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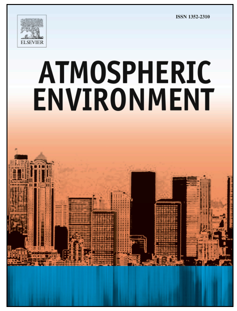

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Estimating emissions from tourism activities

M. A. Russo[1*], H. Relvas[1], C. Gama[1], M. Lopes[1], C. Borrego[1], V. Rodrigues[2], M. Robaina[2], M. Madaleno[2], M. J. Carneiro[2], C. Eusébio[2], A. Monteiro[1]

[1]CESAM and Department of Environment and Planning, University of Aveiro, Portugal

[2] GOVCOPP and Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Portugal

*Corresponding author: michaelarusso@ua.pt | Phone: +351 234370220 | Fax: +351 234 370309

ABSTRACT

Data on atmospheric pollutant emissions from tourism activities was identified as a critical knowledge gap. Building an emissions inventory is a standard procedure that most countries perform for regulatory or research purposes. At a European level, these inventories are developed using the standard Nomenclature for Reporting (NFR sectors). However, none of the NFR are exclusively for tourism or explicitly include it. This paper presents a methodology to estimate the emissions from main touristic activities, focusing on Portugal as a case study. The emissions were distributed using tourism data as a proxy, namely the contribution of tourism to characteristic industries, as well as the nights spent in tourism establishments by non-residents. The proxy data was used to distribute emissions throughout the municipalities, using the national reported emissions data as a starting point. An analysis of the spatial distribution of tourism emissions was performed, highlighting that tourism has a significant impact on atmospheric emissions over specific areas (up to 40.1%), and contributing to areas where air pollution is already an environmental stress factor (urban centres of Porto and Lisbon). While this methodological framework was developed specifically for Portugal, it may be adapted to assess atmospheric pollutant emissions from tourism activities in other regions. Beyond the methodology proposed and the analysis of the results, other alternative methods to estimate emissions from the tourism sector are discussed and suggested.

Key words: air pollution; atmospheric emissions estimate; tourism; economic sectors

1. INTRODUCTION

Recently, tourism has been identified as one of the largest sources of externalities and responsible for the overexploitation of certain environmental resources (Jones and Munday, 2004). Therefore, increased awareness on the issue of tourism has led to it being a central discussion point in the scientific community (Becken et al., 2017; Saenz-de-Miera and Rosselló, 2014). An increase in travel and other services industries has both direct, indirect and induced environmental impacts, causing the same forms of pollution as any other industry: air emissions, noise, solid waste, or even architectural/visual pollution. While extensive research has documented the significant economic impact of such service industries as tourism, little has been written about their effect on environmental quality (Saenz-de-Miera and Rosselló, 2014), specifically on how air pollution will affect tourists' experiences (Law and Cheung, 2007) and visitors' quality of life (Eusébio and Vieira, 2013). The majority of publications related to air quality impacts indicate that air pollution is closely linked to increased premature mortality and hospitalization induced by a number of diseases, with the most prevalent being of respiratory origin (Costa et al., 2014). Compared with residents in polluted areas, tourists are more susceptible to acute effects (Zhang et al., 2015). Among the externalities related to tourism, greenhouse gas (GHG) emissions have become a recurring topic of discussion in literature (Becken and Simmons, 2008), which has also included global warming issues (Becken, 2002). Some regions have registered an exponential growth in tourism, making them an interesting case study for the link between tourism and atmospheric pollution (UNWTO, 2010). There have been studies focusing on the impacts of negative environmental factors on tourism, how it affects visitor perception of atmospheric pollution and its connection to an increased trip dissatisfaction and reduced likelihood of visitors to return (Jarvis et al., 2016). In some cases, during peak air pollution episodes, monthly visitors to certain locations could decrease by more than 25 000 people, as poor air quality discourages some tourism activities (Chen et al., 2017). Heavily polluted areas can also suffer from reduced visibility, which may change tourists' perceptions and decrease enjoyment (Anaman and Looi, 2000; Latif et al., 2018; Law and Cheung, 2007; Zhang et al., 2015).

Even though economic activities have long been related with air pollution, such as energy production (Casler and Blair, 1997) or transport (Peeters et al., 2007), tourism has only recently been investigated as a potential cause for these environmental issues (Saenz-de-Miera and Rosselló, 2014). To date, the majority of studies have focused on translating tourism into CO_2 emissions as a way of quantifying its environmental impact. This has been achieved by gathering data regarding energy consumption and generated waste, and then applying a CO_2 emissions factor to the data (Basarir and Cakir, 2016; Katircioglu et al., 2014; Ng et al., 2016; Rosselló-Batle et al., 2010). For an extensive air quality analysis, detailed emissions for atmospheric pollutants are required for each activity sector. Currently, there are no studies where an emissions inventory was built specifically for tourism.

Nowadays, Portugal is one of the most important tourism worldwide destinations. The international recognition of Portugal as a tourism destination has increased considerably in last years. Consequently, in 2018, this country received the title of World's Leading Destination, in the World Travel Awards. In this country, tourism is one of the most important economic activities. According to the World Travel & Tourism Council (World Travel & Tourism Council, 2018) the total contribution (direct, indirect and induced effects) of travel and tourism to Gross Domestic Product (GDP) was of 17.3%. In terms of employment, 20.4% of the total employment is generated, directly and indirectly, by the tourism industry. Therefore, the main objective of paper is to quantify direct emissions from tourism in each municipality in Portugal, as a first step in developing the data required for an in-depth air quality analysis.

The paper is organized as follows. In section 2, the data used and methodology developed to estimate emissions from tourism are detailed. In section 3, the total emission values and spatial distribution of the emissions throughout the country are presented. Finally, in section 4, the main conclusions are summarised.

