capacity of the protected area administration» [48] (p.19).

For the calculation of the ECC, additional correction factors related to physical and cultural infrastructure systems were applied to the RCC Formula (4). The Infrastructure Correction Factors (ICF) were normalized and weighted, with their sum constituting the Infrastructure Endowment composite index (IEI), as shown in Formula (5):

$$\mathrm{IEI} = \sum_{i=1}^{5} \mathrm{Icf}_i \quad (5)$$

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where Icf_1 is the prevailing tourism supply; Icf_2 is the tourism accommodation offer intensity; Icf_3 is the material cultural heritage endowment; Icf_4 is the station intensity for passenger transport; Icf_5 is the local public transport offer. For this purpose, the Effective Carrying Capacity (ECC) is given by the Formula (6):

$$ECC = f\,(RCC, IEI) \tag{6}$$

In the geographical-territorial model, the ECC is, therefore, the result of a serial site's capacity to accommodate tourist demand, considering both the environmental and infrastructural territorial characteristics. Its estimation represents the actual and weighted measure of the tourism carrying capacity (TCC), obtained through a gradual process of geographical-territorial adaptation of the model proposed by Cifuentes [48]. In line with existing literature, this study treats the terms ECC and TCC as interchangeable.

3.2.4. The Correction System Based on EEI and IEI: Indicators, Weighting, and Spatial Representation

The use of the Ecological Endowment Composite Index (EEI) and the Infrastructure Endowment Composite Index (IEI) enables the adjustment of the various levels of carrying capacity, ultimately deriving the ECC for each municipality and each area.

The estimates were conducted based on the construction of a database developed using statistical information available from official secondary sources (Table 2).

Table 2. Composite indices: set of indicators.

Correction Factors	Indicators	Description	Variables	Reference	Source	Year
Ecological Endowment Composite Index (EEI)						
Ecf_1	Population density	Ratio of administrative municipality's land area to resident population [number of inhabitants per sq. km]	Resident	[106]	ISTAT	2021
			Land area (sq. km.)	[106]	ISTAT	2021
Ecf_2	Ecological efficiency	Sorted municipal waste fraction detected in the administrative municipality [%]	Separate waste [t]	[106]	ISPRA	2020
Ecf_3	Ecological pressure	Municipal Waste generated by municipal inhabitants [kg]	Municipal Solid Waste (MSW) [t]	[108]	ISPRA	2020
Ecf_4	Environmental endowment	Presence of Protected Areas (EUAP2010) [%]	Protected Areas (EUAP2010) [h]	[109]	ISTAT	2010
Ecf_5	Unconsumed land	Share of unsealed land [%]	Unconsumed land [h]	[108]	ISPRA	2019
Infrastructure Endowment Composite Index (IEI)						
Icf_1	Prevailing tourism supply	Relationship between hotel receptivity with non-hotel receptivity	Bed-places in hotel and non-hotel accommodations	[106]	ISTAT	2019
Icf_2	Tourism accommodation offer intensity	Ratio of total beds in accommodations to municipal population	Bed-places in hotel and non-hotel accommodations	[106]	ISTAT	2019

Icf_3	Material cultural heritage endowment	Number of archaeological assets and number of architectural assets	Number of subway stations	[110]	MIC	2017
Icf_4	Station intensity for passenger transport	Ratio of the number of railway stations and metro stations to the territorial area of the administrative municipality [per 100 sq. km]	Number of stations belonging to the categories: Platinum; Gold; Silver and Bronze	[111]	ISTAT	2015
				[112]	RFI	2022
Icf_5	Local public transport offer	Ratio of the number of vehicles for local public transport (LPT) to residents	Number of bus and trolleybus cars intended for passenger transport	[111]	ISTAT	2015

It is important to note that the analytical model required the search and selection of a significant volume of data, which was not always fully reflected in the available sources. The collected data exhibit adequate coverage and territorial representativeness at the municipal level. Furthermore, to enable the implementation of the spatial analysis approach, the data were precisely georeferenced across the territory.

The selection of the indicators used to construct the correction factors took into account, in the context of complex territorial systems characterized by varying degrees of tourism exposure, the multidimensionality of tourism impacts [25,25,26,29,30,30,89,113–118]. The indicators provide raw data on environmental, anthropic, and infrastructural components, elaborated at the municipal scale. Adopting a coherent approach in relation to the phenomenon being measured, the polarity of each elementary indicator was defined.

The EEI and IEI are calculated as the sum of normalized indicators on a scale from 0 to 1 and recalibrated through the assignment of weights.

The spatial representation of the two indices (Figures 3 and 4) provides an informative framework that enables the development of preliminary observations on the territorial and tourism-related aspects of the area influenced by the "Via Appia, *Regina Viarum*". In both cases, the different shades of color used in the maps reflect variations in endowment levels: darker colors indicate areas with higher endowment, while lighter colors represent zones with lower endowment. This representation facilitates the visual analysis of areas with greater potential to support the tourism development of the Via Appia, while also serving as a useful tool for interpreting the spatial distribution of ecological and infrastructural resources.

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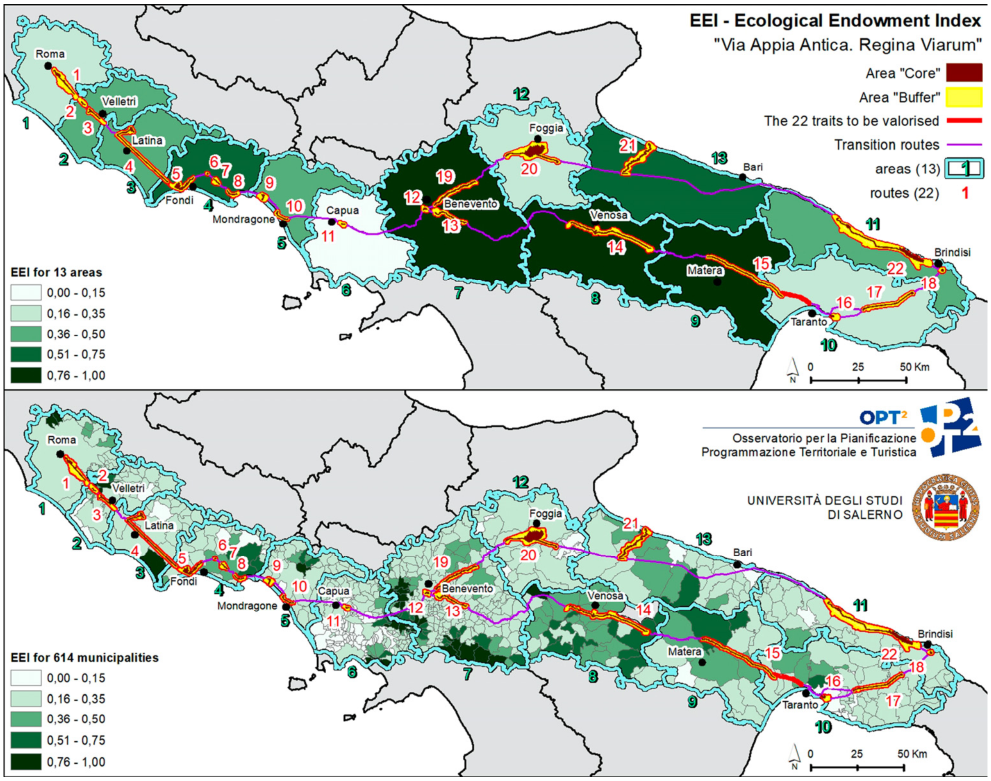

