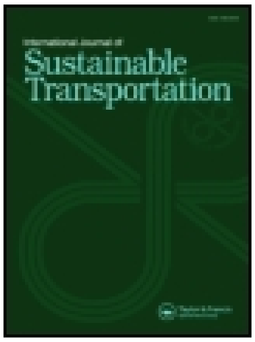

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Climate change impacts and tourism mobility: A destination-based approach for coastal areas

Federico Cavallaro, Olga Irranca Galati, and Silvio Nocera

IUAV University of Venice, Venezia, Italy

ABSTRACT

Even if the concepts of climate change, tourism and transport are strictly connected, the scientific literature has mostly considered their pairwise relations, linking tourism to climate change, transport to climate change, or tourism to transport. This paper aims at considering the three concepts as a whole, exploring the three-cornered interaction between climate change-tourism-transport, and highlighting both the effects of climate change on tourism travel demand and the contribution of tourism transport to CO_2 emissions. To this aim, a heuristic method for assessing implications of climate change on future CO_2 emissions in coastal destinations is presented and then tested on the Italian town of Misano Adriatico. The results reveal a variation in summer tourism demand under different climatic and socio-economic scenarios; accordingly, by 2035 total carbon emissions produced by tourism transport could decrease from 550.57 tCO_2 (status quo) to 216.91 tCO_2 (optimistic scenario) with the adoption of more sustainable transport means made by tourists. This result contributes to the achievement of the environmental targets expressed by the local sustainable urban mobility plan, thus making tourism transport an active driver in the achievement of its goals. With adequate modifications, the method can be applied to other types of tourist cities, thus helping local stakeholders and policymakers to understand the carbon effects of tourist modal choices and develop sustainable strategies.

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KEYWORDS
CO_2 emissions; climate change resilience; tourism transport; travel demand; scenario analysis

1. Introduction

Tourism is one of the world's fastest-growing economic sectors with a business volume of 10.2% of the Gross Domestic Product worldwide, surpassing oil exports, food industry and the vehicle market (WTTC, 2017). Globally, international tourist arrivals have increased from 25 million in 1950 to 278 million in 1980, 674 million in 2000 and 1,401 million in 2018 (UNWTO (United Nations World Tourism Organization), 2019). The highest figure is registered in Europe with 710 million in 2018, which corresponds to 50% of the overall international tourist arrivals (UNWTO (United Nations World Tourism Organization), 2019); more than 47% of them are in coastal areas (Eurostat, 2018). Transport is the largest component of GHG emissions generated by tourism with about 75% of overall emissions, and is expected to further grow in the next years (Peeters et al., 2016).

The relationship between tourism and transport does not need to be discussed since there is no tourism without a physical displacement (via transport means) and both are linked to climate change since these highly affect it and are consequently affected by it (Page & Ge, 2009). On the other hand, climate change drives tourism demand and influences the choice of visitors, in terms of transport modal share and activities (Lise & Tol, 2002). In scientific research, these three issues have mostly been considered as binaries: (i) *tourism-climate change*, (ii) *transport-climate change* and (iii) *tourism-transport*. The triple relation, which considers the impact of climate change on tourism demand and the subsequent implications of its variation in greenhouse gas (GHG) emissions, has been the object of less discussion, especially when referring to coastal areas.

To address this issue, this paper proposes a method to quantify the impacts of climate change on future travel demand generated by tourism and to measure the contribution of tourism transport to climate change in terms of CO_2 emissions in a given tourist coastal destination. The variation of CO_2 emissions can be considered a valid indicator of climate change since CO_2 counts for more than 75% of overall GHG emissions (IPCC, 2014). The paper is structured as follows: Section 2 provides a literature review on the controversial interaction between tourism, transport and climate change. Section 3 describes a method to estimate the influence of climate change on tourism and transport systems and to quantify the overall emissions produced by the tourism transport component. Section 4 shows the applied method on the Italian city of Misano Adriatico and an explanation of the obtained results. Finally, Section 5 draws some conclusions and final remarks about this research, making the case study results more generalizable.

CONTACT Silvio Nocera nocera@iuav.it Università Iuav di Venezia, Venezia 30135, Italy.
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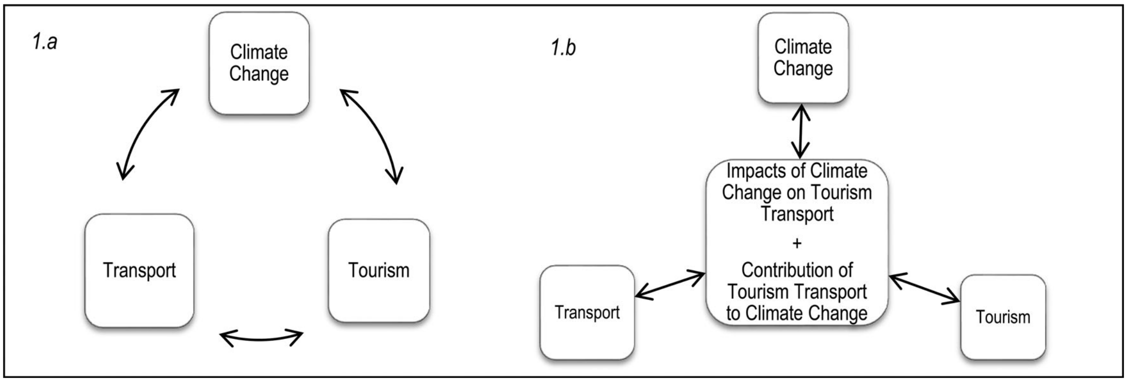


Figure 1. Relation between climate change, transport and tourism. 1.a) pairwise relation; 1.b) bi-directional relation.

2. Tourism, transport and climate change: a bi-directional approach

The link between tourism demand, mobility and climate change has been the object of continuous attention by scholars in last 10 years (see for instance Dwyer et al., 2010; Scott et al., 2012; Becken & Hay, 2012; Weir, 2017). Due to its extent, the literature dealing with such issues cannot be presented comprehensively in this section. However, some selected studies may help in revealing the pairwise approaches adopted and some of the main research lines developed so far. The relationship between climate change and tourism is the first relevant topic (Scott, 2011), which can be assessed through alternative approaches. Among them, specific indices may be adopted. The ancestor is the Tourism Climate Index (Mieczkowski, 1985), which has then been flanked by the Climate Index for Tourism (De Freitas et al., 2008), the Modified Climate Index for Tourism (Yu et al., 2009) or the Holiday Climate Index (Scott et al., 2016). Through climate indexes, Rosselló-Nadal (2014) studied the effects of climate change to measure the attractiveness of tourist destinations. Gössling et al. (2012) assessed the influence of climate change on tourism demand, providing a framework for a better comprehension of the consumer behavior and demand response of tourists to climate change. The inverse relationship (i.e., the contribution of tourism to climate change) is also a relevant aspect since tourism accounted for 8% of total GHG emissions (Lenzen et al., 2018). Dubois et al. (2011) have assessed the potential implications of tourism development, through the development of alternative backcasting scenarios. Tailored solutions to reduce its incidence have thus to be found, which are specific for the area object of evaluation (Sun, 2016).

Also referring to climate change and transport, the relationship may be bidirectional. The impacts of climate change on transport are multiple and include aspects related to infrastructures, operations and travel demand/travel behaviors, and uncertainty (Cavallaro et al., 2017b; Nocera et al., 2018a, 2018b). On the other hand, transport is also one of the main sectors that contributes to the overall anthropogenic emissions, with almost a quarter of Europe's GHG emissions (EEA, 2016). The quantification of the overall emissions produced by each mean of transport (Kelly et al., 2009; Jardine, 2009; Howitt et al., 2010) and the economic valuation of the impacts of climate change produced by the transport sector have become interesting research fields (Nocera et al., 2015), which should lead to the development of the most appropriate mitigation and adaptation strategies to reduce the overall emissions and to face the negative externalities generated by transport (Rattanochet et al., 2015).

Finally, the relationship between tourism and transport is the most obvious, since the former cannot exist without the latter. Transport is part of the tourism industry mainly because it provides accessibility (Campa et al., 2016), but also because it has an increasing role as an influencer for tourism promotion and development. The implications of this relationship are multiple, from the connection between infrastructural development and tourism development (Khadaroo & Seetanah, 2008), to the use of public transport of visitors within a destination (Le-Klähn & Hall, 2015). Their movement within a destination area can determine several negative externalities (congestion, air pollution, GHG emissions, etc.) that should induce policymakers to rethink the mobility plans according to the needs of both tourists and residents. Tourism could play a strategic role in promoting a sustainable way of moving inside the city (La Rocca, 2015) and doing longer journeys (Albalate & Fageda, 2016). On the other hand, sustainable urban mobility plans (Wefering et al., 2013) have to consider the tourist component in defining the most adequate strategies for the achievement of the strategic goals.