2. DATA & METHODS

2.1 Tourism data

To estimate the impact of tourism on air quality, 2015 data from the Portuguese Tourism Satellite Account and Tourism Statistics were used as it is the most up to date data available. First, in order to analyse the direct economic relevance of tourism, the Gross Value Added (GVA) together with the GVA generated by tourism characteristic activities (GVAGT) were used (Table 1)

Table 1. Contribution of tourism characteristic activities to the Gross Value Added of Portugal 2015 (INE, 2019)

Tourism characteristic activities	Total GVA (a) [€/year]	Total GVAGT (b) [€/year]	% GVAGT ((a/b)*100)
Hotels and similar	3 263 946	3 197 032	97.95
Second homes - own account	1 066 429	1 066 429	100.00
Restaurants and similar	5 281 649	2 412 898	45.68
Railway passenger transport	192 157	106 015	55.17
Road passenger transport	966 251	234 460	24.26
Water passenger transport	79 019	57 143	72.32
Air passenger transport	903 142	610 028	67.55
Passenger transport supporting services	2 729 962	68 802	2.52
Passenger transport equipment rental	856 350	320 589	37.44
Travel agencies and similar	269 744	194 205	72.00
Cultural services	434 612	146 067	33.61
Sports and recreational services	602 516	177 293	29.43
Connected activities	3 504 143	233 234	6.66
Non-specific activities	136 688 984	1 633 455	1.20
Total	156 838 904	10 457 651	6.67

In 2015, the GVA generated by tourism characteristic activities represented 6.67% of national GVA. However, an analysis of the different tourism characteristic activities clearly reveals a great variety in the contribution of tourism to the GVA of theses economic activities. For example, in the case of tourism accommodation (hotels and similar), it is responsible for 97.95% of the total GVA generated, while in the case of road passenger transport, tourism only contributes 24.26% to the total GVA.

2.2 Emission data

In the EU, the official reporting of emissions under the UNECE convention (EMEP protocol) adopted the Nomenclature for Reporting (NFR) sectors to develop emissions inventories; these represent different activities for which emissions must be estimated. Each year, member states are required to develop national emissions inventories using this system and update the data in the EMEP database (https://www.emep.int/).

NFR are aggregated into Gridding NFR (GNFR), which are more encompassing sectors that include each NFR related to the same general activity. Currently there are 14 GNFR, and various NFR for each of them in the Portuguese Inventory Report developed by the Portuguese Environmental Agency, with NFR emissions detailed at a municipality level. Since only a few of them are going to be detailed in this paper, for more information regarding which GNFR sectors exist and what they encompass, refer to CEIP 2019.

For an overview of the sectors and their contributions in terms of emissions, Figure 1 displays each of the reported sectors and highlights those that are directly linked with tourism and a focus of this study. The emission data shown below (for 2015) includes the total emission values for each of the reported sectors and their contributions to the national total per studied pollutant. This work will focus on NOx (NO + NO_2) and PM10, since they are two critical pollutants in Portugal that regularly exceed legislated air quality limit values in the country (APA, 2019). Nonetheless, a brief exposition of data regarding SO_2 and CO emissions (critical pollutants for Aviation and Shipping, which are sectors strongly connected to tourism), is also included in section 3.1 and Figure 2.

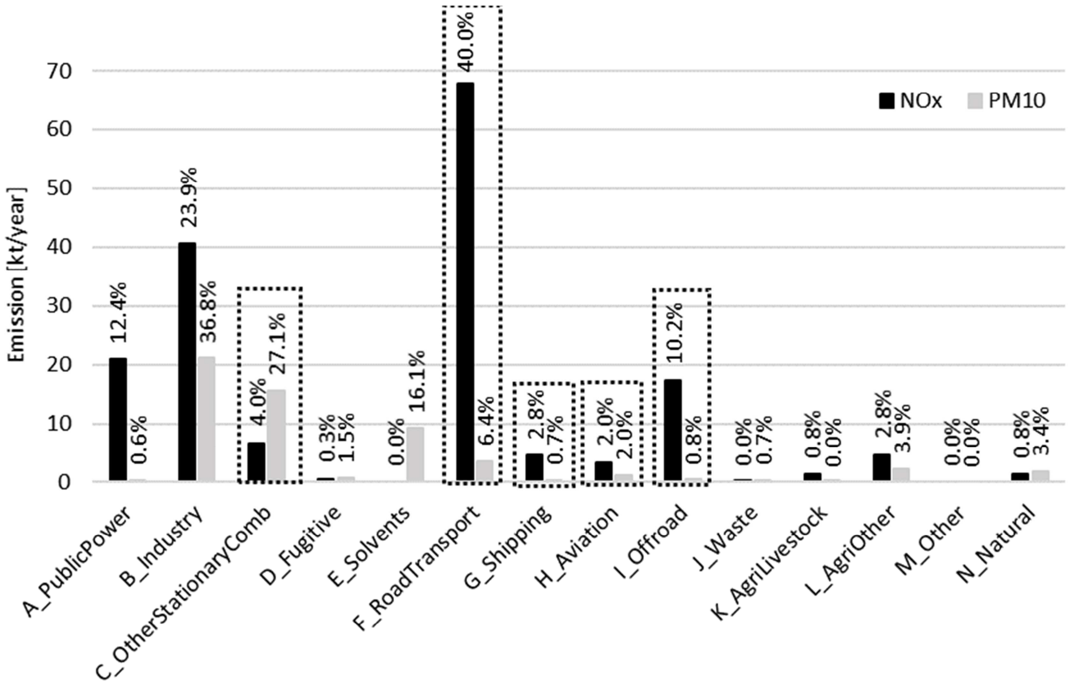


Figure 1. 2015 national emission totals by GNFR sector for NOx (black) and PM10 (grey) in kilo tonnes (kt) per year with highlights for sectors directly linked to tourism (dotted lines).

With a contribution of 40.0%, road transport is the largest source for NOx emissions, followed by the industrial sector with 23.9%. In each of these sectors, the emissions mostly originate from internal combustion engines or industrial combustion processes. This explains why PM10 contributions are lower for these sectors, since combustion is the main source for NOx.