Figure 3. Ecological Endowment Composite Index (EEI) of the "Via Appia Antica. *Regina Viarum*". Source: Autorhs' elaboration.

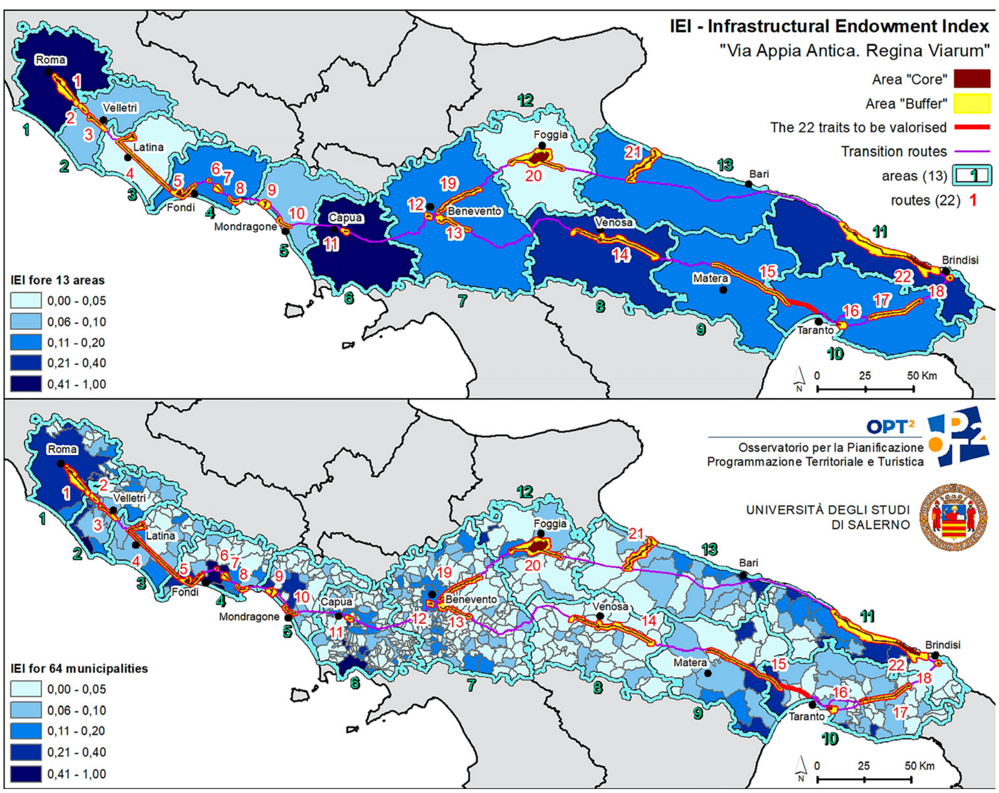

Figure 4. Infrastructure Endowment Composite Index (IEI) of the "Via Appia. *Regina Viarum*". Source: Autorhs' elaboration.

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3.3. *Dynamic Estimation of Tourism Carrying Capacity*

The methodology has been further developed to account for the dynamic nature of the TCC tool.

The aim of this research is to test the tourism absorption capacities of the areas that compose a serial site. In particular, it is assumed that tourist pressure on territorial endowments (both infrastructural and ecological) will progressively increase over time.

Therefore, through the application of specific variation coefficients in the growth of tourist arrivals and bed places, modifications are induced in the PCC values of the municipalities. In contrast, the respective ecological and infrastructural correction factors, described by the EEI and IEI indices, are kept constant over time, acting as parameters to determine the threshold values. Building on these assumptions, the procedural framework of the three levels of carrying capacity—physical (PCC), real (RCC), and effective (ECC)—facilitates the evaluation of the territories' ability to absorb potential increases in tourism over time, under various scenario conditions.

Thus, the scenario assumptions enable the estimation of the different reactions in the ECC of the areas comprising the serial site observed in the following years. This analysis identifies the decade 2024-2034 as the forecast period for estimating the effects of UNESCO recognition.

The ECC, as the PCC, is expressed in percentage terms, values exceeding 100% represent situations of congestion and overuse:

- ECC <20% Very low impact;
- 21% ≤ ECC <40% *Low impact*;
- 41% ≤ ECC <60% *Moderate impact*;
- 61% ≤ ECC <80% *High impact*;
- 81%≤ ECC<100 Very high impact;
- ECC ≥100 Congestion and overuse

3.3.1. Scenario 1 - Ordinary Dynamics

Scenario 1 - Ordinary Dynamics considers the evolution of the ECC in absence of specific policies aimed at fostering tourism growth. This Scenario projects the trends in tourism demand and accommodation supply observed during the 2014-2019 period onto the forecasting period. This choice reflects the researchers' intent to present a measure as neutral as possible regarding the consequences of the SARS-CoV-2 pandemic. The assumption is that during the forecast period, the system will continue to exhibit five-year growth trends of 7.3% in bed capacity and 7.9% in tourist arrivals for the hotel sector, and 30.2% and 30.7%, respectively, for the accommodation sector (including both hotel and extra hotel facilities). Scenario 1 is represented by the following formula (7) – (8):

$$ECC_{2029} = f\,(eNS_{2024}, eBP_{2024}, Trend_{2019\text{-}2024}, Cf) \quad (7)$$

$$ECC_{2034} = f\,(eNS_{2029}, eBP_{2029}, Trend_{2019\text{-}2024}, Cf) \quad (8)$$

where eNS is estimated nights spent at tourist accommodation establishments; eBP is estimated bed places in tourist accommodation establishment; Trend represents trend of nights spent and bed places based on ISTAT data 2014-2019 [106]; Cf are the correction factors used for the calculation of the EEI and IEI.

