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Environmental and self-sufficiency assessment of the energy metabolism of tourist hubs on Mediterranean Islands: The case of Menorca (Spain)

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HIGHLIGHTS

- We modeled the entire energy metabolism of tourist hubs in islands.
- Results showed that a tourist in Menorca consumes from 4000 to 6000 MJ per trip.
- External mobility (trip to the island) accounts for 77% of the total CO_2 emissions.
- Photovoltaic systems could provide enough power to achieve self-sufficiency.
- Tourists at hotel hubs have higher energy consumption than other types of hubs.

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ABSTRACT

Energy performance of island tourism has been analyzed in the literature. However, tourist services tend to concentrate in tourist hubs, especially where mass tourism predominates (e.g., Mediterranean), and the energy metabolism of these systems has not yet been assessed. The present paper models and estimates the energy metabolism of tourist hubs in the Menorca Island (Spain) by integrating social, geographical and environmental methods. Mobility (both external and internal) and consumption of lodging services were characterized through surveys to users (tourists) and business managers. An environmental assessment evaluated CO_2 emissions, and energy self-sufficiency potential was estimated via GIS data. The results indicate that, on average, a tourist consumes 4756 MJ with associated emissions of 277 kg of CO_2 per stay (20 days on average). Of all the energy flows, external mobility contributes the most to total emissions (77%). For every day spent in a tourist hub, a tourist consumes between 29 MJ and 93 MJ in lodging services, consumption that could be 100% satisfied by photovoltaic systems, and these systems would result in positive effects for the island. Sustainable tourism management might focus on promoting environmentally friendly transportation, energy efficient practices, and environmental communication through ecolabeling.

1. Introduction

Tourism, defined as "the activities of persons traveling and being in a place outside their usual environment for not more than one consecutive year for leisure, business and other reasons" (UNWTO), is the fastest growing economic sector in many countries and regions worldwide. It accounts for 5% of global GDP (UNWTO, 2012) due to the high contribution of tourism to Gross Value Added (GVA). Additionally, tourism is one of the most dynamic sectors of the world economy (Radulescu, 2011) and is responsible for between 6% and 7% of total world employment, up to 25% in areas where tourism is the main source of economic support (UNWTO, 2012).

The Fordian tourism period (1900–1950), which was characterized by reduced bourgeois mobility to foreign countries for therapeutic reasons (Riera et al., 2009), shifted to a mass tourism

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with a boom of users in the 60s due to improved labor conditions for the working class, which led to a massive increase in tourist mobility (Apostolopoulos and Gayle, 2002). This shift resulted in the now-predominant type of tourism: mass tourism, which is concentrated in coastal areas (such as the south Mediterranean) and is characterized by reduced interest in local culture and heritage.

Although the current tourism model results in economic and social development, it is associated with a number of environmental impacts (Apostolopoulos and Gayle, 2002; Cànoves et al., 2004; UNWTO, 2008) and produces 5% of the global emissions of CO_2 (World Economic Forum, 2009). Gössling (2002) summarizes the global environmental impacts of tourism as follows: changes in land cover and land use, large energy use, effects on biodiversity (biotic exchange and extinction), disease exchange and dispersion, and changes to people's perception and understanding of the environment.

However, tourism has been identified as an economic sector that is dependent on the environment and its resources (e.g., landscape) (Radulescu, 2011). Therefore, the need for a more environmentally friendly tourism model has introduced the concept of eco-tourism or sustainable tourism. The first definition of this model is found in the Manila Declaration on World Tourism (1980), which states that “the satisfaction of tourism requirements must not be prejudicial to the social and economic interests of the population in tourist areas, to the environment or, above all, to natural resources, which are the fundamental attraction of tourism, and historical and cultural sites”. This sustainable model aims to guarantee the quality, continuity and balance between tourism and environmental needs (Radulescu, 2011) while ensuring the future use of natural and cultural resources (Honey and Krantz, 2007) and satisfying the tourist with a nature-based model (Lu and Stepchenkova, 2012) that equally distributes the economic and social benefits throughout the population.

Mass tourism destinations (e.g., sun and beach) tend to concentrate the requisite tourism infrastructure and services by the creation of tourist hubs (Montaner Montejano, 1991), which are areas that have recently evolved into “all-inclusive” tourism resorts in developing regions with an emergent economy and large coastal areas to exploit (Papatheodorou, 2004). These tourist hubs are associated with the presence of extensive construction, commercial and services areas, which have a significant impact on land use and occupancy. This impact is greater in areas such as the Mediterranean, where tourism is seasonal due to the climate conditions, in contrast to temperate areas with lower seasonality (e.g., the Canary Islands or Cancun). Because tourist hubs are the primary mass tourism destinations, their design are largely responsible for environmental impacts, which therefore tend to be seasonal (Deyà Tortella and Tirado, 2011). First, tourist hub infrastructure is overused during high season and underused in the off season because the hubs are designed for the population peaks. This has collateral effects related to urbanization, such as biodiversity impacts (e.g., barrier effects, impacts on fragile areas). Secondly, peak water demands may match the minimum rainfall values in some areas, such the Mediterranean, causing hydric stress in the summer (Agell et al., 2011; OSE, 2011; Weaver and Opperman, 2000).

Energy consumption is also related to the high demand that must be supplied through an oversized infrastructure. Energy has been identified as one of the most significant impact factors of tourism, due not only to the energy consumption during the stay but also to transportation to the destination, particularly on islands. In 2004, 39% of anthropogenic greenhouse gas (GHG) emissions were due to energy consumption (IPCC, 2007), of which transportation contributed 23% (Kahn Ribeiro et al., 2007). Additionally, households and commercial buildings represented 8% of overall emissions (IPCC, 2007). Quantification of tourist hub energy metabolism is necessary to show the contribution of each flow and identify potential energy reduction strategies. The energy metabolism refers to the characterization of the energy flows of a system from an industrial ecology perspective (Ayres and Ayres, 2002).