Regarding PM10 emissions, the highest contributors are industry and stationary combustion, with 36.8% and 27.1%, respectively. Stationary combustion accounts for residential combustion emissions, which are a significant contributor to PM10 emissions due to cooking, heating and auxiliary engines that primarily use biomass or fossil fuels (Carvalho et al., 2009). Both aviation and shipping emissions are residual when compared to these other sectors.

None of the tourism activities is directly linked to the national reported emission sectors (NFR), so to estimate the contribution of tourism to total emissions, it was necessary to estimate the share of tourism in each NFR sector. The GNFR/NFR pairs, along with the tourism characteristic industries to which they can be related to, are identified in Table 2.

Table 2. GNFR and NFR sector pairs associated to tourism activities

GNFR	**NFR**	**Corresponding tourism characteristic industry**	**Emissions calculation methodology**
C_OtherStationaryComb	Commercial/	Hotels and similar	Emissions are estimated from fuel

	institutional: Stationary & Residential: Stationary	& Restaurants and similar	sales for each municipality (APA, 2017).
F_RoadTransport	Road transport: Passenger cars & Road transport: Heavy duty vehicles and buses	Road passenger transport	Emissions from road transport were calculated using the COPERT V model (APA, 2017).
I_Offroad	Railways	Railway passenger transport	Emissions estimates are calculated using railway fuel consumption and pollutant emission factors (APA, 2017).
H_Aviation	International aviation LTO & Domestic aviation LTO	Air passenger transport	Emissions are estimated from Landing/Take-off cycles (LTO) (APA, 2017).
G_Shipping	National navigation (shipping)	See section 2.3.1	The STEAM shipping emissions model was used to calculate emissions from ships (Jalkanen et al., 2009; Johansson et al., 2017; Russo et al., 2018).

Since aviation and shipping emissions cannot be distributed throughout the municipalities, the analysis of these sectors focused on national totals. While to understand how emissions from the other sectors are distributed throughout the country, the spatial comparison between total and tourism emissions is shown in the figures included in the results section.

2.3 Tourism emissions estimation

In this section, the methodology applied to each of the sectors is detailed. The objective was to link a tourism indicator with the emissions from each GNFR to estimate tourism emissions in each municipality, using the national reported emissions data as a starting point. Note that the same methodology was used to estimate values for both NOx and PM10 emissions.
To calculate the overall tourism indicator, the total GVA for relevant tourism characteristic industries (listed in Column 3 of Table 2) and the corresponding GVAGT were used to obtain the percentage of tourism in each sector (cross referencing the data from Table 1 and Table 2). As already stated, the data used was for the year 2015, for both emissions and tourism activity data.

2.3.1 National percentage of Tourism in each GNFR

In this section, the methodology for the emissions estimate calculation is detailed. For the stationary combustion, railway transport and aviation emissions, the methodology was straightforward. Using Eq. 1, the percentage of the corresponding NFR (Table 1) was calculated directly.

$$\%TOUR_{GNFR} = \frac{\text{Reported Emission}_{NFR}}{\text{Reported Emission}_{GNFR}} * 100 * \%GVAGT_{GVA} \qquad \text{(Eq. 1)}$$

where,

- $\%TOUR_{GNFR}$ – is the percentage of tourism in GNFR
- $\text{Reported Emission}_{NFR}$– is the emissions reported for the NFR
- $\text{Reported Emission}_{GNFR}$– is the emissions reported for the GNFR
- $\%GVAGT_{GVA}$– is the percentage of tourism in characteristic industries' GVA

For road transport and shipping emissions, additional steps were needed according to the available data for each of these sectors.

First, since passenger transport is divided into two separate NFR, namely Passenger cars and Heavy duty vehicles and buses, in Eq. 1, the $Reported\ Emission_{NFR}$ variable needs to be the sum of passenger cars and buses. To separate heavy duty vehicles and buses, the number of each vehicle class, the average pollutant emission factor per kilometre and the distance travelled for each class, were used to calculate their respective emissions (Eq. 2). The ratio of heavy duty vehicles to buses was found by comparing those values to the reported national total (truck emissions were calculated using the same method as buses).

$$\%Bus_{NFR} = \frac{\sum \text{nº Buses} * D_{\text{travelled bus}} * EF_{bus}}{\text{Total Bus}_{emiss} + \text{Total Heavy Truck}_{emiss}} * 100 \qquad \text{(Eq. 2)}$$

where,

- $\%Bus_{NFR}$ – is the percentage of bus emissions in NFR
- nº Buses – is the number of buses of each vehicle class
- $D_{\text{travelled bus}}$ – is the average distance travelled per bus vehicle class
- EF_{bus} – is the emission factor for each bus vehicle class
- Total Bus_{emiss} – is the total bus emission value
- $\text{Total Heavy Truck}_{emiss}$ – is the total heavy truck emission value

For shipping emissions, two datasets from the STEAM model (Jalkanen et al., 2009) were used. One is the result of a simulation considering all ships as emission sources. The other is a simulation for ships that were considered as entirely dedicated to tourism, cruise ships. Therefore, instead of using an estimate from the GVAGT data (Table 1), cruise ship traffic emissions in an area up to 100 km from the Portuguese coast were compared to total shipping emissions in the same area.

2.3.2 Spatial distribution of tourism emissions

To allocate tourism emissions to each municipality throughout the country, each GNFR was treated differently according to the available proxy data.