In order to assess the impact of UNESCO recognition on the evolution of ECC, adjustments were made to the trends of Scenario 1, and two additional scenarios were proposed, as described below.

3.3.2. Scenario 2 - UNESCO Effect

The Scenario 2 – UNESCO effect examines the evolution of ECC following the potential increase in pressure resulting from the site's designation as a World Heritage Site. Scenario 2 assumes that, with UNESCO recognition, the ECC will grow at a more pronounced rate compared to Scenario 1. The developing of this Scenario based on tourism trends observed in similar serial sites. This led to the formulation of a five-year growth coefficient of 18.75%, defined within the study as the UNESCO Coefficient (C_{UNESCO}). Scenario 2 is expressed by the following Formulae (9) (10):

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$$ECC_{2029} = f\,(eNS_{2024},\ eBP_{2024},\ Trend_{2019\text{-}2024},\ Cf,\ C_{UNESCO}) \quad (9)$$

$$ECC_{2034} = f\,(eNS_{2029},\ eBP_{2029},\ Trend_{2019\text{-}2024},\ Cf,\ C_{UNESCO}) \quad (10)$$

where eNS is estimated nights spent at tourist accommodation establishments; eBP is estimated bed places in tourist accommodation establishment; Trend represents trend of nights spent and bed places based on ISTAT data 2014-2019; Cf are the correction factors used for the calculation of the EEI and IEI; C_{UNESCO} represents a five-year growth coefficient of 18.75 percent.

3.3.3. Scenario 3 - Overflowing/Stress Test

Scenario 3 - Overflowing/ Stress test explores the hypothesis that the ECC, in the presence of UNESCO recognition, grows to such an extent that it pushes the territorial tourism hospitality systems towards a situation of widespread overflowing. In order to analyze Scenario 3 a five-year growth coefficient of 50% was applied, referred to in this study as the Overflowing Coefficient ($C_{OVERFLOWING}$). Scenario 3 is expressed by the following formula (11) – (12):

$$ECC_{2029} = f\,(eNS_{2024},\ eBP_{2024},\ Trend_{2019\text{-}2024},\ Cf,\ C_{OVERFLOWING}) \quad (11)$$

$$ECC_{2034} = f\,(eNS_{2029},\ eBP_{2029},\ Trend_{2019\text{-}2024},\ Cf,\ C_{OVERFLOWING}) \quad (12)$$

where eNS is estimated nights spent at tourist accommodation establishments; eBP is es-timated bed places in tourist accommodation establishment; Trend represents trend of nights spent and bed places based on ISTAT data 2014-2019 [107]; Cf are the correction factors used for the calculation of the EEI and IEI; $C_{OVERFLOWING}$ represents a five-year growth coefficient of 50 percent.

4. Results

Tables 3 and 4 show the values obtained from applying the TCC calculation method to each of the 13 areas and to the entire area of influence of the Via Appia. The first two columns report the trends in tourist arrivals and bed availability for the period 2014–2019; the following columns show the PCC values calculated for the years 2014 and 2019. The last three columns present the ECC values obtained for the different scenarios considered over the time intervals 2019–2024, 2024–2029, and 2029–2034.

Table 3. Effective Carrying Capacity (ECC) in percentage values based on the Physical Carrying Capacity (PCC) calculated for the hotel and extra hotel (accommodation establishment). Source: Authors' elaboration.

Effectice Carrying capacity (ECC)

Accommodation establishments
hotel and extra hotel (val %)

the 13 areas	Nights spent trend 14-19	Bed places trend 14-19	PCC		Ordinary ECC scenario 1 f(PCC, trend, EEI, IEI)			UNESCO ECC scenario 2 f(PCC, trend, EEI, IEI, Coeff. UNESCO)			Overflowing ECC scenario 3 f(PCC, trend, EEI, IEI, Coeff. overflow.)		
			ISTAT data		Estimate			Estimate			Estimate		
	2014-19	2014-19	2014	2019	2019-24	2024-29	2029-34	2019-24	2024-29	2029-34	2019-24	2024-29	2029-34
1	29.8	46.5	38.2	33.9	30.0	26.6	23.6	30.0	30.4	30.9	30.0	36.8	45.2
2	59.5	3.8	5.3	8.1	8.3	12.7	19.6	8.3	19.3	30.1	8.3	19.8	31.4
3	0.0	0.0	19.0	10.5	10.5	10.5	10.5	10.5	10.6	10.7	10.5	10.7	10.9
4	1.6	13.0	15.9	14.3	12.7	11.4	10.3	12.7	12.2	11.7	12.7	13.4	14.0
5	100.0	22.5	5.9	12.8	11.6	19.0	**31.0**	11.6	34.4	56.8	11.6	35.0	58.8
6	38.8	5.8	31.2	41.0	44.7	58.6	76.9	44.7	74.3	102.7	44.7	80.6	120.9
7	89.3	6.4	4.6	8.2	10.5	18.7	33.3	10.5	27.0	50.1	10.5	28.8	56.7
8	0.0	0.0	13.0	11.8	11.8	11.8	11.8	11.8	12.9	14.0	11.8	14.6	17.9
9	55.8	22.3	15.1	19.2	18.7	23.8	30.3	18.7	32.4	42.9	18.7	34.5	48.8
10	10.9	31.2	16.3	13.8	10.7	9.0	7.6	10.7	10.1	8.7	10.7	10.4	9.3
11	42.9	26.2	16.6	18.8	16.7	18.9	21.4	16.7	25.0	29.3	16.7	26.4	32.8
12	29.9	24.8	16.0	16.6	13.3	13.9	14.4	13.3	18.0	18.8	13.3	18.0	18.8
13	39.8	32.9	22.1	23.2	19.5	20.5	21.6	19.5	26.7	29.2	19.5	28.4	33.1
	30.7	**30.2**	**26.4**	**26.5**	**26.6**	**26.7**	**26.8**	**26.6**	**30.5**	**35.1**	**26.6**	**36.9**	**51.3**

* Note: to limit model bias, the negative trends were treated as a null trend (grey cells).