Although initial research on the environmental impacts of tourism focused mainly on the negative impacts on the local flora and fauna (e.g., Weaver and Lawton, 2007), understanding energy metabolism and other resources flows has received attention over the last decades. For example, Deyà Tortella and Tirado (2011) quantified the hotel water consumption of Mallorca Island and Hadjikakou et al. (2013) estimated to total water use (both direct and indirect) of tourism in the Mediterranean. Specifically, energy and transportation were key issues in several studies due to their importance regarding sustainability. Examples include the accounting of the total CO_2 emissions associated with tourism transport to Antarctica (Farreny et al., 2011) and the analysis of road transport in the island of Lanzarote (Spain) (Martín-Cejas and Ramírez, 2010). Furthermore, Beccali et al. (2009) paid attention to the energy consumption of hotels and the energy saving measures considered in this sector. Moreover, industrial ecology tools have been used to assess the environmental performance of tourism, and new methods have been applied, such as life cycle assessment (e.g., Chambers, 2004; De Camillis et al., 2008; König et al., 2007; Kuo and Chen, 2009; Kuo et al., 2012; Sisman, 1994) or the ecological footprint indicator (e.g., Gössling et al., 2002; Hunter and Shaw, 2007; Martín-Cejas and Ramírez, 2010).

Tourism studies have also been carried out at different scales. Geographical boundaries are generally used, such as for country analysis (e.g., Perch-Nielsen et al., 2010). Moreover, islands have been the object of some studies due to the importance of air travel in the energy balance (Gössling et al., 2002; Kuo et al., 2012; UNWTO, 2008). On the other hand, other tourism studies have assessed services, such as a package holiday (Chambers, 2004) or different accommodation services (Petti and Tontodonati, 2002). However, the role of tourist hubs as functional entities that concentrate multiple services and facilities with specific energy and environmental flows has not yet been characterized.

The Mediterranean is a tourist zone with a high presence of mass tourism concentrated in tourist hubs, representing 18.5% of the tourist market, of which Spain is the fourth most popular tourist destination worldwide, with 56.7 million tourists during 2011 (UNWTO, 2012). Spanish tourism is concentrated (26%) in the Balearic Islands (OSE, 2011), with Menorca Island accounting for 4.1% (OSE, 2011) of all Spanish tourism. Tourism in Menorca started later than in the other Balearic Islands (late 1970s) because Menorca was considered a political–military geostrategic point and, from the economic point of view, tourism had to compete with an advanced agriculture and a strong industrial base (Fullana, 2005). As a result, the touristic model of Menorca is unique, with a high-quality environment and the specified goal to preserve this environment. In 1993 the island was declared a UNESCO Biosphere Reserve, even though most of the tourist areas that were analyzed had already been built. Menorca has been energy dependent on Mallorca since 1975 because there is only one thermal plant for power generation (OBSAM, 2011).

The Mediterranean may be one of the most responsive regions to global climate change (Giorgi, 2006; Giorgi and Lionello, 2008). Consequently, the tourism industry may be affected (Valls and Sardà, 2009), making it a less sustainable activity not only environmentally but also economically (Perry, 2006). Hein et al. (2009) estimated that current Spanish touristic volume could be reduced between 5% and 14% based on the current estimated temperature increase projections. This may incentivize tourism management to become more active regarding strategies to reduce the current contribution of tourism activities to climate change, specifically regarding those highest contributing flows such as energy and transportation.

In this context, there is a need to characterize the energy metabolism of tourist hubs where mass tourism is concentrated, to assess their environmental performance, to analyze the potential for energy self-sufficiency and to identify sustainable strategies for improving tourism management. Moreover, this research focuses on the evaluation of the entire aggregation of infrastructures and services (i.e., tourist hub system) instead of isolated systems (i.e., buildings), according to the trends observed in the Mediterranean. Menorca was selected as a case study due to the specifications of the touristic model and the representation of the Mediterranean islands through the heterogeneity of its tourist hubs.

The main objective of this paper is to analyze the energetic metabolism and the associated emissions of the tourist hubs of Menorca (Balearic Islands). To achieve this goal, the specific aims are as follows: (a) characterize the tourist hubs, (b) characterize the tourist profile, (c) quantify the energetic flows associated with mobility, not only external but also internal, (d) determine the energy consumption during the stay, (e) evaluate the photovoltaic production potential for each hub, (f) identify the influence of the type of hub (hotel, mixed, or residential) on the energetic profile, and (g) define the most relevant strategies for a sustainable energy model for the tourist hubs and for the entire island.

2. Methods

2.1. Study system: the tourist hubs

Menorca Island is one of the Balearic Islands located in the Mediterranean Sea (Fig. 1). It has 44 tourist hubs (PTI, 2006), of which 10 were selected as a representative sample of the different

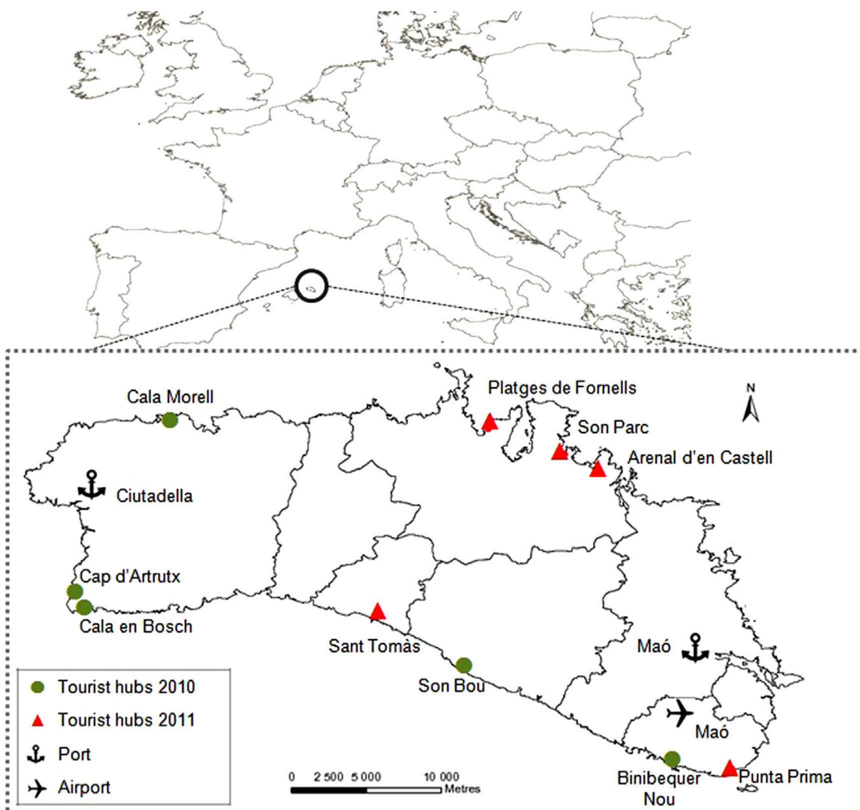

Fig. 1. Menorca is located in the West Mediterranean sea. The 10 tourist hubs analyzed are distributed among the different municipalities of Menorca, identified by year of data collection.