First, since stationary combustion is closely linked with lodging establishments, restaurants and similar commercial businesses, the spatial distribution factor used was the nights spent by non-residents in lodging establishments (hotels and similar). This corresponds to an indicator that provides information on how many tourists are in each municipality, which is the equivalent of a percentage of tourism in each municipality for this sector.

$$\text{TOUR Emiss}_{\text{mun stat comb}} = \text{Emissions}_{\text{GNFR}} * \%\ \text{TOUR}_{\text{GNFR}} * \%\ \text{TOUR}_{\text{mun}} \qquad \text{(Eq. 3)}$$

where,

- $\text{TOUR Emiss}_{\text{mun stat comb}}$ – is the stationary combustion tourism emission in the municipality
- $\text{Emissions}_{\text{GNFR}}$ – is the national emissions for GNFR sector
- $\%\text{TOUR}_{\text{GNFR}}$ – is the percentage of tourism in GNFR
- $\%\text{TOUR}_{\text{mun}}$– is the percentage of tourism in the municipality

Second, as there is no data with higher detail to differentiate each of the municipalities regarding road transport, a flat percentage was applied. This assumption has its limitations, since the number of tourists and the type of transportation used vary for each municipality. Whenever possible, proxy data with higher detail should be used for this type of disaggregation, for example, data regarding rental car and taxi services or a description of the car fleet in each municipality.

$$\text{TOUR Emiss}_{\text{mun road}} = \text{Emissions}_{\text{GNFR mun}} * \%\ \text{TOUR}_{\text{GNFR}} \qquad \text{(Eq. 4)}$$

where,

- $\text{TOUR Emiss}_{\text{mun stat comb}}$ – is the road transport tourism emission in the municipality
- $\text{Emissions}_{\text{GNFR mun}}$ – is the GNFR emissions for the municipality
- $\%\text{TOUR}_{\text{GNFR}}$ – is the percentage of tourism in road transport GNFR

Finally, for off-road emissions, using the same equation as road transport, the $\%\text{TOUR}_{\text{GNFR}}$ for rail passengers was used to calculate the rail emissions in each region. If the $\%\text{TOUR}_{\text{mun}}$ is 0% or if the municipality does not have rail infrastructures, the emissions in this municipality are zero.

3. TOURISM EMISSIONS

In this section, emissions for C_OtherStationaryComb, F_RoadTransport and I_Offroad are compared in terms of the contribution of tourism to each of these sectors. A brief analysis of total values is presented first, and then the spatial distribution of both total and tourism emissions throughout the municipalities in Portugal is analysed and discussed.

3.1 Total emissions

Figure 2 shows total and tourism emission values for the three studied sectors, C_OtherStationaryComb, F_RoadTransport, I_Offroad, H_Aviation and G_Shipping for NOx, PM10, CO and SO_2.

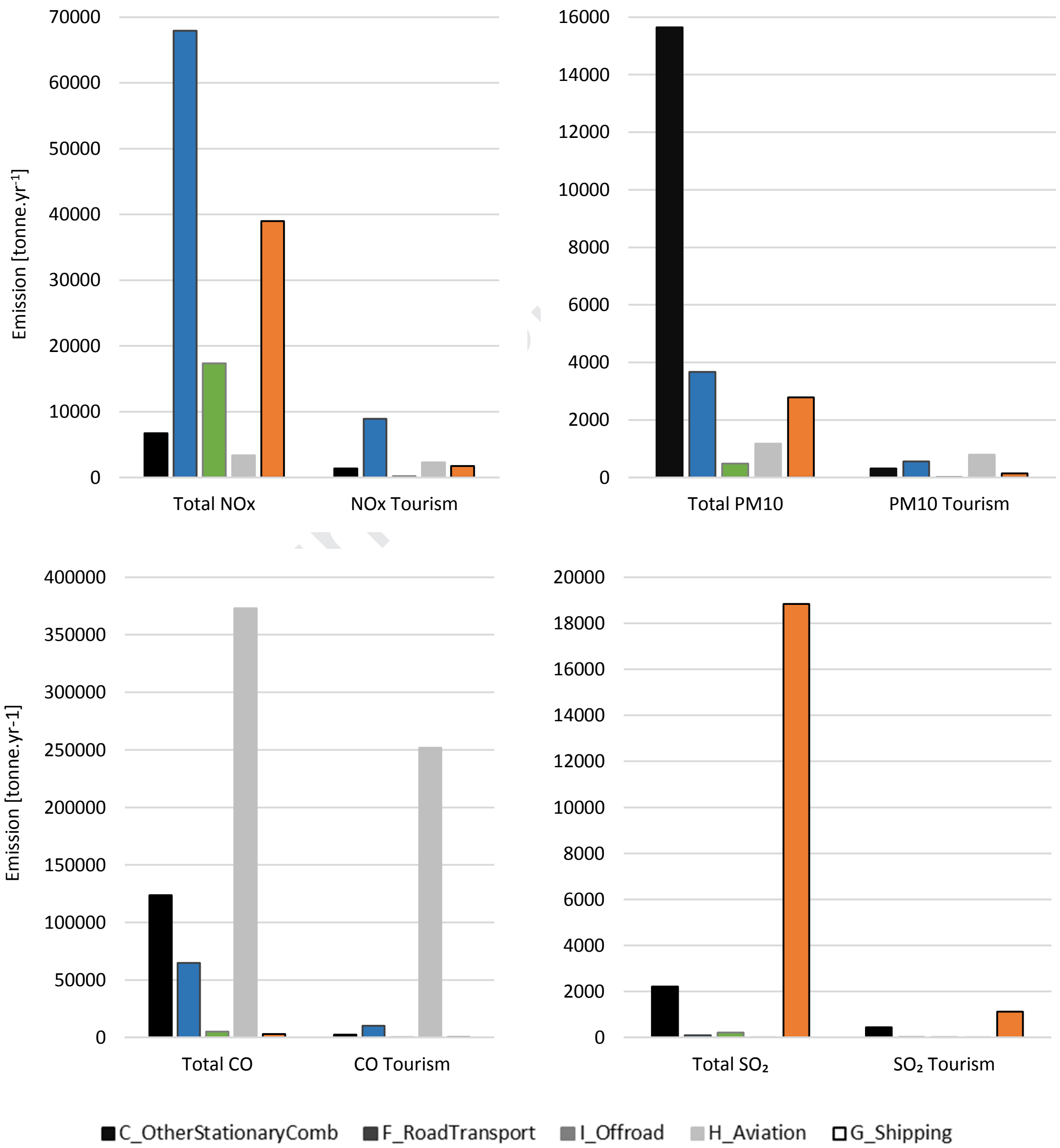


Figure 2. Total and tourism emissions for C_OtherStationaryComb, F_RoadTransport and I_Offroad, H_Aviation and G_Shipping in tonnes per year (NOx, PM10, CO and SO_2).