The dual relations that were shown so far (Figure 1a) may also be considered with a more integrated approach (Figure 1b). In this perspective, the connections between tourism, mobility and climate change have been the object of some contributions (Dickinson et al., 2010; Peeters & Dubois, 2010; Davies & Weston, 2015). Tourism transport can be considered as a victim of climate change since the latter can influence the travel demand and modify the pattern of movements; but it is also a vector, because of the high percentage of GHG emissions produced by the tourism transport. Referring to this aspect, Gössling (2002) has faced the impact of tourism transport on the environment, deriving that tourism transport is responsible for the major consumption of energy (94%), followed by accommodation (4%) and activities (2%). More recently, Lenzen et al. (2018) have quantified tourism-related global carbon flows between 160 countries, and their carbon footprints, finding that

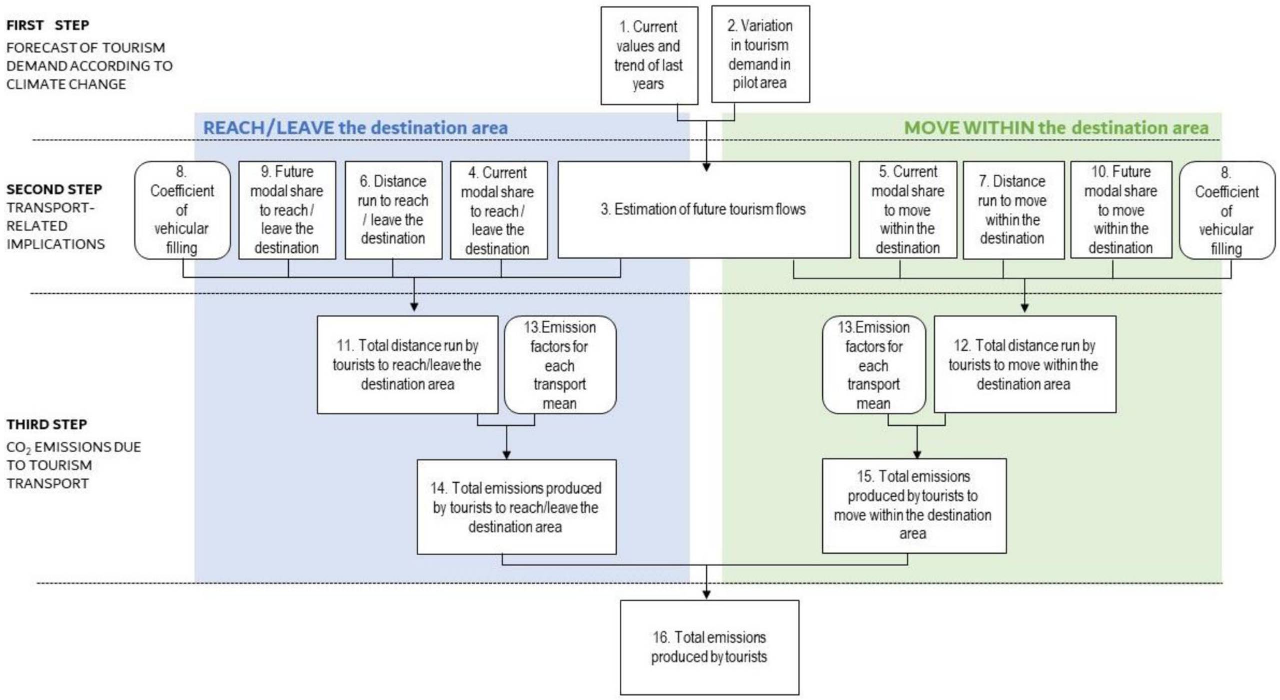


Figure 2. Scheme of the methodology adopted to test the relationship between climate change and tourist mobility.

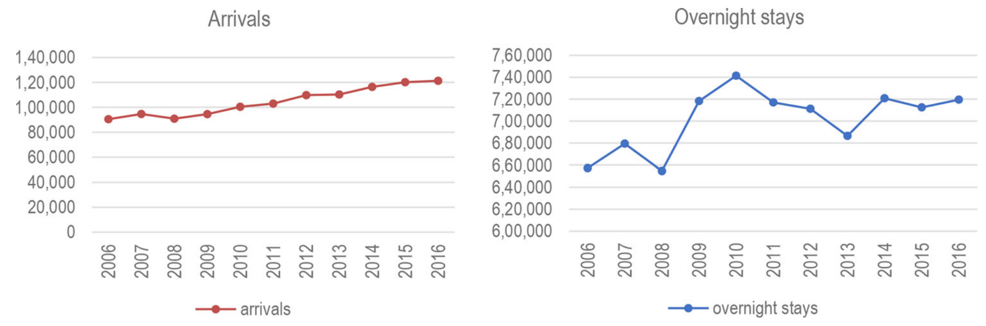
tourism's global carbon footprint has increased from 3.9 to 4.5 $GtCO_{2eq}$ between 2009 and 2013 - four times more than previously estimated. Referring to the role of climate change on tourism transport, only a few contributions are available. Cavallaro et al. (2017a), for instance, have investigated this relationship in a case study in the Alps: by analyzing expected changes in tourism travel demand provoked by climate change, they propose a method to forecast the variation in tourist mobility and implications in terms of related externalities. Besides the scientific literature, some European initiatives – such as TopDAd (2015), SEEMORE (2015) and MOBILITAS (2017a) – have demonstrated the increasing interest in finding concrete solutions to internalize the expected impacts of climate change on tourist mobility and to reduce the GHG impacts from transport. Particularly, the EU-funded project MOBILITAS ("MOBIlity for nearLy-zero CO2 in medITerranean tourism destinAtionS") investigates the issue of tourism transport in coastal areas in seven Mediterranean countries and ten regions affected by intense flows during the summer period, quantifying the variations expected by climate change on tourist arrivals, proposing a set of concrete solutions to minimize their impacts and quantifying the savings of GHG emissions. The next section systematizes the approach adopted in this project, by presenting a heuristic method to assess the tourism-related CO_2 emissions caused by tourism transport, according to future climate scenarios.

3. A method to deal with tourism, transport and climate change

As recalled in the previous section, the relationship between tourism, transport and climate change is complex and can be addressed in different ways, according to the thematic, geographical and temporal dimensions of the analysis. This section proposes a methodological framework to understand the implications deriving from climate change to the tourist mobility for policymakers operating at the local scale. To this aim, the heuristic method summarized in Figure 2 is based on three main steps: forecast of future tourism demand (section 3.1); definition of transport-related implications (section 3.2); and consequences in terms of CO_2 emissions (section 3.3). Based on data related to the destination profile, tourism sector, and transport system, the method elaborates alternative scenarios to enable policymakers and stakeholders to better understand the effects of tourist choices on the destination areas and developing new strategies.

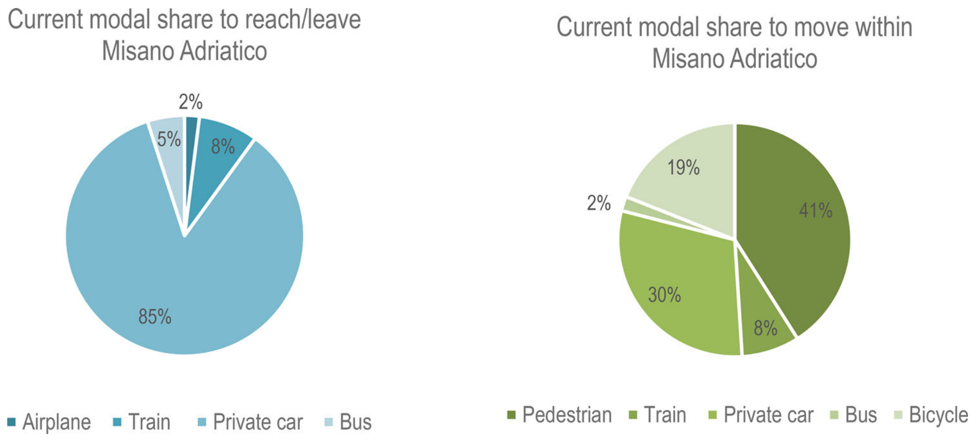
3.1. First step: a forecast of future tourism demand according to climate change

Tourism-related trips include different components (Scuttari et al., 2013): inbound Tourism, outbound Tourism, inbound same-day trips, outbound same-day trips, daily trips during holidays (visits). Referring to the first two groups, arrivals, overnight stays, and length of stays are the main indicators for quantitative analysis. They are not static through the years, but they vary according to several factors, including the climate variability registered in anomalous years and, referring to a broader temporal horizon, the impacts of climate change (e.g., altering of mean temperatures and precipitation patterns). In Europe, this phenomenon may have critical consequences for the traditional tourist destinations and affects their competitiveness (Amelung & Moreno, 2012; Peric et al., 2013; Arent et al., 2014; TopDAd, 2015). In order to define the future tourist demand of a region and its variation according to climate change, an estimation of future climate is necessary. A reliable dataset that provides a



Graph 1. Tourist arrivals (left) and overnight stays (right) in Misano Adriatico, 2006 – 2016.

Graph 2. Arrivals and overnight stays in 2035 in RCP 4.5/SSP4 (left) and 8.5/SSP5 (right), absolute values and variation with 2015.



Graph 3. Current modal share to reach/leave (left) and to move within (right) Misano Adriatico in 2015.

long trend (Table 1) is the first information required. Generally, the three indicators refer to specific periods of the year *r*, such as summer, winter and shoulder seasons.

Subsequently, the variation rates in tourism demand due to climate change need to be estimated. This means providing standard climatic variables – such as temperature, precipitation, humidity, and cloud cover – and socio-economic variables that have a significant impact on the number of tourist arrivals and overnight stays. To this aim, the model developed by the EU project Tool-Supported Policy Development Interactive Tool for regional adaptation (TopDAd, 2017)[1] allows obtaining the future variation rates of tourism, according to climate change impacts (Table 2). This tool maps potential changes in overnight stays within the summer and winter seasons respectively, as well as changes in tourist flows, including shifts between regions, time, and activities (Lockers et al., 2015). Based on the Tourism Climate Index (Mieczkowski, 1985), ToPDAd works with climate scenarios, based on the combination of GHG concentration (so-called Representative Concentration Pathways-RCP; van Vuuren et al., 2011) and socioeconomic scenarios (so-called Shared Socio-economic Pathways-SSP; O'Neill et al., 2012). The model takes into account three different RCPs, representing three global warming scenarios, that are named according to radiative forcing target level for 2100 and five SSPs, which are built on the basis of qualitative and quantitative indicators, such as the level of international cooperation, market freedom and regional equality as well as the development of GDP, population and demographic statistics. Their main characteristics are presented in Table 2, sections I & II.