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Table 4. Effective Carrying Capacity (ECC) in percentage values based on the Physical Carrying Capacity (PCC) calculated for the hotel sector. Source: Authors' elaboration.

Effectice Carrying capacity (ECC)

Hotel sector (val%)

The 13 areas	*Nights spent trend 14-19*	*Bed places trend 14-19*	PCC		Ordinary ECC scenario 1 f(PCC, trend, EEI, IEI)			UNESCO ECC scenario 2 f(PCC, trend, EEI, IEI, Coeff. UNESCO)			Overflowing ECC scenario 3 f(PCC, trend, EEI, IEI, Coeff. overflow.)		
			ISTAT data		*Estimate*			*Estimate*			*Estimate*		
	2014-19	**2014-19**	**2014**	**2019**	**2019-24**	**2024-29**	**2029-34**	**2019-24**	**2024-29**	**2029-34**	**2019-24**	**2024-29**	**2029-34**
1	4.6	8.9	49.4	47.4	45.6	43.8	42.1	45.6	51.6	58.5	45.6	64.7	91.9
2	0.0	0.0	19.1	16.2	16.2	16.2	16.2	16.2	16.5	16.9	16.2	17.1	18.0
3	0.0	0.0	32.3	19.7	19.7	19.7	19.7	19.7	19.8	19.9	19.7	20.0	20.4
4	0.0	0.8	26.4	23.5	23.4	23.2	23.0	23.4	24.6	25.9	23.4	26.9	31.1
5	93.1	0.0	9.4	20.7	22.8	44.1	85.2	39.9	77.9	152.2	39.9	79.4	157.8
6	16.3	4.0	42.1	47.1	48.2	53.9	60.3	52.7	62.7	74.5	52.7	68.9	90.2
7	40.0	0.0	5.9	8.6	10.0	14.1	19.7	12.1	17.9	26.4	12.1	19.4	31.1
8	0.0	0.0	13.4	10.2	10.2	10.2	10.2	10.2	11.1	12.0	10.2	12.5	15.4
9	64.3	0.0	19.9	33.0	40.2	66.1	108.7	54.2	92.6	158.0	54.2	98.3	178.4
10	1.3	20.8	21.5	18.1	15.0	12.6	10.5	15.1	13.0	11.2	15.1	13.5	12.1
11	28.6	12.3	23.1	26.4	25.4	29.1	33.3	30.3	36.1	43.0	30.3	38.4	48.6
12	18.3	7.1	20.9	23.1	21.5	23.8	26.3	25.5	28.1	31.1	25.5	28.1	31.1
13	18.9	13.8	27.3	28.5	26.5	27.7	28.9	29.8	32.6	35.7	29.8	35.1	41.2
	7.9	**7.3**	**38.7**	**38.9**	**39.1**	**39.4**	**39.6**	**39.1**	**46.2**	**54.5**	**39.1**	**57.6**	**84.8**

* Note: to limit model bias, the negative trends were treated as a null trend (grey cells).

The first step of the analysis involved calculating the PCC as the initial step in determining the ECC. The PCC was calculated for: i) the total set of accommodation facilities; ii) the hotel sector; iii) the non-hotel sector. The calculation was performed separately for each category. However, the discussion focuses on the first two categories, and the cartographic representation of the tourist load is based on the PCC calculated for the hotel sector. This is due to the greater structural rigidity of the hotel sector in responding to fluctuations in tourist demand, which generally requires longer planning and adaptation times. The lower resilience of the hotel supply is clearly visible when comparing the trends reported in the first two columns of Tables 3 and 4. The latter also provides the specific ECC values calculated based on the physical carrying capacity of the hotel sector.

For the year 2019 only, the PCC corresponds to the ECC. The estimated tourist load is 26.5% (Table 3). It is important to note that in the same year, tourist arrivals across the entire accommodation system exceeded 48 million, with the Rome area (Area 1) alone accounting for 68%. Overall, tourist arrivals in the influence area increased by +30% compared to 2014 (36.7 million) (Table A1). **Figure 5** shows the spatial distribution of tourist carrying capacity values in the territory in 2019, highlighting the differences between the 13 areas and among individual municipalities. As previously mentioned, the cartographic evidence illustrates the results obtained starting from the hotel PCC. The color scale uses increasingly intense shades of orange to represent higher levels of tourist load. These figures highlight a highly heterogeneous territorial configuration of tourist demand, with a discontinuous tourism space [119], in which areas and municipalities show very different current levels of tourism exposure. Data on actual and estimated tourist arrivals, in absolute values, are provided in the Appendix B section (Tables A1 and A2).

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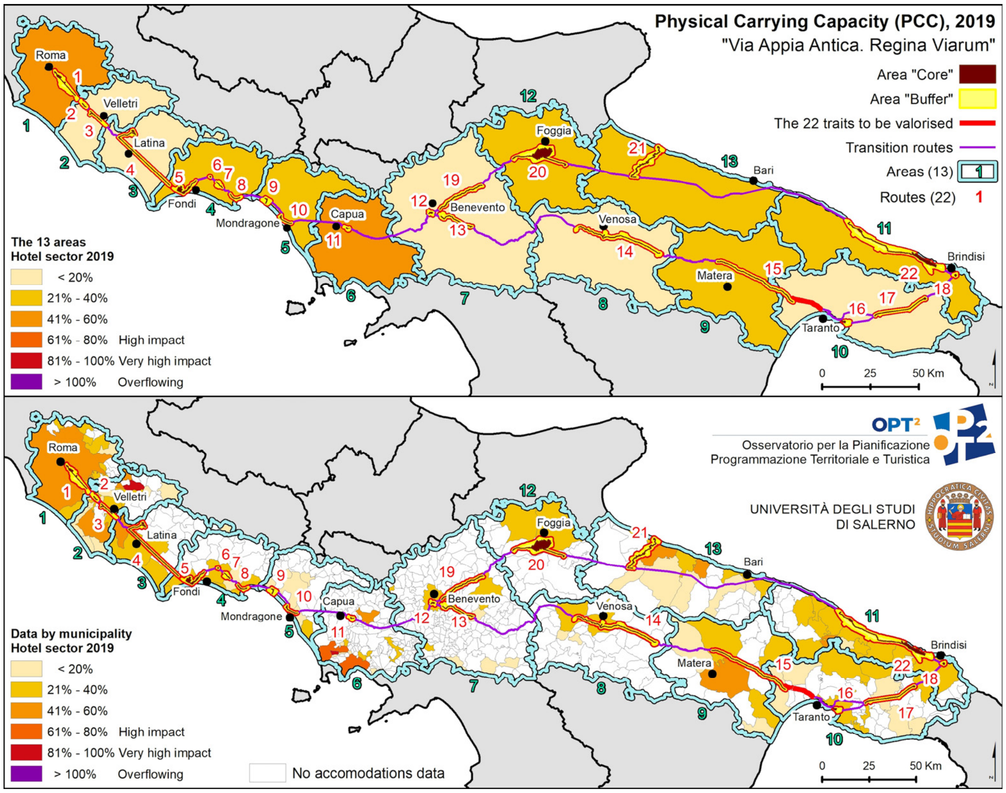

Figure 5. Effective Carrying Capacity (ECC) or Physical Carrying Capacity (PCC), as calculated for the year 2019 for "Via Appia. *Regina Viarum*". Source: Authors' elaboration.

Starting from this baseline, what changes in tourism load levels could be observed at area and municipal scales under different scenario assumptions? **Figure 6** illustrates the spatial distribution of the ECC estimated under the "Ordinary Dynamics" scenario in 2034, developed on the basis of the hotel PC. In this case, tourist arrivals and bed availability were increased based on trends recorded in previous years. Forecasted tourist arrivals are expected to reach approximately 107.3 million by 2034 (Table A1). As before, the territorial distribution is shown for the 13 areas and the municipalities within the scope.

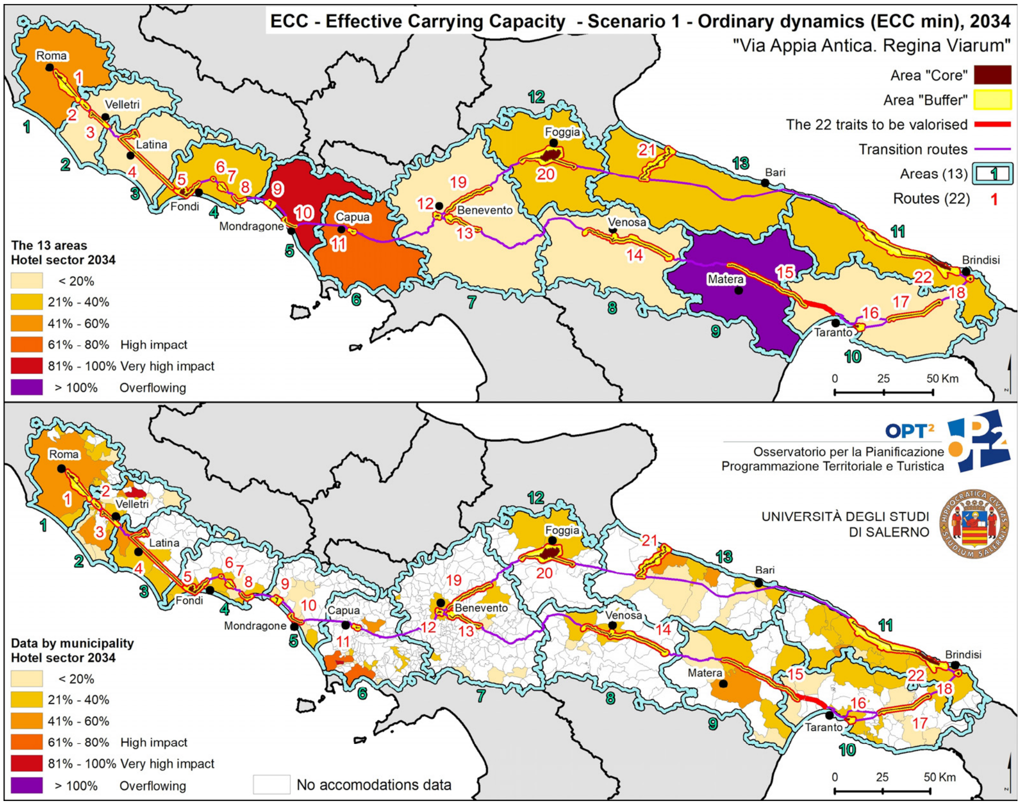

Figure 6. Effective Carrying Capacity (ECC), Scenario 1 Ordinary dynamics, as calculated for the year 2034 for "Via Appia. *Regina Viarum*". Source: Authors' elaboration.

The increase in tourist arrivals within the system results in moderate variations in territorial tourism load. Indeed, during the periods 2019–2024, 2024–2029, and 2029–2034, the carrying capacity remains between 26.6% and 26.8% when calculated using the PCC of all accommodation facilities (Table 3); and ranges between 39.1% and 39.6% when using the PCC of the hotel sector alone (Table 4). In both cases, the carrying capacity remains within low-impact levels.

At the area level the increase in tourism load is more pronounced in the Capua Area (Area 6), where the ECC would rise from a Moderate impact in 2019 (41.0%) to a High impact in 2034 (76.9%) (Table 3). When limiting the analysis to the initial PCC values of the hotel sector, the scenario immediately appears more critical in some areas. In this case, tourist arrivals in 2034 would reach about 47.2 million (Table A2). The Domitian Area (Area 5) would see the tourism load rise to 85.2%, while Area 9 would reach 108.7% (Table 4; Figure 6). In Area 5, increased tourist flows would compound an already high population density, further raising the territorial tourism load. Conversely, Area 9, which includes the Matera region, is more likely to face congestion and overuse risks due to limited initial infrastructure. However, such risks would only materialize if the tourist growth trend initiated by the "Matera European Capital of Culture" experience continues.

In all other areas, the tourism load on the territory remains at less significant levels. This is also reflected at the municipal level. In some cases, tourism movements—combined with low estimated flows and the territorial characteristics described by the EEI and IEI indices—suggest a higher absorption capacity of the areas.

Figure 7 shows the spatial distribution of ECC values estimated under the "UNESCO effect" scenario, with projections for 2034 based on the hotel PCC. The application of the variation coefficient associated with the UNESCO effect results in an incremental estimate of tourist arrivals during the forecast periods, reaching approximately 140.3 million in the Appia's influence area (Table A1). Even in this case, considering the area as a whole and using different calculation bases, the increase in tourism load remains compatible with existing ecological and infrastructural capacities. Over the

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projected periods, territorial ECC increases from 26.6% to 35.1% (Table 3), and from 39.1% to 54.5% (Table 4). This latter value indicates a Moderate impact condition on the territorial system.

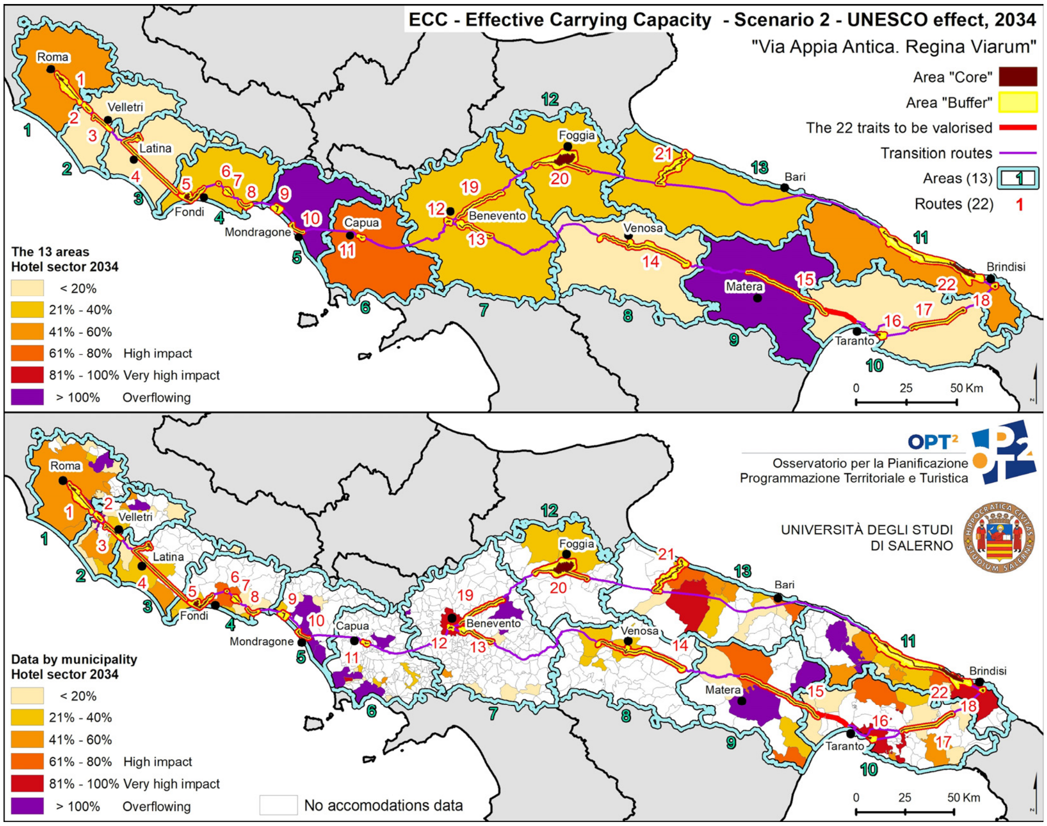

Figure 7. Effective Carrying Capacity (ECC), Scenario 2 UNESCO effect, as calculated for the year 2024 for "Via Appia. *Regina Viarum*". Source: Authors' elaboration.

The area-level detail would show differentiated trends, with some areas experiencing a sharper increase in tourism load. On the one hand, areas already found to be more sensitive under Scenario 1 would naturally see a worsening of their load conditions by 2034. On the other hand, the territorial absorption capacity would vary, with a rapid increase in load in Areas 5, 7 and 9, leading to Moderate impact levels, while Area 6 reaches an overflowing condition when considering the PCC of the overall accommodation system (Table 3).

The 2034 projection, based on hotel PCC, results in two areas reaching higher levels of congestion and overuse of territorial resources (Areas 5 and 9) (Figure 7; Table 4). The UNESCO coefficient leads to an estimate of tourist arrivals around 59.1 million (Table A2). These greater flows would increase the number of municipalities experiencing Very High Impact conditions or even surpassing 100% of ECC, beyond those previously identified, signaling stronger tensions between tourism growth and the absorption capacity of local resources (Figure 7).

Finally, **Figure 8** highlights ECC levels estimated under the extreme **Overflowing/Stress Test** scenario, assuming the hotel PCC as the reference baseline for calculations. This scenario serves to test the resilience of the territorial system in the face of exceptional tourist pressures. Here, the variation coefficient brings tourist arrivals up to approximately 205 million in 2034 (Table A1). In that year, territorial carrying capacity would reach 51.3% when using the PCC of all accommodation facilities—still within a Moderate impact range (Table 3); but would climb to 84.8% when based on hotel PCC, indicating a significant risk of congestion and overuse of local resources (Table 4). At the same time, the uneven distribution of ecological-infrastructural endowments would increase the number of areas—and particularly municipalities—exceeding critical thresholds of tourism load.

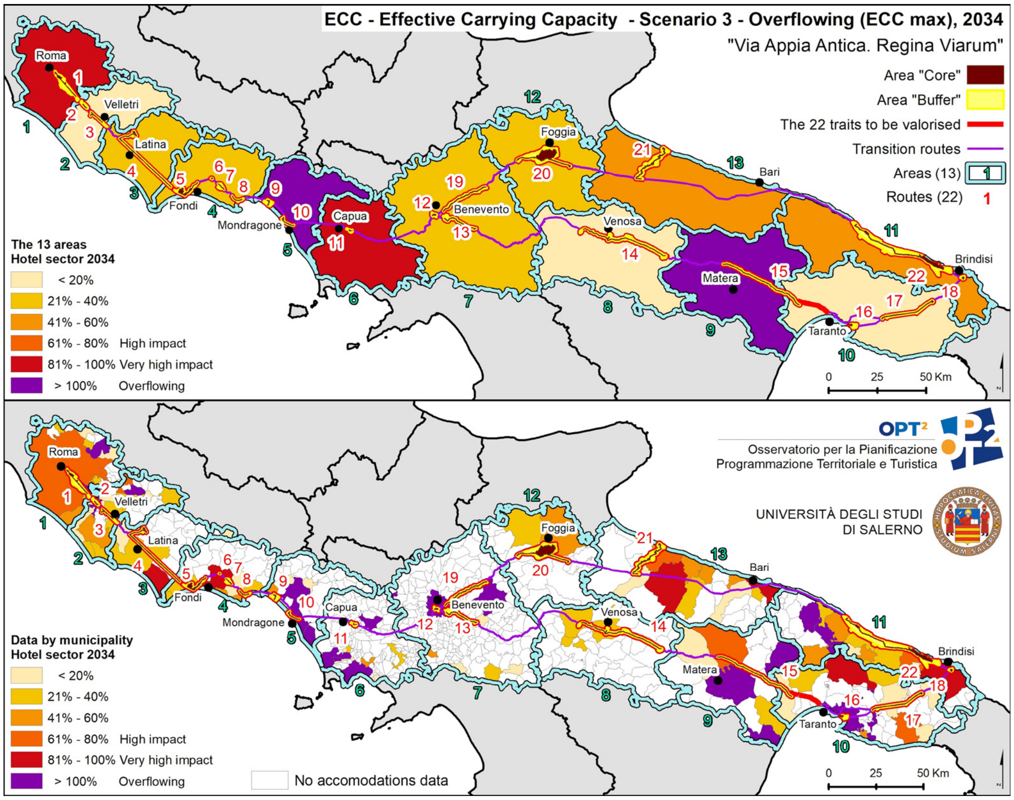

Figure 8. Effective Carrying Capacity (ECC), Scenario 3 Overflowing (ECC max), as calculated for the year 2024 for "Via Appia. *Regina Viarum*". Source: Authors' elaboration.

5. Discussion and Conclusion

This article introduced a methodology for estimating the tourism carrying capacity (TCC) of large-scale distributed sites. The model is defined as "geographical-territorial" because it proposes an estimation of carrying capacity attributed to the territorial (municipal) scale, rather than being limited to the analysis of individual tourist sites. To this end, it draws inspiration from the Cifuentes model, which adopts an ecosystem-based and process-oriented approach, considering the TCC (or ECC – Environmental Carrying Capacity) as the result of complex and interdependent dynamics.

The evaluations derived from the model and related scenarios provide a nuanced analytical framework, offering valuable insights for further exploration. Nevertheless, some evaluative and operational implications can already be highlighted. The model generates time-dependent ECC values; the scenarios illustrate how municipalities and areas respond to induced increases in tourist flows. However, the results are strongly influenced by the EEI and IEI indices, which reflect the characteristics and capacities of the territory at the time of the model's construction and remain fixed in future projections. This is a crucial aspect, as it clearly demonstrates that the TCC is influenced—either separately or in combination—by both the intensity of tourism demand and the characteristics and capabilities of the territorial supply system.

The granular evaluations derived from the model and related scenarios provide a nuanced analytical framework, offering valuable insights for further exploration. Nevertheless, some evaluative and operational implications can already be highlighted. The model generates time-dependent ECC values; the scenarios illustrate how municipalities and areas respond to induced increases in tourist flows. However, the results are strongly influenced by the EEI and IEI indices, which reflect the characteristics and capacities of the territory at the time of the model's construction and remain fixed in future projections. This is a crucial aspect, as it clearly demonstrates that the TCC is influenced—either separately or in combination—by both the intensity of tourism demand and the characteristics and capabilities of the territorial supply system.

These differing reactions correspond to distinct planning tasks and objectives in both tourism and territorial domains. On the one hand, there is a need to systematically mitigate the multidimensional impacts of tourism by strategically strengthening and effectively optimizing infrastructure and services at multiple levels. On the other hand, it is essential to promote diversified tourism development in less exposed areas, creating the necessary conditions not only for such development to occur but also for it to be sustainable over time. This includes preserving and enhancing local resources while minimizing environmental and community impacts.

Accordingly, it is crucial to adopt a systemic vision, planning for an integrated territorial offer that enables a balanced distribution of tourist flows, harmonizing the different dimensions of sustainability and capitalizing on the opportunities arising from the deconcentration of high-pressure destinations. From this perspective, strengthening monitoring and evaluation systems is also essential to support informed intervention strategies and ensure adequate adaptive capacity over time.

From an operational standpoint, the model presents room for improvement, which can be leveraged through the integration of additional indicators and alternative statistical sources. During its construction, the model encountered some limitations primarily related to the availability, update frequency, and territorial coverage of data. In many cases, information was not available at the municipal level and, where it was, coverage was not uniform across all municipalities. Furthermore, actual tourism demand is likely underestimated, as the analysis could not account for excursionists or the seasonal variability of tourism flows.

Nevertheless, these limitations can be addressed by expanding and enriching the information base. The integration of new indicators and alternative data sources would enhance the depth and multidimensionality of the territorial endowment indices, while also improving the accuracy of the estimates. Additionally, it would allow the model to be applied at finer spatial resolutions—both below the municipal scale and to differentiated territorial aggregations.

Tourism planning is not an autonomous or isolated process from territorial planning, which is based on an integrated vision of the area's environmental, cultural, socioeconomic, and settlement resources, as well as on the democratic and participatory involvement of local communities in decision-making processes. In tourism areas, the concept of tourism carrying capacity plays a critical role, as it provides a useful tool for translating the inherently abstract notion of sustainability into measurable operational parameters—both qualitatively and quantitatively, and in relation to spatial dimensions.

Within this perspective, TCC—when embedded in a coherent planning framework—serves as an essential operational mechanism for translating the principle of sustainability into concrete, manageable metrics. It contributes to regulating tourism pressure on sites and destinations and supports the activation of feedback loops for continuous monitoring and adaptive management of tourism strategies. Similarly, strategic planning, by supporting a systemic and long-term vision articulated through a coherent sequence of goals and actions, becomes a key activity for guiding the orderly transformation of territories and their tourism development, while mitigating the negative impacts of uncontrolled tourism growth.

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Abbreviation

The following abbreviations are used in this manuscript:

BP	Bed Places
Cf	Correction factors (generic, including Ecf and Icf)
$C_{overflowing}$	Overflowing Coefficient
C_{UNESCO}	UNESCO Coefficient
DPa	Bed places Available
ECC	Effective (o Admissible) Carrying Capacity (synonymous of TCC)
Ecf	Ecological correction factors
EEI	Ecological Endowment composite index
eNS	Estimated Nights Spent
EUAP2010	Elenco Ufficiale delle Aree Protette
GOr	Gross Occupancy rate
Icf	Infrastructure correction factors
IEI	Infrastructure Endowment composite index
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
ISTAT	Istituto Nazionale di Statistica
LPT	Local Public Transport
MiC	Ministero della Cultura
MSW	Municipal Solid Waste
NS	Nights Spent
PCC	Physical Carrying Capacity
RCC	Real Carrying Capacity
RFI	Rete Ferroviaria Italiana
SARS-CoV-2	Severe Acute Respiratory Syndrome COronaVirus 2
TCC	Tourism Carrying Capacity
UNESCO	United Nations Educational, Scientific and Cultural Organization

Appendix B

Table A1. Nights spent in total accommodation establishments. Source: Authors' elaboration.

Nights spent in Accommodation establishments
Hotel and extra hotel (val. absolute)

OPT² Osservatorio per la Pianificazione e la Programmazione Territoriale e Turistica

The 13 areas	ISTAT data		Estimated nights spent Ordinary dynamics - Scenario 1			Estimated nights spent Unesco effect - Scenario 2			Estimated nights spent Overflowing - Scenario 3		
	2014	**2019**	**2024**	**2029**	**2034**	**2024**	**2029**	**2034**	**2024**	**2029**	**2034**
1	24 448 335	31 741 825	41 211 128	53 505 337	69 467 186	41 211 128	61 232 423	90 980 516	41 211 128	74 110 901	133 275 305
2	474 698	757 176	1 207 748	1 926 441	3 072 806	1 207 748	1 950 961	3 151 526	1 207 748	1 991 828	3 284 938
3	660 790	364 543	364 543	364 543	364 543	364 543	367 028	369 530	364 543	371 169	377 916
4	1 681 729	1 709 054	1 736 823	1 765 043	1 793 722	1 736 823	1 871 139	2 015 842	1 736 823	2 047 965	2 414 847
5	275 230	725 499	1 450 998	2 901 996	5 803 992	1 450 998	2 932 819	5 927 940	1 450 998	2 984 191	6 137 430
6	3 475 430	4 824 556	6 697 399	9 297 260	12 906 360	6 697 399	9 794 739	14 324 504	6 697 399	10 623 871	16 852 310
7	179 444	339 677	642 989	1 217 140	2 303 975	642 989	1 265 922	2 492 359	642 989	1 347 226	2 822 783
8	132 494	112 530	112 530	112 530	112 530	112 530	122 219	132 742	112 530	138 367	170 136
9	828 770	1 291 022	2 011 098	3 132 802	4 880 143	2 011 098	3 261 574	5 289 581	2 011 098	3 476 195	6 008 625
10	1 048 726	1 162 705	1 289 072	1 429 172	1 584 499	1 289 072	1 460 723	1 655 231	1 289 072	1 513 307	1 776 549
11	2 247 306	3 210 559	4 586 687	6 552 659	9 361 296	4 586 687	6 785 677	10 038 927	4 586 687	7 174 041	11 220 925
12	153 141	198 936	258 425	335 705	436 093	258 425	335 705	436 093	258 425	335 705	436 093
13	1 158 424	1 619 304	2 263 546	3 164 099	4 422 939	2 263 546	3 290 542	4 783 498	2 263 546	3 501 280	5 415 823
V.Appia	**36 764 517**	**48 057 386**	**62 819 059**	**82 115 039**	**107 338 120**	**62 819 059**	**93 893 613**	**140 339 742**	**62 819 059**	**113 524 568**	**205 157 923**

Table A2. Night spent in hotel. Source: Authors' elaboration.

Nights spent in sector hotel (val. absolute)

OPT² Osservatorio per la Pianificazione e la Programmazione Territoriale e Turistica

The 13 areas	ISTAT data		Estimated nights spent Ordinary dynamics - Scenario 1			Estimated nights spent Unesco effect - Scenario 2			Estimated nights spent Overflowing - Scenario 3		
	2014	**2019**	**2024**	**2029**	**2034**	**2024**	**2029**	**2034**	**2024**	**2029**	**2034**
1	21 468 871	22 460 767	23 498 490	24 584 158	25 719 985	23 498 490	28 990 125	35 765 163	23 498 490	36 333 403	56 178 765
2	413 825	344 762	344 762	344 762	344 762	344 762	351 761	358 903	344 762	363 427	383 103
3	430 994	262 422	262 422	262 422	262 422	262 422	264 211	266 012	262 422	267 192	272 049
4	633 072	570 094	570 094	570 094	570 094	570 094	604 919	641 871	570 094	662 960	770 954
5	199 919	386 142	745 830	1 440 565	2 782 441	745 830	1 456 409	2 843 981	745 830	1 482 815	2 948 043
6	3 510 121	4 081 032	4 744 800	5 516 528	6 413 775	4 744 800	5 868 969	7 259 484	4 744 800	6 456 371	8 785 351
7	121 757	170 420	238 532	333 867	467 305	238 532	351 964	519 338	238 532	382 126	612 161
8	99 298	64 675	64 675	64 675	64 675	64 675	70 244	76 291	64 675	79 524	97 783
9	470 477	773 025	1 270 131	2 086 910	3 428 933	1 270 131	2 168 238	3 701 394	1 270 131	2 303 785	4 178 641
10	777 461	787 741	798 157	808 711	819 404	798 157	828 246	859 469	798 157	860 805	928 370
11	1 571 449	2 021 548	2 600 566	3 345 427	4 303 634	2 600 566	3 477 544	4 650 263	2 600 566	3 697 740	5 257 809
12	118 000	139 555	165 047	195 197	230 853	165 047	195 197	230 853	165 047	195 197	230 853
13	923 526	1 097 795	1 304 948	1 551 192	1 843 901	1 304 948	1 624 087	2 021 274	1 304 948	1 745 579	2 334 992
V.Appia	**30 738 770**	**33 159 978**	**35 771 898**	**41 104 508**	**47 252 184**	**35 771 898**	**46 251 914**	**59 194 296**	**35 771 898**	**54 830 923**	**82 978 874**

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