As seen in section 2.2, F_RoadTransport is the largest contributor to total NOx emissions of the studied sectors (≈ 67.1 kt), while C_OtherStationaryComb is responsible for the highest PM10 emission total (≈ 15.6 kt), with tourism having a non-negligible contribution to both of them. For the studied sectors, especially for the aviation sector, tourism represents 67.6% of activities, which is reflected in the emission values of this sector. Relevant sectors for NOx emissions are C_OtherStationaryComb (20.6%) and F_RoadTransport (13.1%). For PM10, other than aviation, there is a significant contribution of tourism characteristic industries to emissions in the F_RoadTransport sector, accounting for 15.1% of total emissions. In the remaining sector and emission pairs, the contributions only range from 1.1% to 5%. Most of the tourism CO emissions are from H_Aviation, followed by F_RoadTransport and C_OtherStationaryComb, however, overall values (except aviation) of this pollutant are low. Similarly, SO_2 emissions are almost entirely due to G_Shipping, which is expected since this sector is the main source of sulphur emissions. Nonetheless, there is still some noticeable contribution to these emissions from C_OtherStationaryComb, while others are also quite low.

Is it of note that the total emissions from shipping in Figure 2 are higher than the national reported data from Figure 1. This is due to the national totals only accounting for national maritime navigation, yielding significantly lower results than the methodology applied in the STEAM model, which provides more accurate results (as explained in Russo et al., 2018).

3.2 Spatial analysis

The spatial distribution obtained with the described methodology of total and tourism emissions can provide valuable insight into possible hotspots present in the country, and where future strategies regarding tourism characteristic activities can be most effective in reducing their air pollutant emissions. As previously explained, considering the available data, the spatial distribution focused on the stationary combustion, road transport and offroad emissions sector.

Figure 4 shows the C_OtherStationaryComb sector emissions (total and tourism) for NOx and PM10, in each municipality. Additionally, the percentage of tourism in each municipality calculated above is also shown. The stationary combustion GNFR is divided into three primary NFR, namely residential, commercial/institutional and agriculture/forestry/fishing stationary emissions. As these emissions are closely linked with population, it was expected that their distribution be mainly throughout coastal areas and in some of the more populated inland cities.

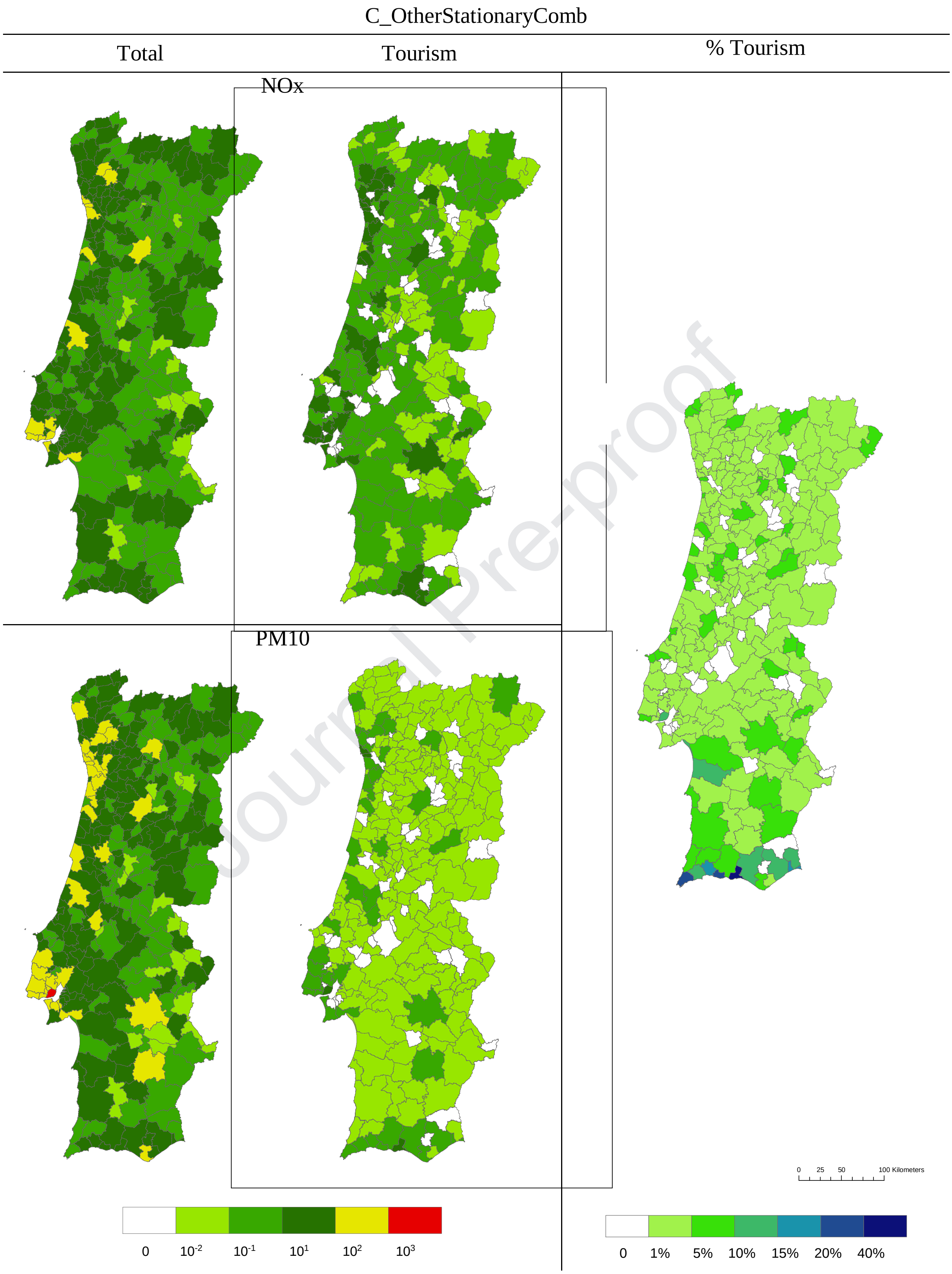


Figure 3. Total and tourism C_OtherStationaryComb emissions for each municipality in tonne per year (NOx above, PM10 below), and percentage of tourism in each municipality.