Three different adaptation strategies have been further considered (Table 2, section III): a no adaptation strategy

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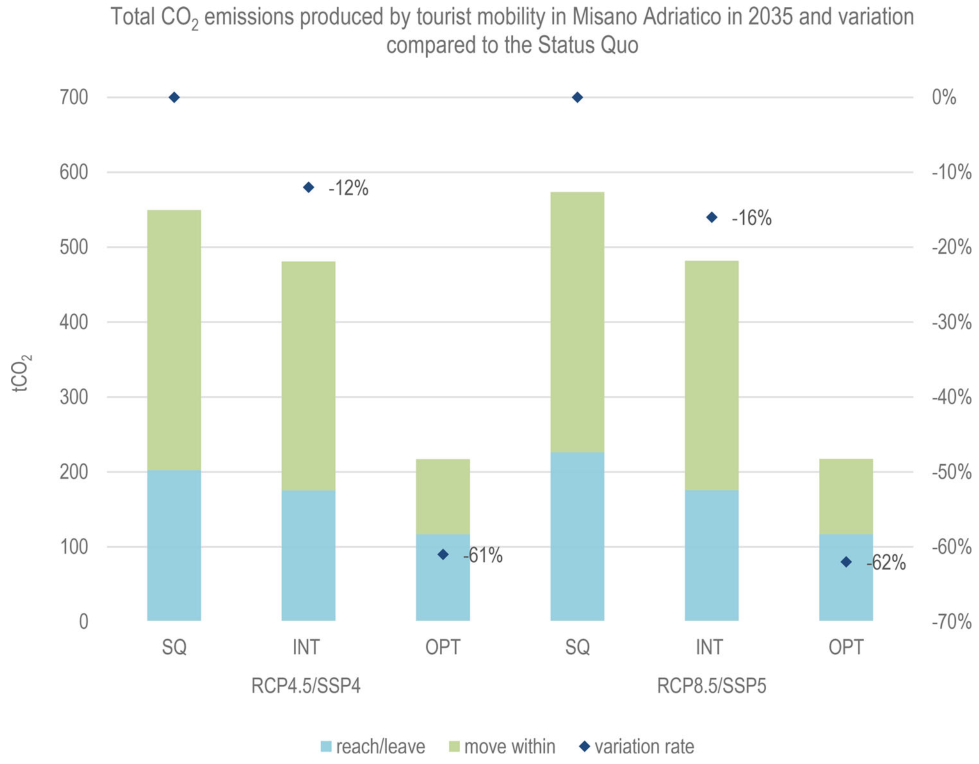
[1] Interested readers may particularly refer to the methodological description of TopDAd, available at: http://topdad.services.geodesk.nl/web/guest/methodology



Graph 4. Total emissions produced by tourists to reach/leave and to move within in Misano Adriatico in 2035 (tCO_2) and variation rate compared to the SQ scenario.

Table 1. Tourism demand: current values and trend of the last years.

Data	Index	Description
Arrivals (tourists)	***a***	It refers to the tourist arrivals in the reference year *r* and not to the actual number of people traveling. The same person visiting the same country several times during the year is counted each time as a new arrival.
Overnight stays (tourists*days)	***o***	Each night a guest/tourist (resident or non-resident) actually spends (sleeps or stays) in a tourist accommodation establishment or non-rented accommodation, in the reference year *r*.
Length of stays (days)	***l***	The average number of nights spent by a tourist in the destination area, in the reference year *r*.

(NA), if the region does not adapt to climate change at all; a partly successful adaptation strategy (PSA), if the region adapts by taking selected actions that help tourists to manage heat stress. Finally, with a successful adaptation strategy (SA), the region takes a more complete set of actions that protect tourists from heat stress and other events related to climate change. In this case, increasing temperatures have no negative effects on the attractiveness of the region. The mitigation and adaptation strategies are different for each SSP. For example, the higher economic growth in the SSP5, generated by the fossil fuel dependency, increases the mitigation challenge, whereas moderate and unequal economic growth (SSP3 and SSP4) raises the relative burden of adaptation efforts. For our purposes, two of them – SSP4 and SSP5 – are combined with the two above-mentioned scenarios RCP8.5 and RCP4.5, in order to obtain consistent integrations. The two RCP-SSP combinations are summarized in Table 2, part IV.

It is then possible to obtain the variation rates (5-year interval) of future tourist overnight stays that depend from several variables: (i) the type of tourism (e.g. summer tourism); (ii) the region; (iii) the specific area of the region selected; (iv) the destination adaptation strategy; (v) climatic-socioeconomic scenario (RCP4.5/SSP4 or RCP8.5/SSP5); (vi) timeframe. The different variables are then selected and variation rates (Table 3) are applied to the values of overnight stays measured in the reference year (Formula 1):

$$o_{ys} = o \cdot (1 \ + \beta_{ys}) \tag{1}$$

where: o_{ys} is the future tourist overnight stays in the year y according to the TopDAd scenario s; o is the tourist overnight stays in the reference year r, considered the starting point of the scenarios development; β_{ys} is the variation in the overnight stays (expressed in %) in the year y according to the TopDAd scenario s. Positive values mean an increase of overnight stays, while negative values mean a decrease of overnight stays.

TopDAd toolset does not provide variation rates of future tourist arrivals in the destination area, but this information

Table 2. RCP and SSP. Source: modified from van Vuuren et al. (2011), O'Neill et al. (2012), TopDad (2017).

Data		Description
I	RCP 8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_{2eq}) by 2100.
	RCP 4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_{2eq}) at stabilization after 2100.
	RCP2.5	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_{2eq}) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).
II	SSP1 - Sustainability (low challenges)	This scenario represents a progress toward sustainability with reduction of resources depletion and fossil fuel consumption coupled by socioeconomic improvements such as reduction of inequality, technology development and environmental awareness. Institutions implement sustainable policies.
	SSP2 - Current trends continue	Current trends of recent decades continue. Albeit progresses toward the use of sustainable sources of energy are achieved, unmitigated emissions remain moderately high due to the increase of population, and moderate technological change in energy sector. Disparities remain high in some regions.
	SSP3 - Fragmentation (High Challenges)	This scenario represents a fragmented world, with many countries facing extreme poverty and a strongly growing population often living in unplanned settlements. Countries failed in achieving global development goals. Unmitigated emissions are relatively high. Local institutions are weak and do not cooperate with each other.
	SSP4 - Adaptation Challenges Dominate	This scenario represents an unequal world where both richness and wealth are distributed unequally. The richness part produces the large amount of GHG emissions whose impacts hit the poorest. Government institutions work well in the rich countries. Mitigation strategies do not work, and technological changes are slow.
	SSP5 - Mitigation Challenges Dominate	This scenario is based on fossil fuels, which dominate the future development and are expected to solve social and economic issues. Even if it enables rapid economic growth across the world and helps in adapting to the impacts of climate change, this kind of strategy is incompatible with ambitious emission mitigation targets.
III	No Adaptation Strategy (NA)	No region adapts to climate change.
	Partly Successful Adaptation Strategy (PSA)	Regions with a mean monthly heat index of more than 29 adapt by taking actions that protect tourists from or help tourists to manage heat stress. Adaptation is only partly successful and, in this case, increasing temperatures have no negative effects on the attractiveness of a region.
	Successful Adaptation Strategy (SA)	Regions with a mean monthly heat index of more than 29 adapt by taking actions that protect tourists from or help tourists to manage heat stress. Increasing temperatures have no negative effects on the attractiveness of a region.
IV	RCP 4.5/SSP4	RCP4.5, representing global warming at a more moderate pace, is combined with the SSP4 that stands for unequal and divided world with a wealthy minority causing most of the emissions and the poorer majority getting most of the impacts. Gradually tightening mitigation and adaptation regulation, but not enough to curb emissions soon.
	RCP8.5/SSP5	The SSP5 exhibits very high levels of fossil fuel use with high socio-economic challenges to mitigation and low socio-economic challenges to adaptation. This scenario is combined with the highest Representative Concentration Pathway (RCP8.5) that represents a world with rapidly developing global warming, also beyond 2100, resulting in average global temperature rise of about 4 degrees Celsius compared to 1990. Failed climate policies but high economic growth.

Table 3. Future variation of tourism demand in a pilot area.

Data	Index	Description	Combinations
Overnight stays percentages (%)	β_{ys}	Percentage of people changing destination and month during the summer period or winter period. Positive values mean an increase of overnight stays, negative values mean a decrease. On TopDAd, the variable selected is "Tourists change destination and month in the season"	• RCP4.5/SSP4 – NA, PSA, SA • RCP8.5/SSP5 – NA, PSA, SA

can be obtained by dividing the future overnight stays (Formula 1) by the length of stays as expressed in Formula 2:

$$a_{ys} = \frac{o_{ys}}{l} \tag{2}$$

where: a_{ys} is the total future tourist arrivals in the year y with the TopDAd scenario s; l is the length of stay; o_{ys}, y, s have been previously defined.

The outputs of this phase are the variations of the two tourist indicators in a specific destination area, during summer and winter seasons, with values provided at 5-year intervals. The number of future arrivals and overnight stays are differentiated according to the different climatic-socioeconomic scenarios and destination adaptation strategies (Table 4).

3.2. Second step: transport-related implications

According to the model of tourism developed by Lamont (2009), the second step aims at defining the total amount of kilometers run by tourists to reach, to move within and to depart from the destination area. The input data is partly derived from the output of the first step (Table 4) and it is partly obtained through primary data on the *current modal share* as well as *the distance run by a tourist* (Tables 5 and 6). This information can be either modeled through the multinomial probit model (Van Can, 2013), the multinomial logit model (Asero & Tomaselli, 2015) or collected with the support of local stakeholders thanks to ad-hoc surveys. The probit model guarantees the possibility to predict how tourists might transfer to other transport modes and is recommended for detailed analysis. The major issue concerns the conversion of tourists into traffic flows, i.e. defining the tourist component in the whole travel demand (*current modal share to reach/leave/move within the destination area)*. Modeling tourism demand is still an open question, due to the huge behavioral heterogeneity of these users. Some studies have tried to define the main exogenous and endogenous components that influence tourists' choices (van Middelkoop et al.,

Table 4. Estimation of future tourism flows.