Table 1
Tourist hubs characteristics: municipality, population (permanent and peak), permanent occupancy, total surface and surveyed users, by tourist hub.

Tourist hub	Municipality	Population			Total surface [m^2]	Surveyed users
		Permanent	Peak	Permanent occupancy (%)		
Cala en Bosch	Ciutadella	204	5201	3.9	364256	117
Son Bou	Alaior	175	1704	10.2	172800	57
Punta Prima	Sant Lluís	485	2730	17.7	797400	64
Arenal d'en Castell	Es Mercadal	426	4297	9.9	375100	116
Sant Tomàs	Es Migjorn Gran	158	3910	4.0	454200	73
Platges de Fornells	Es Mercadal	262	4599	5.7	484000	84
Cap d'Artrutx	Ciutadella	401	3465	11.6	528244	98
Son Parc	Es Mercadal	369	3604	10.2	2328700	71
Cala Morell	Ciutadella	244	1634	14.9	677630	32
Binibèquer Nou	Sant Lluís	530	2582	20.5	797886	79

types of tourist hubs in the island as well as the coastal Mediterranean. The analyzed hubs are Punta Prima, Arenal d'en Castell, Sant Tomàs, Platges de Fornells, Son Parc, Cala en Bosch, Son Bou, Cap d'Artrutx, Cala Morell and Binibèquer Nou (Fig. 1). The case study set accounts for 43.6% of the total accommodation vacancies of the Island (PTI, 2006).

The tourist hubs selected are representative of different types of hubs in the Mediterranean coast. Demographic and territorial facts highlight the contrasts within the sample (Table 1). Tourist hubs are representative of the territory (situated in different municipalities), have different population patterns (from 158 to 530 permanent inhabitants), and are divergent in occupied surface (from almost 2 ha to more than 23 ha of tourist hub area). Finally, mass tourism representativeness is shown by the low values of permanent occupancy (from 3.9 to 20.5%), values that note an underuse of hub infrastructure. Moreover, this underutilization is more extreme for hotel hubs (3.9–17.7%) than in the residential hubs (14.9–20.5%).

2.2. Energy and environmental metabolism

The study system includes the entire energy metabolism observed in the coastal tourist hubs of Menorca and is based on a lifecycle approach; therefore, the beginning to the end of the trip is considered. Energy flows can be divided into three main stages (Fig. 2): the external mobility of the user associated with the round-trip to the destination, the internal mobility within the island and the power consumption of the tourist facilities used during the stay. Only electricity is considered for power consumption in lodging services because it accounts for the largest fraction of energy consumed in lodging and households in Menorca (OBSAM, 2009), as well as the managers indicated electricity as the unique source of energy in the questionnaires. Finally, we quantified the self-sufficiency potential of the tourist hub via the use of solar photovoltaics. This is considered a complete analysis of the energy consumption and its environmental impact since the system has been expanded to also include transportation as well as an evaluation of touristic infrastructure underuse (i.e., infrastructures designed to satisfy the peak population in summer).

2.3. Tools

The research combined three different tools to evaluate the entire energy and environmental metabolism of tourist hubs. Social and geographic tools were integrated for data gathering with the aim of characterizing energetic metabolism, while environmental accounting methods were used to assess the environmental metabolism. Finally, GIS and environmental accounting were combined to assess the self-sufficiency potential (Fig. 2).

2.4. Social tools: surveys

Although the socio-environmental institute OBSAM monitors some tourism aspects such as the tourism distribution by nationality or the total amount of accommodation vacancies that could be used in the assessment, data per tourist hub areas is not available. A survey was therefore conducted on the island of Menorca (July–August 2010 and 2011) to determine tourist profiles and mobility habits during their stay on the island. The model is based on the survey proposed by Agell et al. (2011) and consists of 18 questions divided into four sections: tourist profile (origin, means of transport, and length of stay), type of accommodation, internal mobility (movement patterns) and social information (education and income) (Appendix 1).

The sample for the survey (n) was quantified according to Eq. (1) (Groves et al., 2009), considering the confidence coefficient (for 95%, $Z=1.96$), the positive variance (p) and negative variance (q) (both $p=q=0.5$ to estimate the maximum error), the total population ($N=220{,}819$) and the error (E, acceptable up to 5%).

$$n=\frac{Z^2pqN}{NE^2+Z^2pq} \tag{1}$$

A total of 754 tourists were surveyed, distributed among the 10 tourist hubs according to the accommodations established in the Insular Territorial Plan (ITP (PTI, 2003). The distribution of places among the available types of accommodation and touristic hubs were considered for the stratification of the sample. The objective was to take data from 5% of the total number of accommodation places (see Table 1).

Given the lack of information on consumption patterns at island lodging services, a manager questionnaire was also distributed (Appendix 2) to determine the daily average consumption per tourist through questions about electricity consumption habits. The questionnaire was conducted in 45 establishments distributed throughout 8 of the 10 hubs studied (2010 and 2011). For Sant Tomàs and Platges de Fornells, average lodging service power consumption was estimated according to the power consumption of their municipalities during peak tourism months (July–August) (OBSAM, 2012) and peak population values in the different tourist hubs.

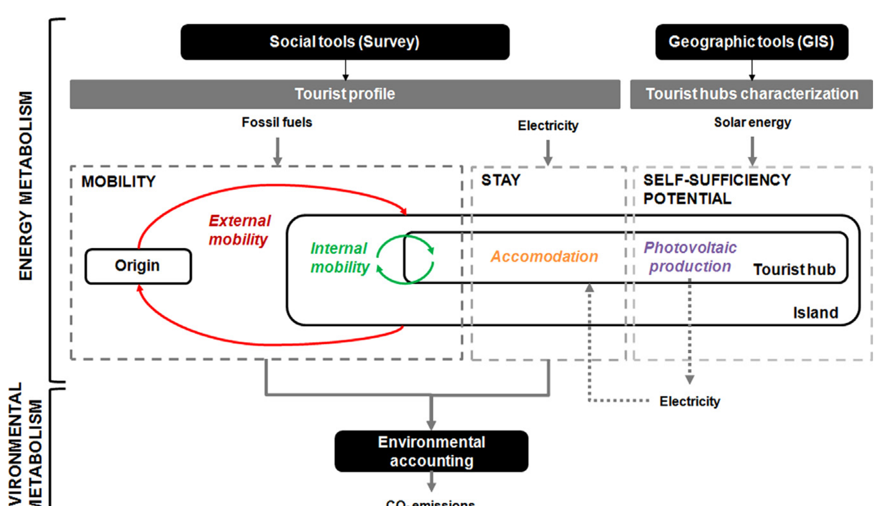

Fig. 2. Energy and environmental metabolism of tourist hubs: tools and flows related to mobility and consumption during the stay and sustainable strategies for self-sufficiency of tourist hubs.