Higher values of tourism emissions are in coastal cities and major urban areas, with most of the inland regions in the country having very low tourism or no available data to be allocated to the municipalities. The spatial distribution of tourism emissions also reflects the contribution of commercial/institutional combustion to total GNFR emissions. This is due to the type of combustion related to emission sources in tourism activities (higher influence of services and restaurants) in this NFR having a higher contribution regarding NOx emissions compared to PM10 to overall emissions. Lisbon shows up as the largest hotspot for PM emissions with 1132 tonnes of total PM10 emitted each year, contrasted by 72 tonnes due to tourism activities, which accounts for 6.3% of the total value. Regarding NOx, total emission values in Lisbon are the highest, with a contribution of tourism to total NOx emissions is 24.1% (89 tonnes from tourism compared to 369 tonnes total). This is to be expected because it is the most populated city in the country. However, in terms of percentage of tourism, the municipality with the highest contribution of tourism to total emissions is Albufeira in the southern coast (40.1% for NOx and 35.8% for PM10). Tourism contributes directly to this sector linking to the commercial and institutional stationary emissions, which includes restaurants, hotels and similar establishments.

Figure 4 shows the spatial distribution for the F_RoadTransport sector. Road transport is divided into various types of vehicles according to their utility, such as passenger transport, services and heavy vehicles. The connection of this sector to tourism is related to the number of passengers transported, and the most critical pollutant for this sector is NOx.

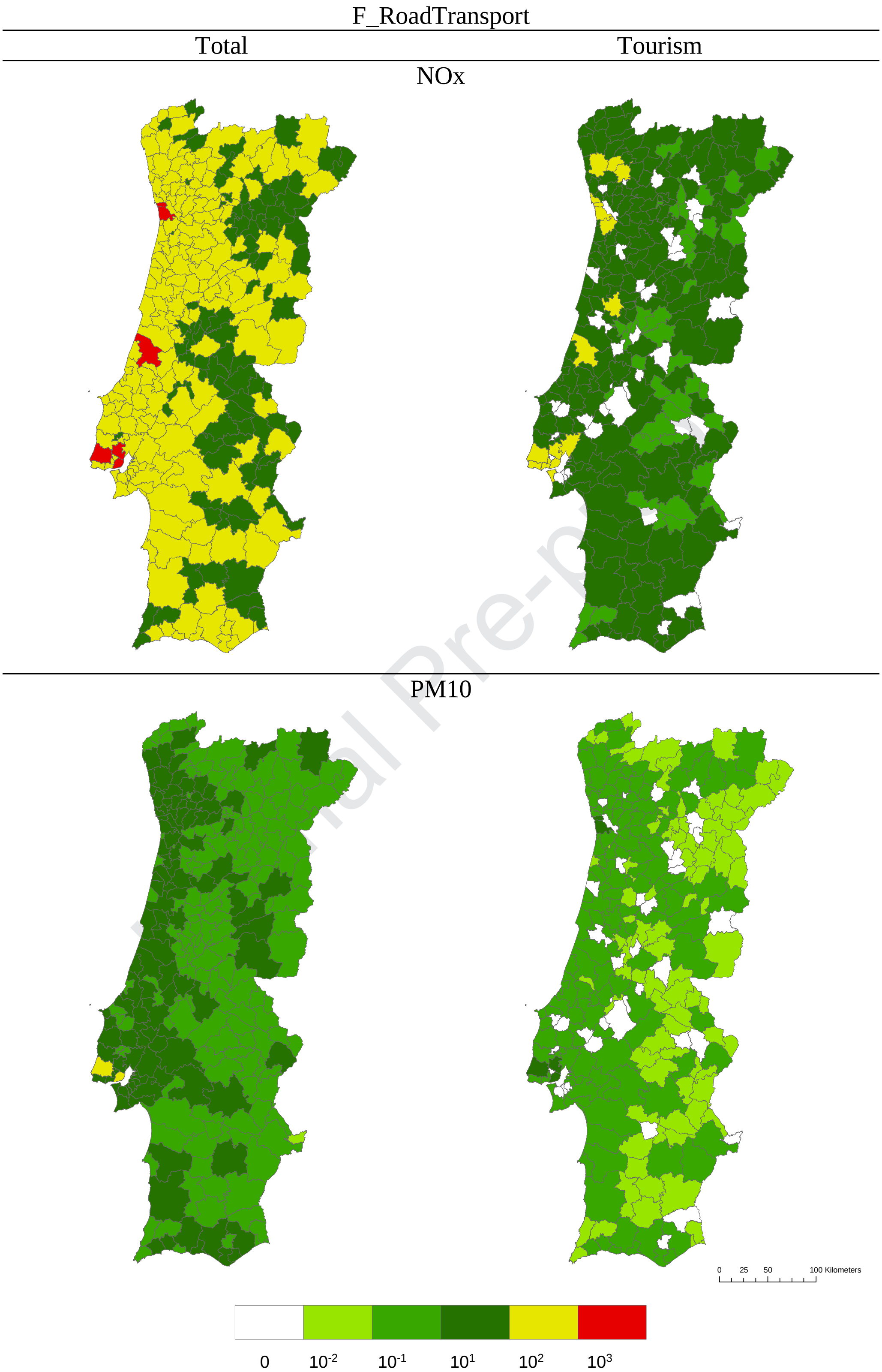


Figure 4. Total and tourism F_RoadTransport emissions for each municipality in tonne per year (NOx above, PM10 below).