Data	Index	Description	Combinations
Future arrivals (tourist)	a_{ys}	The future trend of arrivals according to the TopDAd percentages is obtained dividing the overnight stays by the average length of stays.	RCP4.5/SSP4 – NA, PSA, SA RCP8.5/SSP5 – NA, PSA, SA
Future overnight stays (tourist*day)	o_{ys}	The future trend of overnight stays is obtained multiplying the percentages of TopDAd by the current overnight stays provided by the partners.	RCP4.5/SSP4 – NA, PSA, SA RCP8.5/SSP5 – NA, PSA, SA
Future length of stays (day)	l	The length of stay is considered constant over time even if, due to the new trend of hit-and-run journey, it is expected to be reduced.	No combinations

Table 5. Current modal share to reach/leave and move within the destination area.

Data	Index	Description	Combinations
Current modal share to reach and to leave the destination area (%)	m_t^{ext}	Percentages of tourists that arrive in the destination and leave it through different transport means. These rates are applied to the total annual number of arrivals.	Different transport means considered: Airplane, Train, Private car, Bus, Boat/ship, other
Current modal share to move within the destination area (%)	m_t^{int}	Percentages of tourists that move within the destination with different transport means. These rates are applied to the total annual number of overnight stays.	Different transport means considered: Private car, Bicycle, Walking, Bus, Motorcycle, other

Table 6. Distance run by a tourist to reach/leave and move within the destination area.

Data	Index	Description	Combinations
Distance run by tourist to reach and to leave the destination area (km)	d_t^{ext}	Distance run by tourists to reach and to leave the main arrival and departure points. It is considered only the kilometers run within the pilot area.	Distance run between: highway exit – city center, airport terminal – city center, port terminal – city center
Distance run by tourist within the destination area (km)	d_t^{int}	Distance run by tourists within the destination area with different transport means.	Distance run by: private car, bicycle, walking, bus, motorcycle, other

2003; Scuttari et al., 2013). Exogenous components include all those external elements that influence all tourists regardless of their profile and/or the kind of holiday they had chosen, such as the weather/climate, a shock event that may take place in the destination area, the accessibility of the destination, the transport supply, etc. The endogenous component includes all those elements that shape the tourist profile and his/her habits – the country of origin of the tourist, the income, the nature of the tourist (sedentary or itinerant), the quality of holiday, the kind of tourism (cultural, adventure, historical, relax, etc.). The same difficulties found in the forecast of non-tourist travel demand are increased by the definition of a sample that constantly changes over the year. Some limitations concern also the difficulties to collect sample surveys yearly with an integrated approach to tourism and traffic, as well as the rarity of some data (i.e. same-day visit, hidden tourism, no tourism traffic). For this reason, the reliability of results from this step depends on the quality of data surveys and sources, which are place-specific (availability of local data sources) and sector-specific (availability, accessibility, and quality of data on traffic and on tourism at the local level). If these conditions are not respected, the uncertainty of the method arises considerably (Cappelli & Nocera, 2006; Dias et al., 2018).

Data provided by the stakeholders includes the *current modal share to reach/leave the destination area* and the *current modal share to move within the destination area* (Table 5) in the reference year *r*. The first component (m_t^{ext}) is applied to the arrivals in order to obtain the share of emissions produced by tourists to arrive to and to depart from the destination, while the second component (m_t^{int}) is applied to the overnight stays and it is used to calculate the emissions generated by the movement of tourists within the destination area.

There are also several difficulties in the estimation of the *distance run by tourists to reach/leave/move within the destination area* (Table 6). This figure should be calculated for each transport mean used by tourists to get or move within the destination area. The first component (d_t^{ext}) is the distance run by tourists to reach or leave the destination. For this research, only the kilometers run by tourists within the destination are measured. Indeed, the study does not assess the distance from the origin, since the focus is on the role of local policymakers to reduce GHG transport emissions at the destination. Rather, it calculates kilometers to move from airport, station, highway toll station or port terminal and to return there at the end of the holiday. The second component (d_t^{int}) concerns the distance run by a tourist to move within the destination area. It can be calculated by specific surveys on the field, that contribute on having a clearer vision of the tourist profiles, for instance through the use of smartphone-based GPS technology (Hardy et al., 2017), or through the definition of some models (Lew & McKercher, 2006). If these alternatives are not available, rough values can be used. Both distances mentioned refer to the year *r*.

The second phase step process consists in the definition of *future modal share to reach/leave and to move within the destination area* (Table 7). Based on input data, the future modal shares are calculated according to different scenarios and mobility plans, with a 5-year linear variation (coherently with the outputs of the first phase). These indicators can be expressed as percentages of users that adopt private vehicles

Table 7. Future modal share to reach/leave and move within the destination area.

Data	Index	Description	Combinations
Future modal share to reach/leave the destination area (%)	m^{ext}_{ytm}	Future percentage of tourists that arrive at the destination and leave it with different transport means. It represents future transport modal share according to the three mobility scenarios – Status quo, Intermediate, Optimistic.	Different transport means considered: Airplane, Train, Private car, Bus, Boat/ship, other. Different scenarios analyzed: SQ, INT, OPT
Future modal share to move within the destination area (%)	m^{int}_{ytm}	Future percentage of tourists that move within the destination with different transport means. It represents future transport modal share according to the three mobility scenarios – Status quo, Intermediate, Optimistic.	Different transport means considered: Private car, Bicycle, Walking, Bus, Motorcycle, other. Different scenarios analyzed: SQ, INT, OPT

Table 8. Unitary emission factors for each transport mean.

Data	Index	Description	Combinations
Emission factors (g/km)	ef_{yt}	These factors are obtained through the application of HBEFA model and vary according to the different transport means, their classes and the reference year.	Different transport means: motorcycle, private car, bus

Table 9. Total emissions produced by tourists to reach/leave and move within the destination area.

Data	Index	Description	Combinations
Total emissions to reach and to leave the destination area (tCO_2)	E^{ext}_{yms}	Total emissions produced by tourists to reach and to leave the destination area.	Different transport means: airplane, train, private car, bus, boat/ship, other Different mobility scenarios: SQ, INT, OPT Different TopDAd scenarios: • RCP4.5/SSP4 – NA, PSA, SA • RCP8.5/SSP5 – NA, PSA, SA
Total emissions to move within the destination area (tCO_2)	E^{int}_{yms}	Total emissions produced by tourists to move within the destination area.	Different transport means: private car, bicycle, walking, bus, motorcycle, other Different mobility scenarios: SQ, INT, OPT Different TopDAd scenarios: • RCP4.5/SSP4 – NA, PSA, SA • RCP8.5/SSP5 – NA, PSA, SA

or other forms of transport (including public transport and alternative modes). Future conditions are derived from three alternative scenarios:

1. *Status quo scenario (SQ)*: is a prosecution of the current modal share extended to the entire period object of analysis. It predicts a future scenario in case no actions are undertaken to modify the present condition.
2. *Intermediate scenario (INT)*: a low modal shift toward more sustainable transport means is expected, with values that are characterized by the average of status quo and optimistic scenarios (as defined above).
3. *Optimistic scenario (OPT)*: these values consider a significant modal shift toward more sustainable transport means (e.g., buses and trains to reach and leave a destination, alternative mobility and public transport to move within a destination), according to the long-term expected values indicated by local mobility plans or relevant policy documents.

The *total distance run by tourists to reach/leave and move within the destination area* can be obtained by multiplying the four components expressed in Tables 6 and 7 by the shares of future tourist arrivals (in case of external component of mobility) and future overnight stays (in case of internal component of mobility), in order to get the total number of kilometers run by tourists with different transport means, according to (3) and (4):

$$D^{ext}_{ytms} = a_{ys} \cdot m^{ext}_{ytm} \cdot c_{tm} \cdot d^{ext}_{t} \tag{3}$$

where: D^{ext}_{ytms} is the total distance run by all tourists to reach and to leave the destination in the year y with the transport mean t, according to the mobility scenario m and the TopDAd scenario s; m^{ext}_{ytm} is the future modal share expressed in percentage to reach and to leave the destination in the year y with the transport mean t according to the mobility scenario m; c_{tm} is a coefficient of vehicular filling that transforms passengers into vehicles. It varies according to the transport mean t and to the mobility scenario m; d^{ext}_{t} is the distance run by tourist to reach and to leave the destination area with the transport mean t; a_{ys}, y, s have been previously defined.

$$D^{int}_{ytms} = o_{ys} \cdot m^{int}_{ytm} \cdot c_{tm} \cdot d^{int}_{t} \tag{4}$$

where: D^{int}_{ytms} is the total distance run by all tourists to move within the destination with the transport mean t in the year y, according to the mobility scenario m and the TopDAd scenario s; m^{int}_{ytm} is the future modal share expressed in percentage to move within the destination in the year y with the transport mean t, according to the mobility scenario m; c_{tm} is a coefficient of vehicular filling that transforms passengers into vehicles. It varies according to the transport mean t and to the mobility scenario m; d^{int}_{t} is the distance run by tourist to move within the destination area with the transport mean t; o_{ys}, y, s, t, m have been previously defined.

Table 10. The three-step method proposed to assess the transport-related implications deriving from future tourism demand and related CO_2 emissions.