2.5. Geographic tools: geographic information systems (GIS)

Geographic Information Systems (GIS) were used to digitalize tourist hub information gathered during field work (July–August 2010 and 2011). This tool was used for tourist hub characterization and self-sufficiency assessment. First, land use was identified, differentiating between tourist accommodations, residential, services, commercial, facilities, roads, without use and others. This step was the basis for defining the three tourist hubs categories: hotel, mixed and residential, as well as for identifying major tourist hub characteristics to be analyzed, such as services supply. Second, data for the energy self-sufficiency assessment were gathered because rooftop type is crucial for quantifying the potential production of photovoltaic systems. The roofs of the buildings were classified into three groups: inclined, flat or smaller than 80 m^2 (the minimum area for a profitable photovoltaic system (IDAE, 2006)) (Fig. 3). Finally, other particular elements were also noted, for example swimming pools, non-built private plots or under-construction areas. ArcView (ESRI, Redlands, California) software was used, and the cartographic base was the orthophotomap of Menorca Island of 2007 (accessible on IDE-Menorca http://cartografia.cime.es/portal.aspx).

2.6. GIS and potential production assumptions for the energy self-sufficiency potential

The energy self-sufficiency potential is based on the potential solar photovoltaic self-sufficiency. This renewable energy system was the only one considered in the analysis as: (a) renewable energy is expected to be produced in the same building, (b) rooftops are the focus of the analysis, (c) data is collected through field work and GIS calculations, (d) solar systems are the most suitable for urban areas (La Gennusa et al., 2011), (e) the availability of geothermal points is still not determined for Menorca, and (f) renewable systems are expected to substitute electricity and to be integrated in the grid system.

Fig. 3. Digitization of the touristic hub of Cap d'Artrutx: identification of the type of roof for evaluating the photovoltaic potential.

Although GIS models for predicting the potential implementation of solar energy systems in urban areas are available in the literature (i.e., La Gennusa et al., 2011), a simple model based on (1) field work data collection, (2) GIS rooftop analysis and (3) potential energy production quantification was designed for the case study.

In this model, the roof classification for each tourist hub determined during the field work and the creation of a GIS database were the basis for accounting the potential for electric self-sufficiency for each system. The assumptions used to calculate the implementation area for photovoltaic systems were as follows: First, (a) only 25% of the roofs were considered suitable for installation of a photovoltaic system considering that the roofs of the analyzed systems are homogeneously distributed in all orientations, (b) the minimum size needed to accommodate a photovoltaic system is 80 m^2 (IDAE, 2002a), and (c) the roofs suitable for PV installation are those flat roofs with a slope between -45° and 45°. Second, a yield of 0.73 was considered for PV production systems (Marion et al., 2005).

The average amount of solar energy that can be stored daily for a system (tourist accommodation or hub) is calculated as the energy potential (E_p) (2) based on IDAE (2002b). E_p is calculated based on the average daily irradiation value [$G_{dm}(\alpha,\beta)$] for a determined period of time (monthly or yearly) on a plane with an azimuth α and an inclination β in the area of the considered system (kWh $m^{-2} \cdot day^{-1}$). The installed potential [P_{imp}] of the system (kW) considers the energetic yield of the installation or performance ratio [PR] and the irradiance under standard measurement conditions, which is 1 kW/m^2 [G_{CEM}]. Daily irradiance ($G_{dm}(\alpha,\beta)$) was determined from the photovoltaic GIS system *CM SAF-PVGIS*, available online (IDAE, 2002b), corresponding to the city of Maó (Menorca). The optimum angle considered for calculations was 34°.

$$E_p = \frac{G_{dm}(\alpha,\beta)\, P_{imp}\, PR}{G_{CEM}} \quad (2)$$

The energy self-sufficiency potential is assessed per year according to the potential electricity production of the identified rooftop potential in GIS and the energy consumption of each tourist hub (obtained from the questionnaires to managers and data from OBSAM). The self-sufficiency potential is expressed in percentage (%) and values higher than 100% express surplus of electricity. This surplus of electricity is considered to be sold and injected to the grid, while avoiding storage requirements for later uses. The monthly energy self-sufficiency was also considered in the assessment in order to show the seasonality restrictions for surplus production (i.e., due to increase of population and therefore energy consumption in certain months) as well as to show the quantity of self-sufficient months per type of hub, which are evaluated in the discussion.

2.7. Environmental accounting and indicators: energy flows and CO_2 emissions

The accounting of energy flows and the resulting CO_2 emissions were based on two data sources: the survey, which identified the tourist profile (i.e., origin and transport), and the questionnaire to the managers of lodging services (i.e., the quantification of energy consumption). The calculation method, energy consumption and emission factors considered in the analysis vary according to mode of transport (Table 2). The selection of the methods was performed according to the specifications of the Catalan government for accounting CO_2 emissions (Oficina de Canvi Climàtic, 2011). Allocation per person was done according to factors per passenger (e.g., ship), calculators per passenger (i.e., plane), average consumption per tourist (i.e., lodging) and considering the occupancy of the vehicle (i.e., car). The total values per trip were obtained considering the length of the stay per each tourist (according to Eq. (3)).

The energy metabolism of the tourist hubs is assessed through four indicators: energy consumption per stay (EC) (3), daily energy consumption (EC_d) (4), energy consumption per built area (EC_{ba}) (5) and energy consumption per overall area (EC_{oa}) (6). Indicators aim to show how the different variables might affect the results: tourist profile, length of stay and tourist hub density. These indicators enabled comparison within tourist hubs and types as well as consideration of the three energy flows: external mobility (M_{ext}), internal mobility (M_{int}) and consumption during the stay (S_{ec}).

$$EC\left(\frac{MJ}{Tourist \cdot trip}\right) = M_{ext}\left(\frac{MJ}{Tourist}\right) + \left(\left[M_{int}\left(\frac{MJ}{Tourist \cdot day}\right) + S_{ec}\left(\frac{MJ}{Tourist \cdot day}\right)\right] \cdot \text{Stay length (days)}\right) \quad (3)$$

$$EC_d\left(\frac{MJ}{tourist\ day}\right) = \frac{EC\ (MJ/tourist\ trip)}{Stay\ length\ (days)} \quad (4)$$

$$EC_{ba}\left(\frac{MJ}{tourist\ trip\ (ha)}\right) = \frac{EC\ (MJ/tourist\ trip)}{Built\ area\ (ha)} \quad (5)$$

$$EC_{oa}\left(\frac{MJ}{tourist\ trip\ (ha)}\right) = \frac{EC\ (MJ/tourist\ trip)}{Tourist\ hub\ area\ (ha)} \quad (6)$$

Table 2
Method, variables and specific factors used for the energy modeling and the CO_2 accounting steps, by energy flow: external mobility, internal mobility and consumption during stay.

	Energy modeling			CO_2 accounting	
	Method	Variable	Specific energy consumption	Method	Specific CO_2 emissions
External mobility					
Plane	ICAO Carbon Emissions Calculator version 3 ICAO (2012)	Distance[a] fuel load capacity and load factor	Specific factor for each origin–destination trip	ICAO Carbon Emissions Calculator version 3 ICAO (2012)	Specific factor for each origin–destination trip
Ship	Transport Research Laboratory, Hickman et al. (1999)	Distance[a] boat type load capacity and load factor[b]	1.872 MJ/km · passenger	IDAE (2010a)	0.138 kg de CO_2/km · passenger
Internal mobility					
Car	IDAE (2010a)	Distance[a,c] type of vehicle[a] occupancy[a]	2.34 MJ/km	IDAE (2010a)	0.166 kg CO_2/km
Bus	IDAE (2010b)	Distance[a,c] load factor	0.396 MJ/km · passenger	Online ALSA Calculator (http://www.alsa.es/)	0.029 kg CO_2/km · passenger
Consumption during stay					
Electricity	Questionnaire	Consumption[d] type of lodging service[a] length of the stay[a]	Depends on the tourist hub[f] (MJ/day · tourist) H: 18.0–68.4 M: 18.0–35.7 R: 28.8–93.6	Dones et al.(2007) Ecoinvent 2.0 Database[e]	0.294 kg CO_2/MJ

[a] Data obtained from the survey to tourism users.
[b] Load capacity was adapted according to Balearia (http://www.balearia.com).
[c] Distances accounted through on-line routes generators (i.e. Google maps – https://maps.google.com, Repsol guide – http://www.guiarepsol.com).
[d] Average consumption was obtained from the questionnaire to lodging managers.
[e] The electric mix of the island of Menorca in 2010 (OBSAM, 2011) was used for the calculations.
[f] Consumption ranges are presented according to the results by type of hub (H, hotel; M, mixed; R, residential).

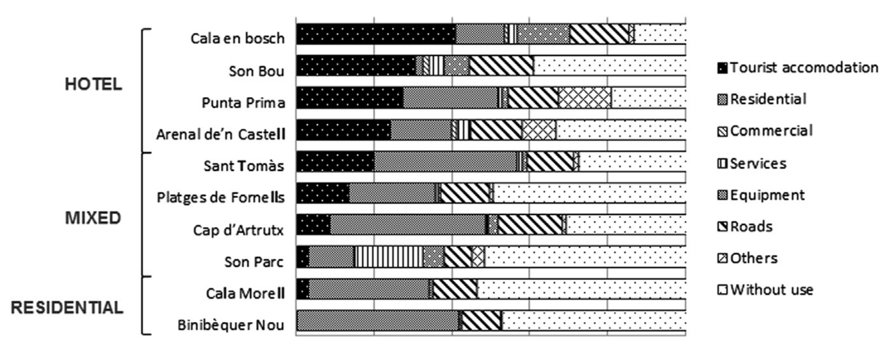

Fig. 4. Land use distribution of the 10 selected tourist hubs. Tourist accommodation land use (in %) was used as threshold for classifying the tourist hubs into hotel, mixed or residential.

3. Results and discussion

3.1. Tourist hub characterization

As a first step the tourist hubs were characterized according to data gathered during the field work. This initial characterization highlighted the need of classifying the different hubs into three groups according to the differences in land use distribution (Fig. 4). Categorization was based on the concentration of regulated tourist accommodations (i.e., hotels, apartments): Hotel hubs, with more than 30% of the surface used for regulated tourist accommodations; residential hubs, with $<10\%$ of the surface used for regulated tourist accommodations; and mixed hubs, with between 10% and 30% of the surface used for regulated tourist accommodations. Land use distribution analysis also quantifies the heterogeneity of the selected tourist hubs (Fig. 4). From the most compact and touristic area (Cala en Bosch, $>40\%$ of regulated accommodations) to the most diffuse and residential area (Binibèquer Nou, 0%), some common and divergent characteristics can be observed. The hubs have reduced commercial and service soil area ($<3\%$), apart from Son Parc, which has a golf pitch ($\approx 20\%$), and Cala Morell and Binibéquer Nou, which have few of these facilities ($<0.2\%$). These land use characteristics resulted in determining factors for the energy metabolism of each tourist hub.

3.2. Tourist profile

The tourist surveys resulted in a user characterization for each hub (Table 3). On average, tourists come mainly from Spain (39%) and the United Kingdom (37%), a distribution that agrees with the most recent Menorca tourism statistics (OBSAM, 2010). However, Spanish tourists tend to concentrate in residential hubs (representing 55.5%), while UK tourists concentrate in hotel hubs (43%). Other nationalities have a lesser presence, with the most important being Italy (9%) and Germany (5%). The distribution of these minority nationalities ($<10\%$) is irregular, especially in hotel and mixed hubs. However, concentration phenomena occur in some cases, such as at Son Bou (9% from Portugal), Cala en Bosch (7% from The Netherlands) and Binibèquer Nou (5% from Switzerland). Furthermore, tourists that visit Menorca for the first time frequent hotel hubs (46%) more than in residential ones (17%).

Regarding the use of lodging services, holiday packages are not usually booked (61% on average), specifically in residential hubs (97%) where second homes are common. All-inclusive holiday packages are the most booked packages in hotel hubs (27%) and mixed hubs (18%), followed by half board (8.7% on average) and only accommodation packages (7.6%). This fact is related to the presence of accommodation services and tourism facilities (e.g., golf) that promote the booking of holiday packages. Finally, the average length of stay is also linked to the type of tourist hub; residential tourist stays last an average of almost 27 days, while hotel hubs have an average stay of only 16 days.

Mobility patterns were also shown to be related to the type of hub. Most tourists of hotel hubs (93%) use a plane to reach the island, while ship use is higher for tourists of residential hubs (27%). The external mobility mode of transport is mainly chosen based on the distance from the origin and is longer for hotel hubs (1941 km). Moreover, ship use is higher in tourist hubs where Spanish, French or Italian tourists are most common (i.e., residential hubs). However,

Table 3
Tourist profile for the different tourist hubs analyzed, according to origin, booking of lodging services, average length of the stay and external and internal mobility.

Tourist hub	Cala'n Bosch	Son Bou	Punta Prima	Arenal d'en Castell	Sant Tomàs	Platges de Fornells	Cap d'Artrutx	Son Parc	Cala Morell	Binibèquer Nou	Average
Type[a]	H	H	H	H	M	M	M	M	R	R	
Tourist profile											
Origin (%)											
Spain	20	51	18	33	19	63	53	26	79	32	**39.4**
United Kingdom	53	14	47	59	50	20	31	41	3	49	**36.7**
Germany	4	7	8	–	1	5	5	12	3	–	**4.5**
Italy	8	3	9	–	27	8	6	14	15	–	**9**
Other	15	25	20	8	2	5	5	7	0	19	**10.6**
First time in Menorca (%)	50	54	45	35	43	28	33	40	9	25	**36.2**
Lodging services (%)											
No booking	33	12	42	65	32	88	79	66	94	100	**61.1**
Only accomodation	22	0	11	7	22	1	3	10	0	0	**7.6**
Breakfast included	3	0	0	0	3	0	0	0	0	0	**0.6**
Half board	16	28	18	7	12	4	2	0	0	0	**8.7**
Full board	0	4	3	21	8	0	4	3	6	0	**4.9**
All inclusive	26	56	26	0	26	7	16	22	0	0	**17.9**
Average length of stay (days)	15	17	17	15	21	19	23	17	25	28	**19.7**
External mobility											
Trip to Menorca (%)											
- By plane	94	100	91	87	96	66	73	84	54	94	**83.9**
- By ship	6	0	9	13	4	34	27	16	46	6	**16.1**
Average distance (km)	1594 ± 689	1327 ± 756	2473 ± 961	2371 ± 1169	2405 ± 900	1624 ± 1564	1093 ± 717	1594 ± 689	2305 ± 976	1463 ± 688	**1824.9**
Internal mobility											
Tourists who travel (%)	38	32	33	25	28	77	41.4	42	58	38	**37.1**
Mean of transportation (%)											
-Own car	10	5	17	18	11	40	42	21	76	32	**27.2**
-Rental car	24	23	20	24	38	42	30	34	18	56	**30.9**
-Bus	34	39	50	34	31	15	25	22	9	18	**27.7**
-Taxi	7	11	–	–	–	–	13	–	6	14	**5.1**
-Bycicle	6	0	–	–	–	–	5	–	15	4	**3**
Average distance (km)	20	16	15	14	14	39	24	22	34	18	21.6

[a] Tourist hubs are classified by typologies: Hotel [H], Mixed [M] and Residential [R].

trends are the opposite in internal mobility. Tourists in residential hubs travel more (48%), and the associated distances are larger (26 km daily), than for the other hubs. Moreover, private transportation is more common for this type of hub than in hotel hubs (where bus accounts for almost 40% of the internal mobility). On average, internal mobility was more intense (21.6 km) than tourism-related mobility at the country level, such as in Norway (17 km) (Høyer, 2000). However, the presence of cars (58%) is lower than in other islands, such as Lanzarote where 77% of the mobility is performed by car (Martín-Cejas and Ramírez, 2010).

3.3. Energy and environmental metabolism

The energy consumption per tourist and trip varies depending on the tourist hub analyzed, and ranges from 3418 MJ (Platges de Fornells) to almost 6800 MJ (Son Bou). On average, this value is larger in residential hubs (~5900 MJ) than in other types of tourist hubs (<5000 MJ) (Table 4). However, patterns are different regarding the flow where energy is consumed. The contribution of external mobility to the energy consumption is higher in hotel hubs, which concentrate more international tourists that have traveled greater distances. Moreover, in residential hubs the use of ships is more common, decreasing the energy input per passenger, as it is a transport option for countries significantly closer to the island, such as Spain (~40%) and Italy (~5%). By contrast, tourists in residential hubs consume more energy for daily internal mobility because they travel by car. In addition, the daily distances are larger because residential hubs have lower availability of services (<0.2% of land use) and equipment (<2.5%). This contrasts with hotel hubs (up to 9% of services and up to 15% of equipment). Moreover, mixed and residential hubs are more territorially dispersed. Therefore, tourists in hotel hubs tend to stay in the same town or nearby while covering smaller distances (16 km) than tourists in mixed (25 km) and residential (26 km) hubs. In agreement with this, the consumption during the stay is larger in residential hubs due to the availability of facilities to tourists in houses, as opposed to staying in a hotel. The contribution of external mobility to the total energy consumption (67% on average) was higher than in other island scale analyses: <63% in different islands of Taiwan (Kuo et al., 2012).

On the other hand, daily energy consumption per tourist showed a different trend than the total energy consumption per trip. A tourist in a hotel hub consumes more energy (~300 MJ·day^{-1}) than in other types of tourist hubs (<225 MJ·day^{-1}). This fact is due to a shorter stay of tourists in hotel hubs. Although hotel hub tourists have a lower daily consumption (internal mobility and during the stay) the overall consumption per day is larger when accounting for external mobility. Notwithstanding the lower consumption in external mobility, the daily consumption patterns accounted for the largest energy consumption per trip due to a longer stay in residential hubs. Finally, energy consumption indicators per area (both built and overall area) were higher for hotel hubs, which are denser than mixed and residential hubs (characterized by a dispersed construction). Moreover, hotel hubs have a higher land use intensity (13% on average) than mixed (9%) and residential (7%), according to the built and total area ratios. The consumption per

Table 4
Energy requirements, CO_2 emissions and self-sufficiency potential, by tourist hub.

Tourist hub	Cala'n Bosch	Son Bou	Punta Prima	Arenal d'en Castell	Sant Tomàs	Platges de Fornells	Cap d'Artrutx	Son Parc	Cala Morell	Binibèquer Nou	Average
Type	H	H	H	H	M	M	M	M	R	R	-
Average length of stay (days)	15	17	17	15	21	19	23	17	25	28	**20**
Energy consumption											
-MOBILITY											
M_{ext} (MJ/tourist)	3708.0	5389.2	3153.6	3132.0	3175.2	2192.4	2865.6	2937.6	1630.8	3855.6	**3204.0**
M_{int} (MJ/tourist)	702.0	613.7	183.6	108.0	226.8	547.2	1324.8	244.8	1980.0	1209.6	**714.1**
-STAY											
Lodging (MJ/tourist)	1026.0	795.6	673.2	270.0	487.2	678.3	993.6	306.0	2340.0	806.4	**837.6**
-TOTAL											
EC *(MJ/tourist·trip)*	5436.0	6798.5	4010.4	3510.0	3889.2	3417.9	5184.0	3488.4	5950.8	5871.6	**4755.7**
$\mathbf{EC_d}$ *(MJ/tourist·day)*	362.4	399.9	235.9	234.0	185.2	179.9	225.4	205.2	238.0	209.7	**247.6**
$\mathbf{EC_{ba}}$ *(MJ/tourist·trip·ha)*	856.6	3242.8	464.4	730.2	755.7	699.7	690.0	389.7	1573.2	686.7	**1008.9**
$\mathbf{EC_{oa}}$ *(MJ/tourist·trip·ha)*	143.7	403.4	54.7	93.2	85.8	66.9	81.9	15.3	85.1	61.0	**109.1**
CO_2 emissions											
-MOBILITY											
M_{ext} (kg CO_2/tourist)	271.5	221.0	251.6	249.0	254.1	172.9	138.0	234.6	122.5	240.8	**215.6**
M_{int} (kg CO_2/tourist)	21.0	35.7	17.0	16.5	21.0	39.9	62.1	20.4	177.5	39.2	**45.0**
-STAY											
Lodging (kg CO_2/tourist)	21.0	15.3	13.6	6.0	10.5	13.3	20.7	6.8	47.5	16.8	**17.2**
-TOTAL											
Trip emissions (kg CO_2/tourist·trip)	313.1	272.7	282.1	270.9	285.0	226.3	220.0	261.1	346.9	296.2	**277.4**
Daily emissions (kg CO_2/tourist·day)	20.9	16.0	16.6	18.1	13.6	11.9	9.6	15.4	13.9	10.6	**14.6**
Self-sufficiency potential											
Potential PV area (ha)	6.1	2.2	7.2	4.3	4.7	3.7	6.4	7.8	3.3	8.2	**5.4**
Suitable area (%)	16.8	12.7	9.0	11.5	10.4	7.6	12.1	3.3	4.9	10.3	**9.9**
PV production (MJ/year)	505.4	178.9	596.5	351.4	390.6	309.6	532.4	641.5	275.8	679.7	**446.2**
Hub consumption (MJ/year)	318.2	146.2	225.4	119.9	157.7	133.9	122.0	99.4	103.7	59.4	**148.6**
Self-sufficiency potential (%)	159.0	122.0	265.0	293.0	248.0	231.0	436.0	645.0	266.0	1144.0	**380.9**
Monthly avoided CO_2 emissions (t CO_2/month)	7.8	2.8	9.2	5.4	6.0	4.8	8.2	1.0	4.3	10.5	**6.0**

[a] Tourist hubs are classified by typologies: Hotel [H], Mixed [M] and Residential [R].

day lies within the patterns observed in other islands, the tourism energy use per day in some Taiwan islands is between 118 and 502 MJ (Kuo et al., 2012) and is similar to other tourist areas, such as the West Coast of New Zealand (341 MJ per tourist and day) (Becken et al., 2003).

The environmental assessment showed that the carbon footprint of a tourist on the island of Menorca is 14.6 kg CO_2 per day on average (Table 4). Much of the emissions are associated with the external mobility (trip to the island) (77.7%) due to air travel. This value is higher than the estimated contribution in the global market (59%) (Peeters and Dubois, 2010), although it is closer to the contribution of air transport to global tourism GHG emissions for Switzerland (80%) (Perch-Nielsen et al., 2010). The carbon footprint is thus reduced for tourists whose origins are closer to the island (such as tourists from Spain), while it is increased for those farther away (such as tourists from the United Kingdom). The mean of transport also influences the associated emissions of CO_2. For example, the impact of traveling to Cala Morell from Barcelona differs by 15% depending on whether the trip to the island is made by plane (56 kg CO_2) or boat (48 kg CO_2). Regarding the type of tourist hub, a tourist in Menorca has the lowest carbon footprint by staying in a mixed hub (248.1 kg CO_2). In contrast, tourists in residential hubs have the highest CO_2 contribution per stay (321.5 kg CO_2) because the stay is typically longer and internal mobility is higher. Hotel hubs have an associated carbon footprint of 284.7 kg CO_2 per tourist per trip, although they show the highest contributions per day ($\sim$17 kg $CO_2 \cdot day^{-1}$), followed by mixed hubs ($\sim$12 kg $CO_2 \cdot day^{-1}$) and residential hubs ($\sim$12 kg $CO_2 \cdot day^{-1}$) hubs (Table 4).

Therefore, this assessment has revealed strong relationships between the energy and environmental metabolism and (1) the type of tourist hub and (2) the user profile. The type of tourist hubs was determined based on the type of tourist services and the promotion of holiday packages, the availability of services and equipment in the area and the morphology of the settlements. The user profile was primarily determined based on the origin of the tourist, the use of public or private transportation, and the length of the stay.

3.4. Self-sufficiency assessment for power generation in tourist hubs

The available surface potential for the installation of photovoltaic systems, obtained from GIS, adds up to 54 ha for all analyzed tourist hubs, but is unevenly distributed across hub types (from 2.2 ha to 8.2 ha) (Table 4). The residential hubs have higher potential (61% of total) than hotel hubs (20%), which are dominated by vertical (high-rise) buildings. Considering the balance between energy production and consumption during tourist stays, residential areas would net a positive balance throughout the year due to the availability of a large solar collector area and the resulting production potential. Hotel hubs would have a positive balance for only four or five months per year, as they have high power consumption combined with a small roof surface area upon which to install photovoltaic panels due to a compact morphology. Finally, the mixed hubs would have a positive balance for nine to ten months per year; their consumption is not as high as in hotel hubs, and they have smaller potential areas for the installation of photovoltaic systems than residential hubs. For all tourist hub types, self-sufficiency values are positive considering the potential annual photovoltaic production, representing an energy surplus of 387,000 GJ per year. The strategy of moving to photovoltaic energy production could yield power self-sufficiency potential between 122 and 1144% of the current potential in the tourist hub (Table 4).

The photovoltaic production potential may also represent a reduction in the CO_2 emissions associated with coastal tourist hubs by supplying the electricity consumption during tourist visits. The monthly savings of CO_2 emissions is estimated at an average of 7 t per tourist hub (Table 4). Additionally, the extra production of electricity could also feed the demands of the entire island beyond just the tourist hubs if it were injected into the island electrical network. The extra production of electricity would replace electricity from non-renewable sources because most of the energy comes from power plants fueled primarily by diesel (REE, 2012), thereby reducing the CO_2 emission factor of the island mix (currently 1.06 kg/kWh).

Despite the potential production values, the installation of photovoltaic generation systems often encounters resistance in residential areas. In these areas tourist hubs are fragmented with a large number of private owners who are independent from each other, which requires a high degree of collaboration among users. In contrast, solar installation is often more straightforward in hotel hubs due to consolidated decision-making; typically a single manager serves an entire building or even groups of buildings.

4. Conclusions and recommendations for managers

The characterization of tourist hubs through GIS highlighted the heterogeneity of the sample and enabled their categorization into three groups based on the percentage of the surface used for regulated tourist accommodations: hotel hubs ($>30\%$), residential hubs ($<10\%$) and mixed hubs (between 10 and 30%). Moreover, land use issues highlighted differences among these hub types that demonstrated the importance of considering these tourist aggregations as an entire system. For example, compared with residential hubs, the hotel hubs have a significantly higher percentage of land used for services, facilities and shops. Although all the tourist hubs showed a low permanent occupation and, therefore, an underuse of their infrastructures, it occurs more prominently in hotel hubs (3.9%) than in residential hubs (20.5%).

Energy metabolism depends on the tourist profile (based on origin, use of public transportation, and length of stay) and the type of tourist hub (based on type of tourist services, availability of services, and morphology). On average, a tourist consumes 4756 MJ with associated emissions of 277 kg of CO_2 per stay (20 days on average), although depending on the type of tourist hub this consumption per trip ranges from $\sim$4000 MJ (mixed hubs) to $\sim$6000 MJ (residential hubs). Self-sufficiency in power consumption for lodging services could satisfy 100% of tourist consumption, as well as offer potential benefits to the entire island. By installing solar panels, the tourist hubs could achieve energy self-sufficiency. Residential hubs could become energy self-sufficient throughout the entire year, while mixed hubs could achieve energy self-sufficiency only between 7 and 10 months per year. In addition, Menorca Island could increase the percentage of renewable energy contribution to the power mix, and could avoid the occupation of fertile areas by solar farms by taking advantage of rooftops.

This assessment showed that public authorities (policymakers) and the managers of lodging services might play an important role in the development of a sustainable tourism management approach. With regard to tourism-related energy consumption, public government and policymakers should encourage business managers and private property owners towards the installation of energy-efficient facilities (e.g., low-energy appliances and systems) as well as photovoltaic generation systems or other renewable energy sources. The promotion of renewable energy would not only impart positive effects for the tourist facilities, but potentially for Menorca as a whole, which could take advantage of the cleaner energy source during the offseason and by utilizing any energy surplus, thus reducing the environmental burden of the current electricity mix. Policymakers could promote tax incentive policies or develop investment programs for implementing solar energy; likewise, business managers might prioritize the use of renewable energies and enjoy energy savings by investing in their buildings. Most common interventions for achieving energy efficiency in hotels where identified in Beccali et al. (2009) for Italy as the following: retrofit of building envelopes, retrofit of heating plants, use of high efficiency appliances, installation of tri-generation plants, use of active solar systems for DHW and use of photovoltaic systems. Finally, the creation of a best practices code or manual could be a useful tool to improve the knowledge base of managers.

In terms of transportation, policymakers could promote the use of sea travel among tourism company operators as the most environmentally friendly method of transit for external trips (e.g., reduction of 15% per trip for a tourist from Barcelona). This could also result in positive effects for tourists from nearby Mediterranean countries (e.g., Spain, France, Italy). Once a tourist is on the island, energy consumption of internal mobility could be reduced by enhancing public transportation. Public authorities might invest in improving the current services and infrastructures; as shown in the OBSAM's indicator system (Fullana et al., 2010), public transport currently has low usage rates due to the lack of comprehensive coverage of the entire island. Furthermore, the number of tourist services (e.g., supermarkets and shops) could be increased near residential and mixed hubs to shorten the distances traveled during the tourists' stays (e.g., at Cala Morell, no services are available) and therefore reduce emissions associated with shopping trips.

Environmental information could be useful not only for tourists but also for local policy makers. The introduction of an ecolabeling system for tourist accommodations could promote a more sustainable tourism model, as environment would be included as a decision-making criteria in the selection of tourism destinations and accommodations. Therefore, those accommodations with a high score in the ecolabel would show an added value to environmentally responsible tourists and, consequently, investment on more ecological businesses may result in increased choices. Both public authorities and business managers could be included in a process to agree on the design of a tourist ecolabel incorporating environmentally related metrics for the different tourist hubs, lodging services or holiday packages across the island.

Finally, both public and private stakeholders could be responsible for promoting greater environmental awareness (Valls and Sardà, 2009) about the impacts of tourism energy use by developing environmental education campaigns about the optimization of energy consumption (e.g., in the lodging services) and the benefits of using public transportation. Awareness could also be promoted by tourist companies by integrating environmental information in tourism promotions and in marketing documentation.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2013.10.011.

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