In this case, the focus on coastal areas is even more evident, as larger city centres and urbanized areas with a large amount of traffic are mostly near the coast. A few more hotspots for these emissions are noticeable, mainly in and around the largest cities, such as Porto in the north (1079 tonnes NOx), Leiria in the centre (1011 tonnes NOx) and the Lisbon metropolitan area (2311 tonnes of NOx for Lisbon alone). As described in the methodology, a flat percentage is applied in each municipality, therefore the percentage of tourism is always the same (14.4% for NOx and 16.7% for PM10).

After calculating tourism emissions, major metropolitan areas are still an emission hotspot for both pollutants, especially near Porto (156 tonnes of NOx) and Lisbon (334 tonnes of NOx), for both pollutants. Contrary to stationary combustion emissions, the distribution of tourism emissions is not entirely focused on coastal cities (although they are still emission hotspots), with some inland municipalities still reaching over 100 tonnes of NOx emitted per year.

Finally, Figure 5 shows off-road emissions, which include agriculture, forestry and fishing activities (vehicles and machinery emissions), and railways. The former has no direct contribution to tourism, although it does have activities that can be indirectly related to tourism, while the later can be directly linked to tourism using data regarding transported passengers and their activities.

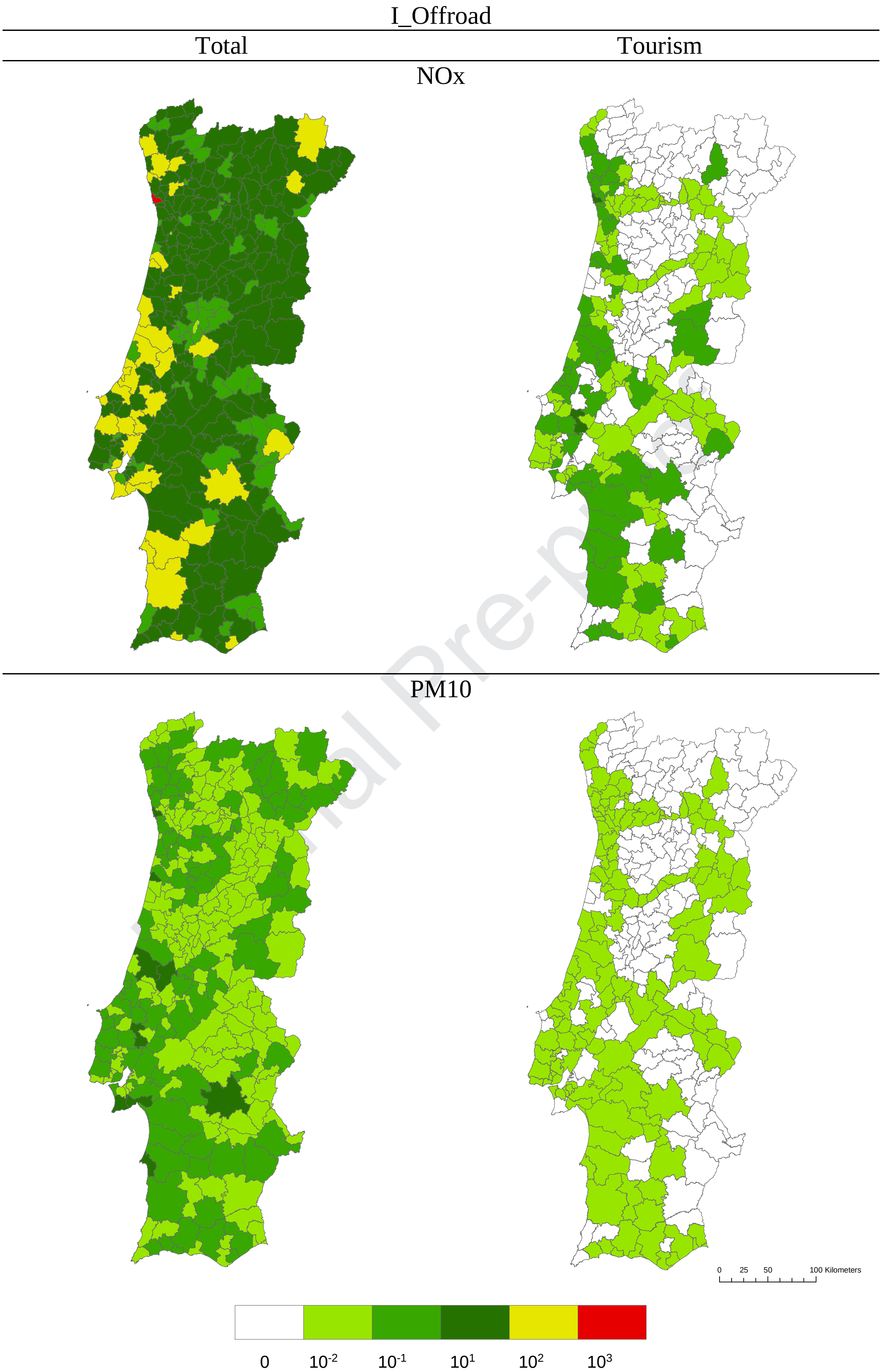


Figure 5. Total and tourism I_Offroad emissions for each municipality in tonne per year (NOx above, PM10 below).