	Sub-step	Description	Source
FIRST STEP – A FORECAST OF FUTURE TOURISM DEMAND ACCORDING TO CLIMATE CHANGE			
Input	1. Current values and trend of last years	Data about tourist arrivals, overnight stays and length of stays	*Questionnaire*
Process	2. Variation in tourism demand in pilot area	Application of the variation rates to the data about arrivals and overnight stays	TopDAd, 2017
Output	3. Estimation of future tourism flows	Data about future tourist arrivals and overnight stays according to different climatic-socioeconomic scenarios	*Authors*
SECOND STEP – TRANSPORT-RELATED IMPLICATIONS			
Input data	3. Estimation of future tourism flows	–	*First step output*
	4. Current modal share to reach/leave the destination area	Percentage of tourists that arrive at the destination and leave it with different transport means	*Questionnaire*
	5. Current modal share to move within the destination area	Percentage of tourists that move within the destination area with different transport means	*Questionnaire*
	6. Distance run by tourists to reach/leave the destination area	Distance run by tourist to reach and to leave the main arrivals and departure points	*Questionnaire*
	7. Distance run by tourists to move within the destination area	Distance run within the destination area with different transport means	*Questionnaire*
	8. Coefficient of vehicular filling	Number of passengers (arrivals/overnight stays) into vehicles, according to the transport mean and the mobility scenario	*Authors*
Process	9. Future modal share to reach/leave the destination area 10. Future modal share to move within the destination area	Future mobility scenarios (Status quo, Intermediate, Optimistic), according to mobility plans or strategic documents	*Mobility plans and scientific literature*
Output	11. Total distance run by tourists to reach/leave the destination area	Total distance run to reach/leave the destination area, according to points 6, 8 and 9	*Authors*
	12. Total distance run by tourists to move within the destination area	Total distance run to move within the destination area, according to points 7, 8 and 10	*Authors*
THIRD STEP – CO_2 EMISSIONS DUE TO TOURISM TRANSPORT			
Input data	11. Total distance run by tourist to reach/leave the destination area	–	*Second step output*
	12. Total distance run by tourist to move within the destination area	–	*Second step output*
	13. Emission factors for each transport mean	Unitary emission factors for each transport mean, as derived from the HBEFA model	INFRAS (2014)
Process	14. Total emissions produced by tourists to reach/leave the destination area	Total emissions to reach/leave the destination area according to point 11 and 13	*Author*
	15. Total emissions produced by tourists to move within the destination area	Total emissions to reach/leave the destination area according to point 12 and 13	*Author*
Output	16. Total emissions produced by tourists	Sum of the total emissions produced by tourists to reach/leave the destination area with those generated to move within it	*Author*

3.3. Third step – CO_2 emissions due to tourism transport

The third step consists in measuring the amount of CO_2 emitted by tourist transport in its two main components: the internal (the movements within the city) and the external ones. The input data is the total distance run by tourists to reach/leave and to move within the destination area and the unitary emission factors for each transport mean. This last aspect deserves particular attention. The elements that affect fuel consumption and CO_2 emissions can be grouped into four main categories (Nocera et al., 2017): vehicle (total vehicle mass, engine size, engine temperature, oil viscosity, gasoline type, vehicle shape, degree of use of auxiliary electric devices), environmental conditions (roadway gradient, wind conditions, ambient temperature, altitude, pavement type, surface conditions), traffic conditions (speed and acceleration) and drivers' behavior. According to these factors, it is possible to distinguish between the micro and the macro approaches to calculate the total emissions. The main differences between them refer to the geographical scale of application and the level of detail during the phase of data collection. The macro models are suitable for large spatial scales (i.e., national or regional) and temporal horizons (months or years). They use average emission factors, kilometers traveled per average speed and average slope gradient of a series of different vehicle types to calculate the amount of emission per link unit (Coelho et al., 2014). The micro models operate at a higher level of complexity. They provide a more accurate fuel consumption and emission estimation, for a particular vehicle type for any given driving cycle. Such models include different levels of speed and various operational modes or driving cycles (acceleration, deceleration, steady-speed cruise and idle), but also significant variables such as the engine power and the road gradient. For this reason, they are used for instantaneous evaluations, referred to a limited territorial context (an intersection, a roundabout, a limited segment of a road, etc.). For the purposes of this research, the adoption of a macro model seems more appropriate. The Handbook Emission Factors for

Road Transport[2] (HBEFA 3.2; INFRAS, 2014) is a well-known traffic situation model and is suitable to provide one of the input data of the third phase – the unitary Tank-to-Wheel emission factors (ef_{yt}, Table 8). HBEFA calculates values for specific vehicle types (for our purposes, cars, coaches, buses and motorcycles), by considering fuels (petrol and diesel), Euro classes (from Euro 0 to Euro 6) and size, calculated according to the area (urban, rural), the type of road (motorway, primary, secondary, local, access), the congestion levels (free flow, heavy, saturated, stop and go), and road gradient (classes between -6% and +6%).

The process phase consists in calculating the total emissions produced by tourists to reach/leave the destination area (Formula 5) and the total emissions produced by tourists to move within the destination area (Formula 6) in the year y, according to the mobility scenario m and the TopDAd scenario s, with all transport means t (Table 9). The unitary emission factors have to be combined with the total distances run by tourists referred to the different transport means t, defined within a range between 1 and the number n of the means available.

$$E^{ext}_{yms} = \sum_{t=1}^{n} D^{ext}_{ytms} \cdot ef_{yt} \tag{5}$$

where: E^{ext}_{yms} are the total emissions produced by tourists to reach/leave the destination in the year y, according to the mobility scenario m and the TopDAd scenario s, with all the transport mean t; ef_{yt} are the unitary CO_2 emission factors during the year y of the transport mean t; D^{ext}_{ytms}, y, t, s, m, n have been previously defined.

$$E^{int}_{yms} = \sum_{t=1}^{n} D^{int}_{ytms} \cdot ef_{yt} \tag{6}$$

where: E^{int}_{yms} is total emissions produced by tourists to move within the destination in the year y, according to the mobility scenario m and the TopDAd scenario s, with all transport means t; D^{int}_{ytms}, ef_{yt}, y, t, s, m, n have been previously defined.

Finally, the sum of these two components determines the yearly overall emissions produced by tourism transport in the destination area and represents the main output of this method (Formula 7).

$$E^{*}_{yms} = E^{ext}_{yms} + E^{int}_{yms} \tag{7}$$

where: E^{*}_{yms} is the sum of the total emissions produced to reach and to leave the destination area and the total emissions generated to move within the destination area, in the year y, according to the mobility scenario m and the TopDAd scenario s, with all the transport mean t; E^{ext}_{yms}, E^{int}_{yms}, y, t, s, m, n have been previously defined.

By iterating this process for each year, the overall emissions produced by tourism transport can be calculated within the pre-established time frame between the reference year r and the future year k (Formula 8).

$$E^{**}_{ms} = \sum_{y=r}^{k} E^{*}_{yms} \tag{8}$$

Table 10 summarizes the method described in this section, providing a short description for the steps presented in Figure 2. Each of them is divided into three elements, i.e. *input*, *process* and *output*: according to the operational research, they represent, respectively, the initial data, the computation of the values according to the Formulas presented in the previous subsections and the results obtained in a specific phase. With reference to the sources, four main documents have to be mentioned. "Questionnaire" refers to a specific questionnaire prepared in the project Mobilitas for the local administrations (MOBILITAS, 2017b). It allows obtaining information about tourism and transport modal share. TopDAd (2017) is a model developed by the EU project "Tool-Supported Policy Development Interactive Tool for regional adaptation" that provides the variation rates needed to calculate the output of the first step. "Author" includes formulas and data described in this section. Finally, INFRAS (2014) refers to the Handbook Emission Factors for Road Transport (HBEFA), a model that gives the unitary emission factors of vehicles.

4. GHG impacts deriving from tourist mobility in Misano Adriatico

4.1. Description of Misano Adriatico

To test the method presented in the previous section, we have selected the Italian municipality of Misano Adriatico as case study. Its technical department, which works in close cooperation with tourism businesses and marketing organizations, has been the main source for primary data related to the tourist and mobility features of the Municipality. They have been collected through a specific questionnaire (MOBILITAS, 2017b). Misano Adriatico is a small town (13,097 inhabitants and 22.34 km^2), located in the Region Emilia Romagna (northern part of Italy), along the Adriatic coast. The territory is characterized by a coastal part that connects the city directly to the Riviera Romagnola and by another hilly part that links the city with the hinterland, in particular with Val Conca, the valley crossed by the Conca river. Misano is no longer an agricultural and rural district and its main activities are related to the tertiary and tourism sectors (population employed in tourism sector in 2016 is 51%). Tourism is largely linked to families who find a comfortable environment to spend a quiet holiday (66%), whereas singles and groups are limited to 17% each of total arrivals. Misano hosts the Santa Monica circuit where two world races are organized, MotoGP and Superbike, and many tourists reach and leave these events almost

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[2] HBEFA expresses the estimations by the use of emission factors related to one type-vehicle and a specific driving mode, as for instance urban, rural or motorway. Emission factors are extracted from real-life situations, derived from the mean values of repeated measurements over a particular driving cycle and expressed in mass of pollutant per-unit-distance. Different type-vehicles are considered to calculate unitary emissions: passenger cars, motorcycles, and urban busses. Each of them is characterised by its size, load, fuelling (petrol and diesel) and Euro class (from Euro 0 to Euro 6). Emissions vary according to several factors such as the area (urban, rural), the type of road (motorway, primary, secondary, local, access), the level of service (free flow, heavy, saturated, stop and go) and road gradient (classes between -6% and +6%).

exclusively with private vehicles (cars and motorcycles), causing congestion and other negative externalities. As many Italian municipalities, even in Misano the number of cars per inhabitant is high (65 cars/100 inhabitants in 2016), well above the European average. Misano Adriatico has a railway station served by regional trains; in summer, few long-distance trains are organized to allow tourists to reach and to leave Misano. No high-speed trains serve this destination, but they stop in the close station of Riccione (4.5 km from Misano Adriatico). Most of the tourists use cars to reach Misano by the Adriatic State Street (S.S. 16) and the A14, which is one of the most crowded Italian highways, especially during the summertime. When a tourist arrives in the city, the parking supply is wide and mainly related to hotels. The locality can also be reached by the airport of Rimini, which today has a small number of flights coming from Russia and from other European Countries. Pedestrian areas are located on the seafront. Several cycle lanes are located along the waterfront and some of them continue to Val Conca. Finally, two electric charging columns have been installed in order to allow people to use electric vehicles.

4.2. Future scenarios

According to the method presented in Section 3, tourist arrivals, overnight stays, and length of stay have been surveyed through a dedicated questionnaire to the local administration. During recent years, the number of tourists has shown an increasing trend (Graph 1, left). However, there was a short-lived downturn in the arrivals in 2008, as a consequence of the international economic crisis. In absolute values, tourist arrivals in 2006 were 90,391. They increased up to 120,292 in 2016 (+34.19%), but from 2015 and 2016 a stabilization is visible. Most of the tourists of Misano Adriatico come from Italy (about 84%). Foreign arrivals represent about 16% of the total arrivals with 96% of them coming from Europe. Similar to the number of arrivals, also overnight stays have increased during the last 10 years, but unlike the former, the overnight stays trend does not increase and varies largely across ten years (Graph 1, right). Two main downturns can be observed. The first one, in 2008, represents the economic crisis. The second one, 2012–2013, embodies one of the most harmful crises for the Italian tourist sector caused by the weakening in domestic demand (Landi, 2013). Between 2012 and 2013, tourist spending has come to a minimum level, with a significant decrease in the number of holidays, fewer people and families going on a holiday, which has become shorter, closer and cheaper ("hit-and-run" tourism). For Misano Adriatico, the 5-year trend is negative and compared to the levels of 2010, a decrease is visible. In 2006, the average length of stay was 7.3 days and decreased to 5.9 days in 2016 (see Appendix I). However, the phenomenon is less intense than in other European cities, probably because Misano Adriatico hosts a settled tourism, composed mainly of "repeaters" and families.

The variation rates of future tourism demand under climate change (as described in 3.1 and referred to 2015 as reference year) show a negative trend in all three adaptation strategies (NA, PSA, SA) and in both climatic scenarios (RCP 4.5/SSP4 and RCP 8.5/SSP5; blue line in Graph 2). This means that every strategy against climate change implemented by Misano Adriatico is expected to get similar results: the locality has to address an expected decrease of overnight stays due to the impacts of climate change. The estimates of future tourist flows – arrivals and overnight stays[3] – are in line with the general predictions of TopDAd: on the one hand, weather conditions will improve in most parts of Europe and for a broader period, with positive consequences on tourism. On the other hand, some Mediterranean destinations will become hotter and subject to more frequent extreme events (TopDAd, 2015). Misano Adriatico belongs to the second group of destinations: losses are expected, both in scenario RCP4.5/SSP4 and in scenario RCP8.5/SSP5 in overnight stays and arrivals. Specifically, the variation of tourist arrivals, with successful adaptation strategy, is modest: compared to 2015 and referred to the year 2035, −1.05% in RCP4.5/SSP4 and -0.82% in RCP 8.5/SSP5. The difference between the two scenarios can be explained by the strong economic growth in SSP5: even if this socioeconomic scenario is combined with the worst climatic scenario that can undermine the tourist choices, tourism demand is sensitive to economic growth because of the increase of incomes that involves the growth in tourism expenditure and leisure travels. Losses are expected in both cases, but in SSP5 they are lower due to the economic growth that compensates the worst climatic conditions provoked by climate change (RCP 8.5). The adaptation capacity of the suppliers (tourist areas, hotels, etc.) can generate different variations in tourist overnight stays. Their rates change if the suppliers decide not to apply any adaptation strategy (-0.70% in RCP 4.5/SSP4 – Graph 2, left; −0.57% in RCP 8.5/SSP5 – Graph 2, right) or if they decide to apply a partly successful adaptation strategy (-0.87% in RCP 4.5/SSP4; −0.69% in RCP 8.5/SSP5). Intuitively, we are expecting that the successful adaptation – both in the RCP4.5 and in RCP8.5 – should limit the losses caused by climate change more than the absence of adaptation, but in Misano Adriatico this condition is not expected to occur. Two different hypotheses can be made: on the one hand, the investment to apply these measures could provoke an increase in the overall expenditure of vacancy and consequently the number of tourist overnight stays decreases, as well; on the other hand, the implementation of some measures that reduce the perception of heat (e.g., constructional measures, shading, air conditioning, etc.) could not compensate the losses because of increased competition of other destinations. In the worst climatic condition, if Misano Adriatico does not implement any adaptation strategy (NA), it will reduce the tourist arrivals from 121,292 (year 2015) to 120,441 (year 2035; Graph 2, right). If it decides to implement partly successful strategies (PSA), the arrivals will become 120,235 (120,022 with successful adaptation).

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[3] For our evaluation, the length of stays is considered constant over time (6 nights), according to the data registered in the last years.

Table 11. Future modal share to reach/leave and move within Misano Adriatico, year 2035.

		Airplane	Train	Private Car	Bus/Urban bus	Feet	Bicycle
Future modal share to reach/leave Misano Adriatico (2035)	**SQ**	2%	8%	85%	5%	–	–
	INT	2%	20%	70%	8%	–	–
	OPT	1%	40%	50%	9%	–	–
Future modal share to move within Misano Adriatico (2035)	**SQ**	–	8%	30%	2%	41%	19%
	INT	–	10%	25%	5%	40%	20%
	OPT	–	5%	8%	3%	50%	34%

The second step consists in the definition of transport-related implications. The current modal shares to reach/leave and to move within Misano Adriatico have been obtained through a separate section of the already mentioned questionnaire distributed to the local administrators. The first component is represented mainly by private car (85%), followed by train (8%), bus/coach (5%) and airplane (2%) (Graph 3, left). As far as the current modal share to move within the destination area is concerned, Misano Adriatico has provided data obtained through a specific questionnaire submitted to tourists. According to these results, the great majority of tourists move within the city on foot (41%), followed by 30% who use the car. About 20% ride a bike to go around the city or reach the beach and only 2% of tourists use public transports, like urban buses.

Also, the distance covered by tourists and transport mean used (see Annex I) should have been provided by Misano Adriatico, but some difficulties have been met in collecting such data. Indeed, if the kilometers between the main transport hubs and the city center are easy to find, the distance run by a tourist via a specific transport mean within the destination area can be calculated more difficultly. Due to the lack of more accurate studies (see also the discussion in 4.2), we have chosen an average data specific for each transport mean (Isfort, 2015). The process phase of the second step is focused on the definition of future modal share to reach/leave and move within Misano Adriatico. According to the scenario described in 3.2, different percentages have been chosen, which are in line with the future political strategies of the municipality and particularly the Sustainable Urban Mobility Plan (SUMP) of the city. In the status quo scenario (SQ), there is a prosecution of the current modal share, extended to the entire period. In the optimistic scenario (OPT), both the arrivals by airplane and by private car are reduced mainly in favor of train and bus (Table 11). Also, in the future modal share to move within the city, the intentions exposed by Misano Adriatico to improve cycling and pedestrian flows have been followed and included into the definition of the new percentages. The territory of Misano Adriatico (mostly flat) and the favorable weather conditions are particularly indicated for a sustainable mobility based on biking and walking. For this reason, the slow mobility in the optimistic scenario is expected to reach respectively 34% and 50%, by 2035. In the status quo, the percentage of these alternative transport means is lower (19% by bike and 41% by feet; Graph 3, right).

The output of this phase is the total distance run by tourists according to the internal and external components of mobility. The number of kilometers run by tourists and calculated through the application of Formula 3 and 4 can be seen in Annex I. It varies according to the different transport means, the climatic-socioeconomic scenario (RCP4.5/SSP4 and RCP8.5/SSP5) and the adaptation strategy implemented by Misano Adriatico (SQ, INT, OPT).

Finally, the third step applies the unitary CO_2 emission factors to the total distance run by tourists, in order to obtain the total amount of CO_2 emissions produced by the two components of mobility – the internal (emissions produced to move within the area) and the external one (the emissions produced to reach and to leave it) in the year 2035. Graph 4 represents the component of mobility obtained by summing the emissions produced by each different transport mean. The six bars represent the mobility scenarios in the two climatic scenarios (RCP 4.5/SSP4 and RCP8.5/SSP5) and the reported values are the average values of the three adaptation strategies (NA, PSA, SA). In both climatic-socioeconomic scenarios, the best strategy is given by the optimistic scenarios. Total emissions to reach, leave and to move within the destinations vary from 550 tCO_2 (RCP8.5/SSP5) to 217 tCO_2 (RCP4.5/SSP4) (Graph 4). By looking at the total emissions produced by tourists to move within the destination area, those produced in the optimistic mobility scenario - RCP 8.5/SSP5 (100.30 tCO_2) are slightly higher than the middle climatic scenario RCP 4.5/SSP4 (100.12 tCO_2) due to a lower loss of tourist overnight stays in the RCP 8.5/SSP5 than in the last one (Graph 4). Anyway, in both cases, the total emissions in the optimistic mobility scenario are more than 60% lower than status quo and intermediate (as visible from the diamonds of Graph 4, which represents the variation compared to the status quo) due to the increase of walking and cycling modal shares (Table 11). Similarly, also in the total emissions produced by tourists to reach and leave the destination area (Graph 4), a reduction of the overall emissions in the optimistic scenario occurs, due to the decrease in the use of private cars and to the raise of the journeys made by train.

By iterating the method for the entire period 2015–2035, the six trends according to different mobility and climatic-socioeconomic scenarios can be calculated. They can be expressed as yearly values (Graph 5, left), or as cumulative values (Graph 5, right), by summing emissions produced by the internal and external components of tourist mobility for the entire period 2015–2035. Referring to the yearly values, in the intermediate and optimistic trend the differences between the RCP4.5/SSP4 and RCP8.5/SSP5 are negligible and the two curves coincide. Indeed, the contribution given by the different mobility strategies (optimistic and intermediate) compared to status quo condition, is clear. Considering the cumulative values (Graph 5, right), the total amount of CO_2 emissions saved thanks to the application of successful mobility policies and strategies can be found. The difference between the status quo (orange) and the optimistic scenario (grey) can be quantified at about 4,200 tCO_2 both for RCP4.5/SSP4 and RCP8.5/SSP5.

4.3. Findings and discussion of results

Results presented in 4.2 reveal that climate change is expected to generate a loss of arrivals and overnight stays in Misano Adriatico. This result is coherent with the condition of other Mediterranean destinations (Perry, 2000). According to our simulations, the most harmful condition for Misano Adriatico is represented by scenario RCP 8.5/SSP5 in all three mobility scenarios, due to the lower decrease of tourist arrivals and to emissions produced by transport. On the contrary, the best performing one is the RCP4.5/SSP4 in the optimistic mobility scenario. Considering total emissions produced by tourists to arrive/depart Misano Adriatico and to move around the town in 2035 (Graph 4), results vary according to the three mobility scenarios considered (status quo, intermediate and optimistic). In the status quo, RCP 4.5/SSP4, the overall quantity of emissions reaches 549.58 $tCO_{2.}$ This value decreases in the optimistic scenario (216.91 tCO_2), thanks to the shift from more pollutant vehicles toward more sustainable types of mobility (see Table 11). Compared to the status quo, the intermediate and optimistic scenarios generate, respectively -12% and -61% of total CO_2 emissions in 2035 (Graph 4), which for the entire period 2015–2035 may lead to a reduction up to 4,200 tCO_2 (Graph 5, right).

Such results derive from some initial assumptions that affect the final values. They can be included in the so-called epistemic and ontological uncertainties (Kujala et al., 2012), which are related to the limited knowledge of the world by modelers, especially when dealing with future forecasts. In most cases, they cannot be eliminated, but only minimized and should be considered as inherent to the proposed method. They include:

- future climate scenarios based on the predictions of TopDAd (2017), which, in turn, rely upon the tourism climate index (see section 2.1). However, this index has been criticized. Scott et al. (2016) underline" *the subjectivity in index weighting and rating systems; the over-concentration on the thermal component and absence of an overriding effect of physical variables; the low temporal resolution; and tourism wide application without recognition of specific climatic requirements of different major tourism segment*". Other indexes, such as the Holiday Climate Index (HCI), may provide more reliable results.
- the analysis of the travel behavior of tourists (mostly related to the movements within the destination), which is a fundamental aspect and requires disaggregate analyses (e.g., through smartphone-based GPS technology) referred to the territory under evaluation. Due to the tight timeframe imposed by European project deadlines, it was not possible to perform such analysis within this research, but its application is expected to guarantee a more accurate definition of the movements to and from and within the destination.
- the case study concerns only tourists with overnight stays. This excludes day-trippers and limits the analysis to a part of total arrivals. A more complete analysis could include also these components, provided that reliable data about daily visitors can be obtained.
- only emissions produced at the local scale (to reach and to leave the closest hubs), and not the whole origin-destination pathway of tourists have been considered. However, emissions from tourist transport do not include only this scale: if a comprehensive analysis is to be performed, the entire trip to reach and to leave a destination should be considered. Indeed, aviation is the generator of the largest proportion of tourism-related emissions (Gössling & Buckley, 2016; Simpson et al., 2008).
- the future length of stay has been considered constant over time, according to the value registered in last five years and the type of destination, characterized by a settled tourism, composed mainly of "repeaters" and families.
- it is assumed that every tourist leaves the destination in the same way that he/she reached it and that a tourist that comes from an external hub, moves only with a private car or taxi, due to the absence of connection by public transport between the airport and the center of Misano Adriatico.

As mentioned in many parts of the paper, results presented are taken from the MOBILITAS project. They are part of a broader study, which assesses the impacts of climate change on tourism mobility and vice versa in nine Mediterranean cities[4]. By comparing the results of these destinations, the loss in Misano Adriatico is expected to be more moderate than other Mediterranean cities, probably due to its attractiveness and popularity as a beach destination for tourists that mostly come from Italy. In absolute terms, the total emissions calculated in Misano Adriatico are not so high if compared with other coastal destinations with higher tourist flows. In Malta, for instance, the same method predicts total emissions in 2035 equal to 21,910 tCO_2 in the status quo scenario, which lower at 13,690 tCO_2 if virtuous transport strategies are applied (optimistic scenario). Such values, which are up to 20 times higher than those registered in Misano Adriatico, depend from different aspects related both to the number of tourists, the distance covered and to the transport means adopted to reach/leave and move within the destination.

5. Conclusions

The relationship between transport, tourism and climate change has been the object of this contribution. The final purpose is twofold: on the one hand, to appreciate the

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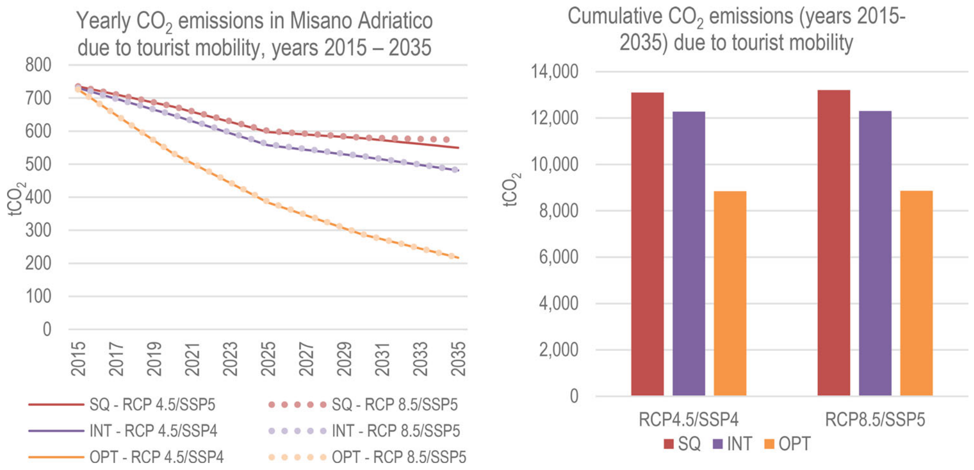
[4] The Mediterranean cities mentioned have been analysed by the European project MOBILITAS (Koper, Rimini, Zadar, Dubrovnik, Nice, Cyprus, Malta, Piraeus) with the same method described in Section 3. The results are obtained by applying the variation percentages provided by the model TopDAd, as explained for the case study of Misano Adriatico.



Graph 5. CO_2 emissions due to tourist mobility in Misano Adriatico, yearly (left) and cumulative (right) values.

impacts of climate change on tourism transport; on the other hand, to define the reverse relationship, i.e. the contribution of future tourism transport to CO_2 emissions. A literature review (Section 2) has discussed the complex relationship between these three themes, showing that they have been principally addressed from different viewpoints so far (i.e. referring to tourism and transport, tourism and climate change or transport and climate change), whereas literature that deals with the three issues is more limited. The present paper has tried to fill this gap, considering the point of view of local policy makers by highlighting the future changes of a destination in tourism demand due to climate change. A heuristic method has been proposed to assess the impacts, based on the development of alternative climate and mobility scenarios. This method has revealed its flexibility to approach an issue characterized by a high degree of uncertainty. Each of them has been developed by adopting three steps that have been presented in Section 3 and can be summarized in the following phases: (i) forecast of future tourism demand under a condition of climate change; (ii) definition of transport-related implications; (iii) consequences in terms of CO_2 emissions. Then, the method has been tested on the Italian municipality of Misano Adriatico (Section 4). Results referred to this coastal area reveal that the losses of tourists due to climate change are expected to be rather moderate, lower than other Mediterranean coastal destinations (-1% in 2035). In terms of mobility, the consequences are dependent from the mobility policies that will be adopted within the destination: indeed, the overall quantity of emissions decreases in the optimistic scenario up to -61%, thanks to the shift to more sustainable vehicles that are expected to be introduced by the recent sustainable urban mobility plan (see Table 11). Whereas, they remain rather stable in the status quo, where a prosecution of the current (car-oriented) policies is assumed.

In interpreting these results, five caveats are necessary, which have to be added to the specific points related to the method presented in 4.3. First, it is important to recall that the effects of climate change are not limited to the increase in the temperature. Beside this aspect, which may be considered unfavorable only by a limited number of travelers (Moreno, 2010), all main effects of climate change in coastal areas should be considered. According to Watkiss et al. (2005), they include sea level rise, extreme weather events, water supply, ecosystems and can have more influence in travelers' decisions. Second, climate change is only one of the elements that can determine the success or failure of a tourist destination. Other aspects not covered within this paper play a main role, such as the international and local economic conjuncture, accessibility, or the development of local tourist attractions. Thus, the values obtained allow a comprehension of the impacts of climate change on tourism and mobility coastal areas, and do not represent the future trend of tourism in such areas. Third, the variation in the total amount of CO_2 emissions from tourist transport can be the result of different conditions: for instance, a decrease of emissions can be caused by a reduction of the tourists that visit a place. Even though environmentally favorable, this determines negative effects to the development of a region. However, a broader use of sustainable transport means (both to reach/leave the destination and to move within it) can determine a reduction of CO_2 emissions, without a contextual loss in the travel demand. Such condition would be ideal, as it would merge the positive environmental effects produced by the shift toward less polluting transport means with the economic ones. Hence, in interpreting the results of the different scenarios in terms of CO_2 emissions, the figures in terms of travel demand should be always considered. Fourth, this paper has assessed the impacts of tourism transport in terms of CO_2 emissions, chosen as indicator of climate change. The final step would be the assessment of the results in terms of climate change by taking into account and addressing the numerous uncertainties related to the physical consequences generated in the destination (Nocera et al., 2018a). Finally, the replicability and the scalability of the method to other contexts have to be discussed. As already mentioned in section 4.3, the analysis of the bidirectional relationship between climate change and tourism mobility has been performed for other Mediterranean coastal areas within the framework of the EU-funded project Mobilitas. Results have been rather heterogeneous, due to the different quality of the data collected by the local partners. However, in those coastal contexts (such as Malta or Rimini) where information has been collected in an appropriate way, scenarios have provided useful information that have been used to define concrete measures for the local mobility system. Beside the coastal areas, the method could be extended to other types of tourist destinations, such as the mountain resorts or historical towns, by considering the adequate adaptations referred e.g. to the transport modes considered, origins and destinations, emissions factors.

Referring to policy implications for the municipality, two distinct evaluations should be made, according to the types of mobility considered. In this context, we should distinguish between movements of tourists to reach/leave the destination and to move within it. The reduction of emissions generated by the former component seems more difficult than of those generated by the latter, for two main reasons. First, it is not exclusively a local issue – i.e. incentivizing or discouraging a transport mean is an (inter)national problem (e.g. train vs. airplane), that requires adequate support policies and measures. Second, the transport means used to reach and to leave a destination depend also on the infrastructures and services available on the territory – i.e. an island can be reached only by boat or by airplane, or some places cannot be reached by specific transport systems (e.g., train). It is however possible to introduce several measures – such as electric shuttle, public transport – to reduce the impact generated by the connection between the city center and the closest hubs. To this aim, it is useful to implement sustainable services of mobility in order to reduce travel connections by private car or taxi. An increase in train connections, as forecasted in the optimistic scenario, could be a solution to obtain a relevant reduction of CO_2 emissions in Misano Adriatico. Trains could become a valid alternative, also considering that the locality lies along the Adriatic railway line, one of the national infrastructural backbones, and that most of the tourists come from Italy. It is also necessary to increase the attractiveness of the last-mile connections in a sustainable way (such as bike sharing, free shuttle, electric shuttle, free transport luggage for families). Some initiatives are still ongoing, with the contribution of national transport providers: for instance, the recent initiative "*Al mare in treno*" [To the sea by train] (2017) encourages tourists to reach their destination in Riviera Romagnola by sustainable transport modes, providing a reimbursement of the train tickets. However, such measures should be better framed in a more comprehensive set of transport policies capable to provide a real alternative to the use of the private vehicle. On the other hand, the internal mobility of coastal areas may be better handled by the Municipality through the selection of mobility solutions to reduce tourism impacts. Cavallaro et al. (2019) have developed a tool that is able to identify the most virtuous solutions within a set of alternatives, according to the socio-economic, territorial and transport-related characteristics of the coastal destination under analysis. The application of this method to tourist destinations is an opportunity for stakeholders and policy makers to better understand the relation between tourism transport and climate change. This awareness can be useful to develop and adopt appropriate transport policy and measures, which consider both the needs of tourists and inhabitants of tourist cities, reducing the future levels of CO_2 emissions generated by tourism transport without curbing its demand.

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Annex

Annex I. Tourism, transport and climate change in Misano Adriatico.

FIRST STEP – A FORECAST OF FUTURE TOURISM DEMAND ACCORDING TO CLIMATE CHANGE

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. Current values and trend of the last years	Arrivals	90,391	94,580	90,884	94,519	100,399	102,907	109,802	110,239	116,344	120,097	121,292
	Overnight stays	657,262	679,519	654,670	718,268	741,448	717,004	711,263	686,518	720,817	712,491	719,606
	Avg. length	7.3	7.2	7.2	7.6	7.4	7.0	6.5	6.2	6.2	5.9	5.9

		RCP 4.5/SSP4			RCP 8.5/SSP5		
		NA	PSA	SA	NA	PSA	SA
2. Variation rates of the tourism (2035)		−0.70%	−0.87%	−1.05%	−0.57%	−0.69%	−0.82%
3. Estimation of future tourist flows (2035)	Arrivals	120,441	120,235	120,022	120,598	120,453	120,298
	Overnight stays	714,560	713,337	712,074	715,486	714,627	713,710

SECOND STEP – TRANSPORT-RELATED IMPLICATIONS

	Airplane	Train	Private Car	Bus/Urban bus	Feet	Bicycle
4. Current modal share to reach/leave the destination	2%	8%	85%	5%	–	–
5. Current modal share to move within the destination	–	8%	30%	2%	41%	19%
	Airplane	**Train**	**Private Car**	**Bus/Urban bus**	**Feet**	**Bicycle**
6. Distance run by tourists to reach/leave the destination	70.87 km	–	6.46 km	–	–	–
7. Distance run by tourists to move within the destination	–	–	12.90 km	24.00 km	2.00 km	4.00 km

		Urban bus	Private car
8. Coefficient of vehicular filling	**SQ**	22.5	1.3
	INT	30	1.3
	OPT	45	1.3

		Airplane	Train	Private Car	Bus/Urban bus	Feet	Bicycle
9. Future modal share to reach/leave the destination are (2035)	**SQ**	2%	8%	85%	5%	–	–
	INT	2%	20%	70%	8%	–	–
	OPT	1%	40%	50%	9%	–	–
10. Future modal share to move within the destination area (2035)	**SQ**	–	8%	30%	2%	41%	19%
	INT	–	10%	25%	5%	40%	20%
	OPT	–	5%	8%	3%	50%	34%

		RCP 4.5/SSP4			RCP 8.5/SSP5		
		NA	PSA	SA	NA	PSA	SA
11. Total distance run by tourists to reach/leave the destination area (2035)	**SQ**						
	Private car	1,017,452.24	1,015,710.60	1,013,913.02	1,018,770.60	1,017,547.27	1,016,242.95
	Bus	3,458.01	3,452.09	3,445.98	3,462.49	3,458.33	3,453.90
	Airport*	262,654.99	262,205.39	261,74.34	262,995.32	262,679.52	262,342.81
	INT						
	Private car	837,901.84	836,467.55	834,987.20	838,987.55	837,980.10	836,905.96
	Bus	4,149.61	4,142.51	4,135.17	4,154.99	4,150.00	4,144.68
	Airport*	262,654.99	262,205.39	261,741.34	262,995.32	262,679.52	262,342.81
	OPT						
	Private car	598,501.31	3,106.88	3,101.38	599,276.82	598,557.22	597,789.97
	Bus	3,112.21	597,476.82	596,419.43	3,116.24	3,112.50	3,108.51
	Airport*	131,327.49	131,102.69	130,870.67	131,497.66	131,339.76	131,171.41
12. Total distance run by tourists to move within the destination area (2035)	**SQ**						
	Private car	2,127,189.47	2,123,548.22	2,119,790.03	2,129,945.77	2,127,388.16	2,124,661.21
	Urban bus	15,243.94	15,217.85	15,190.92	15,263.69	15,245.37	15,225.82
	INT						
	Private car	1,772,657.89	1,769,623.52	1,766,491.70	1,774,954.81	1,772,823.47	1,770,551.01
	Urban bus	28,582.39	28,533.46	28,482.97	28,619.43	28,585.06	28,548.42
	OPT						
	Private car	567,250.53	566,279.53	565,277.34	567,985.54	567,303.51	566,576.32
	Urban bus	11,432.96	11,413.39	11,393.19	11,447.77	11,434.02	11,419.37

THIRD STEP – CO$_2$ EMISSIONS DUE TO TOURISM TRANSPORT

		2015	2020	2025	2030	2035
13. Unitary CO$_2$ emissions for the different vehicles (2035)	**Motorcycle**	86.01	87.91	87.24	86.56	86.37
	Car	207.78	190.91	169.06	163.86	155.88
	Bus	1,184.47	1,150.36	1,107.51	1,069.7	1038.49

		RCP 4.5/SSP4	RCP 8.5/SSP5
14. Total emissions produced by tourists to reach/leave the destination area (2035) (average between NA, PSA, SA)	**SQ**	202.77 tCO$_2$	203.14 tCO$_2$
	INT	175.55 tCO$_2$	175.87 tCO$_2$
	OPT	116.79 tCO$_2$	117.00 tCO$_2$
		RCP 4.5/SSP4	**RCP 8.5/SSP5**
15. Total emissions produced by tourists to move within the destination area (2035) (average between NA, PSA, SA)	**SQ**	346.81 tCO$_2$	347.43 tCO$_2$
	INT	305.47 tCO$_2$	306.02 tCO$_2$
	OPT	100.12 tCO$_2$	100.30 tCO$_2$

		RCP 4.5/SSP4		RCP 8.5/SSP5	
16. Total emissions produced by tourists (2035) (average between NA, PSA, SA)	**SQ**	549.58 tCO$_2$	0%	550.57 tCO$_2$	0%
	INT	481.02 tCO$_2$	−12%	481.89 tCO$_2$	−12%
	OPT	216.91 tCO$_2$	−61%	217.30 tCO$_2$	−61%

Legend: SQ = Status quo; INT = Intermediate; OPT = Optimistic. NA = No Adaptation strategy; PSA = Partly Successful Adaptation strategy; SA = Successful Adaptation strategy. Airport* = Connection to the airport by private car.