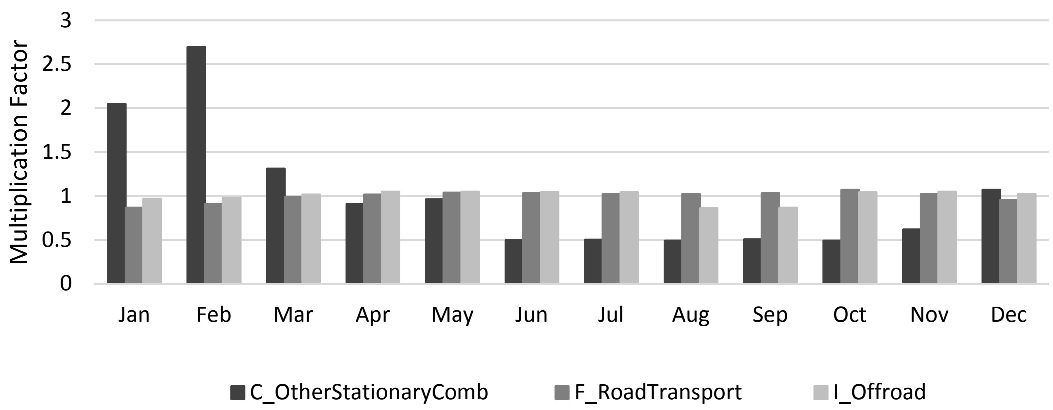
Although still prominent, the spatial distribution of these emissions is less focused on coastal areas, with many inland cities having high NOx emission values. Generally, the vehicles and machinery used in this sector are powered by internal combustion engines and therefore, are similar to road transport. The hotspot for this sector is Matosinhos in the north with 20 tonnes of NOx (1238 tonnes total) and 0.5 tonnes of PM10 (33 tonnes total) emitted due to tourism per year. The total emissions value is in part due to the presence of the Port of Leixões Logistics Platform and associated railway infrastructure. Here the emissions for tourism are overestimated due to other high-emission sources; however, it is still a prominent region for tourism activities.

Railway activities have a low contribution to off-road emissions since most of the trains in Portugal are electric, which is why the largest contribution of this sector to atmospheric pollution could be from indirect impacts related to energy production.

3.3 Time variation

In this section, the time variation of each of the studied sectors and tourism in Portuguese municipalities is investigated. This information is fundamental when using emissions resulting from the methodology suggested in this study, as it focuses on distributing annual emission values for each of the pollutant which has no intrinsic time variation.

Specific Portuguese time profiles used for the GNFR sectors (SNAP 2, 7 and 8) were collected (Menut et al., 2013) and compared with time proxy data related to tourism activity (based on the average of nights spent by non-residents in Portuguese municipalities). Figure 6 shows the studied GNFR sectors and the tourism activity monthly profiles.



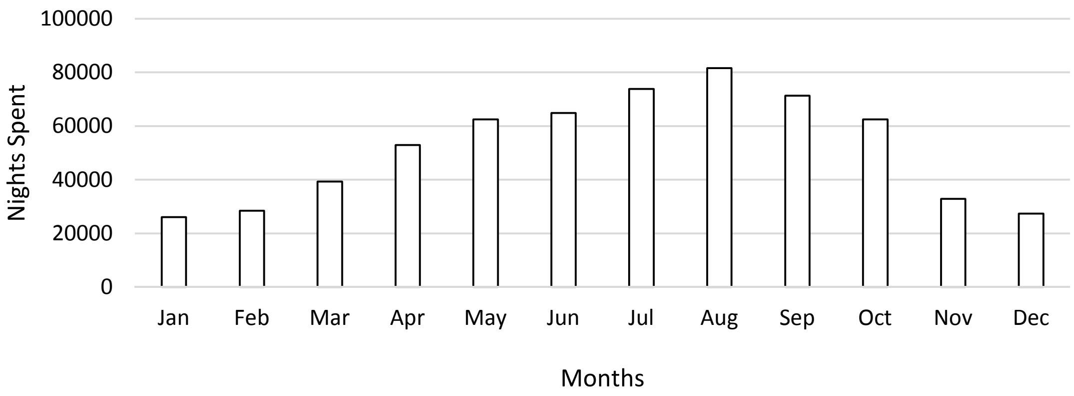


Figure 6. Specific Portuguese monthly profiles used for the GNFR studied sectors (top) and tourism data activity monthly profiles (bottom).

As indicated in the figure, the time profiles are very distinct and none of the emission sectors reflect the temporal evolution of tourism. For example, there is a significant variation from winter to summer in the C_OtherStationaryComb sector, while road and offroad emissions present almost no variation throughout the year. When using these emissions for air quality simulations, or whenever emissions are input data, these specific time profiles for the tourism sector should be taken into account.

4. SUMMARY AND CONCLUSIONS

In order to evaluate the contribution of the tourism sector on the atmospheric pollutants, a methodology to estimate emissions from tourism activities is proposed, using Portugal as a case study. The NFR sectors, recommended for emissions inventories reporting at EU level, were used, in particular the ones that have a direct link to tourism: road and off-road transport, stationary combustion, aviation and shipping activities. The Gross Added Value for characteristic tourism industries was used as proxy data to estimate the contribution of tourism to each economic activity (and corresponding NFR sector). Then, using a specific methodology to each sector the total emissions and their distribution throughout the municipalities in the country was achieved. The analysis of the total emissions suggests that tourism activity is responsible for maximums of 67.6% (both NOx and PM10 for aviation), followed by 20.6% (for NOx in the stationary combustion sector) and 15.1% (for PM10 in the transport sector) of total emissions. The analysis of the spatial distribution of tourism emissions highlighted that tourism has a significant impact on atmospheric emissions over specific areas (up to 40.1%) and contributing to areas where air pollution is already an environmental stress factor (urban centres of Porto and Lisbon). While this methodological framework was developed specifically for Portugal (including the time variations shown, which are specifically for Portugal), the case study may be relevant for many other areas in Europe.

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- Tourism emissions has a maximum contribution of 67.6% (in the aviation sector)
- Spatial distribution shows significant impact on coastal regions
- Tourism adds to areas where pollution is already an environmental stress factor
- The methodological framework presented is easily applied to other countries

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: