CALCULATION OF CARBON EMISSIONS AT THE GREEK AIRSPACE

Psaraki Voula

Pagoni Ioanna

Faculty of Civil Engineering, National Technical University of Athens, 5 Iroon Polytechniou Street, Zografou Campus, 15773 Athens, Greece

**Corresponding author, Tel.: +30 2107721204; E-mail address: vpsaraki@civil.ntua.gr (V. Psaraki).*

ABSTRACT

This paper is concerned with the development of a methodology which calculates aircraft carbon emissions based on traffic data. Carbon emissions are calculated across several dimensions to provide input to relevant policy considerations. These include the climb-cruise-descent cycle, the Landing/Take-off (LTO) cycle at the airports, domestic, international and over-flights, carbon emissions per passenger-km. The fuel consumption database EMEP/CORINAIR is employed (EEA, 2006). Emission forecasts for the period 2008-2030 are estimated. Total CO_2 emissions are presently estimated to be 4.5 million tones and are expected to double in size by 2030. CO_2 emissions at Greek airports contribute a 10% share. A ranking list classification of airports and domestic routes in terms of carbon emissions are generated. Potential applications of the proposed study include the comparative “green” assessment of transport modes as well the quantification of the environmental impact of tourism.

Key words: aviation carbon emissions; database EMEP/CORINAIR; fuel consumption; Landing/Take-off cycle; emissions per passenger-kilometer; Greek airspace.

INTRODUCTION

Air transportation is a key economic sector, supporting economic development and growth, and facilitating mobility. At the same time, aviation is a growing contributor to greenhouse gas emissions. Current estimates of aviation’s contribution to total emissions of greenhouse gases range from 2-3% (IPCC, 2007). The aviation contribution is expected to rise significantly in the future.

The greenhouse gases emitted by aircraft are carbon dioxide (CO_2) and water vapor (H_2O) (IPCC, 1999). These gases enforce the greenhouse effect and could cause climate change. Evidence of climate change is growing, including observations of rising temperature and sea levels as well as an increasing frequency of severe storms and floods. Carbon dioxide is the most important greenhouse gas and is projected to account for around 70% of radiative forcing of climate by the end of the century (IPCC, 2001a). As a result, various carbon calculators have been developed by carbon offset companies, institutions, governments and airlines in order to assess the climate impact of aviation. The calculations are based on a comprehensive carbon footprint of the flight operations specific to routes, types of aircraft utilized, load factors and actual fuel consumption (Jardine, 2009).

This paper deals with the development of a methodology which calculates aircraft carbon emissions based on traffic data including both domestic and international flights as well as over-flights. The Greek airspace is considered as case study. The traffic data include the number and type of aircraft, load factors and the distance flown at the Greek airspace on each route, which all depend on day-time, date and route. The calculation of CO_2 emissions is based on fuel consumption, for which the database EMEP/CORINAIR is employed (EEA, 2006). The distribution of carbon emissions along several dimensions is then determined to provide input to relevant policy considerations. First carbon emissions during the climb-cruise-descent cycle in the airspace are calculated together with its domestic, international and over-flight components. Domestic CO_2 emissions are split into the major routes and a ranked list of pollutant routes is identified showing the importance of the load factor. Emissions expressed in terms of passenger - km are also given to enable comparative assessment with other transport modes. Then attention is focused on airports which form strong localized emission sources. CO_2 emissions produced during the LTO cycle are determined and a ranking list of airports on the basis of CO_2 emissions performance is given. International flights are given special consideration due to their direct link to tourism. The carbon emissions at Greek Airports constitute 10% of the total CO_2 emissions. Total CO_2 emissions are presently estimated to be 4.5 million tones and are expected to double in size by 2030.

CALCULATION OF AIRCRAFT CARBON EMISSIONS

The methodology developed in this paper calculates aircraft carbon emissions using traffic data that include domestic and international flights and over-flights. The methodology calculates carbon emissions during the climb-cruise-descent cycle and during the Landing/Take-off (LTO) cycle at the airports.

The Landing/Take-off (LTO) cycle includes all activities near the airport that take place below the altitude of 3000 feet. This includes taxi-in and out, take-off, climb-out, and approach-landing (Fig.1). Cruise is defined as all activities that take place at altitudes above 3000 feet. No upper limit of altitude is given. Cruise includes climb from the end of climb-out in the LTO cycle to cruise altitude, cruise, and descent from cruise altitudes to the start of LTO operations of landing (EEA, 2006).

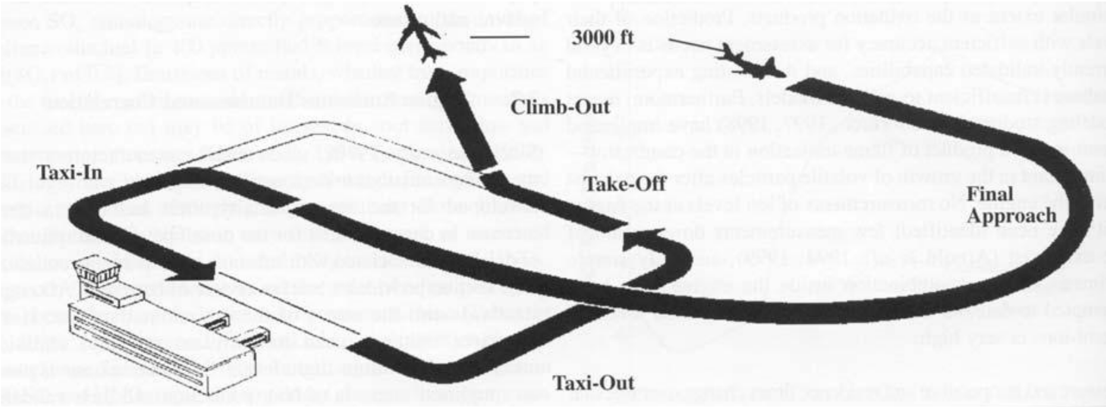

Figure 1 - A typical LTO cycle (Source: Kesgin, 2002).

The calculation of carbon emissions is based on the fuel consumption of aircraft. The fuel consumption is calculated using the detailed (Tier 3) methodology of the EMEP/CORINAIR database (EEA, 2006; 2009). The estimates are made for two classes of flying modes, that of LTO cycle and that of cruise[1].
The input data include the number of flights, the type of aircraft, the load factors and the distance flown on each route. These depend on day-time, date and route. The methodology is developed through the next steps. First, we classify the aircraft within a representative set of generic aircraft types for which fuel consumption data is available at the EMEP/CORINAIR database. Then, distance flown is calculated using the origin and destination airports. These results are used in order to apply the database and estimate fuel and CO_2 emissions.

On the basis of the above, the formula for the calculation of emissions has the form:

$$\textit{Tones } CO_2 = \textit{conversion factor} * \textit{fuel consumed}$$

where conversion factor = 3.157 tn CO_2 per 1 tn fuel.

The carbon emissions at Greek airports are calculated more precisely during the five operation modes: taxi-out, take-off, climb-out, approach landing and taxi-in. Emissions are estimated for all types of aircraft in use that are registered by LTO movements in the airports of Greece. It is noted that emissions from start up of engines are not included in the LTO cycle because there is currently little information available for estimation. Furthermore, emissions from other sources of the airport, such as ground support equipment, auxiliary power units, stationary sources and on-road vehicles, are not included in the estimation developed in this paper.

[1] The assumption is that aircraft emissions up to 3,000 ft settle down and end up as contributions to ambient emission concentrations at ground level.

AIR TRAFFIC AT THE GREEK AIRSPACE

The Greek airport system consists of 40 active civilian airports 21 of which are coordinated, 13 are schedules facilitated and 6 are non-coordinated. 28 serve domestic and international flights. Most of these airports serve military flights as well. The majority of the coordinated airports is situated in the islands and is being coordinated only during the summer scheduling period, when the tourist flows reach their peak. During winter, many airports cease to operate as coordinated airports. They handle almost exclusively domestic flights and accommodate much lower traffic levels than those they have been planned for. The traffic in July and August accounts for 30-40% of the annual traffic in almost all airports. Most of the summer traffic is for vacation purposes and is served by charter flights. Recently, low-cost carriers have also entered these markets.

The airports with the highest traffic volumes are the airports of Athens, Thessalonica, Heraklion, Rhodes, Corfu, Kos, Chania, Zakinthos and Santorine (HCAA, 2008). The remaining airports serve much lower traffic volumes.

Table 1 shows the aircraft movements served by the Athens FIR airspace in 2008.

Table 1 - Aircraft movements in 2008. (Source: HCAA, 2008).

	Domestic	International	Total
Greek	104,346	229,433	335,313
Over-flights	-	271,938	271,938
Total	104,346	501,371	605,717

The monthly distribution of aircraft movements in Athens FIR in 2008 is shown in Figure 2. Significant increases in traffic volumes occur during summer period, particularly for international flights. Tourist demand is the driving force for the summer peak.

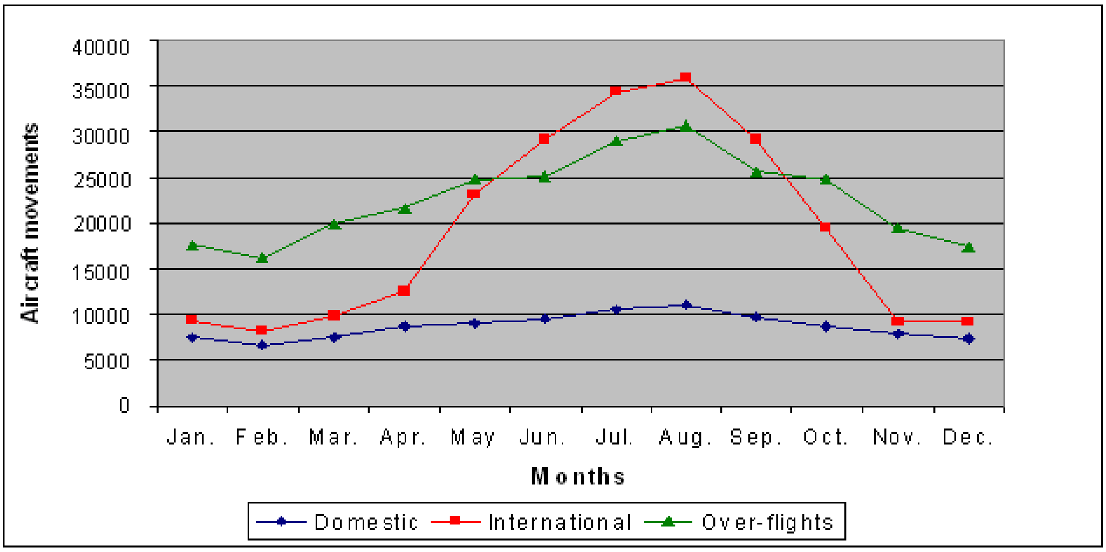

Figure 2 - Monthly distribution of aircraft movements in 2008.

The system of Greek airports is served by a wide range of aircraft types. Type shares are depicted in Figure 3. B737's captures 38% of the aircraft movements, while A320 hold 24% of the total traffic.

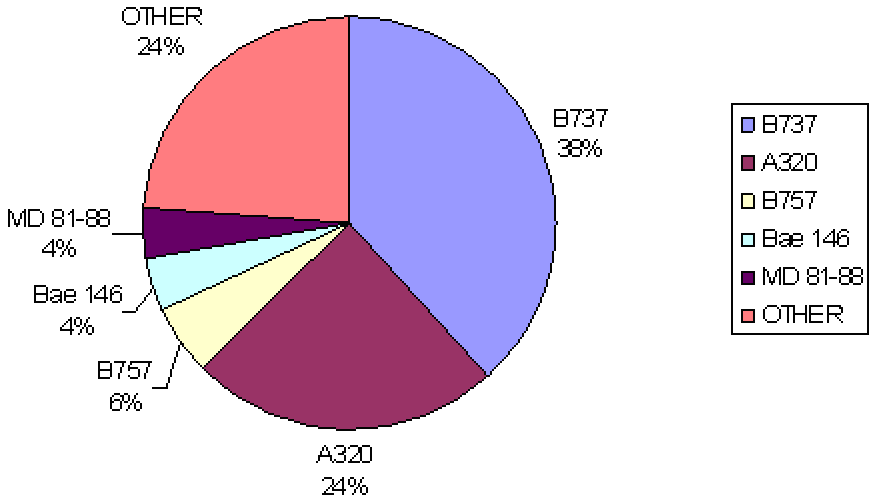

Figure 3 - Distribution of aircraft types in Greek airports.

CARBON EMISSIONS FORECASTS IN THE GREEK AIRSPACE

First, carbon emissions in the Greek airspace for the baseline year (2008) were calculated by the method outlined in section 2. The results are summarized in Table 2.

Table 2 - CO_2 emissions (in tones) at the Greek airspace in 2008.

	WINTER			**SUMMER**			**Total**
	Domestic	International	Over-flights	Domestic	International	Over-flights	
LTO	54,049	55,220	-	109,907	262,153	-	**481,329**
Cruise	83,420	206,488	860,302	160,033	1,063,895	1,721,345	**4,095,485**
Total	137,469	261,708	860,302	269,940	1,326,048	1,721,345	**4,576,814**

The figures of table 2 show total CO_2 emissions and their breakdown into LTO, cruising, winter and summer segments. Cruising covers the part of the trip over the Greek airspace. 500,000 tones per year of CO_2 are emitted at Greek Airports during LTO cycle. Emissions caused by international flights are 4 times those of domestic flights.

Total CO_2 emissions were estimated to be 4,500,000 tones in 2008. Figure 4 shows that over-flights produce a considerable fraction of total emissions at the Greek airspace (56%), while international and domestic flights produce 35% and 9% of total emissions respectively.

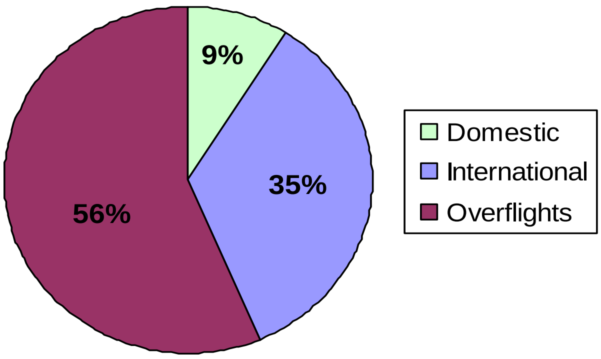

Figure 4 - Distribution of carbon emissions.

Next the evolution of CO_2 emissions in the time period 2008-2030 is considered. Forecasts are obtained using the four scenarios applied by EUROCONTROL regarding the future developments of the aviation industry (EUROCONTROL, 2008). These estimates take into account the introduction of aviation in the European Emissions Trading Scheme in 2012 and the development of new types of aircraft in 2030 which have more seats per airframe than now. However, other factors such as fuel efficiency improvements and changes in load factors are not included. These trends are based on a pre-crisis formula, so the actual evolution may be different from the estimated one. According to this analysis, the most likely outcomes for the average annual air traffic growth are:

3%	conservative estimate
3.7%	average estimate
4.4%	maximum estimate

Adoption of the above values leads to the CO_2 emission trajectories plotted in Figure 5.

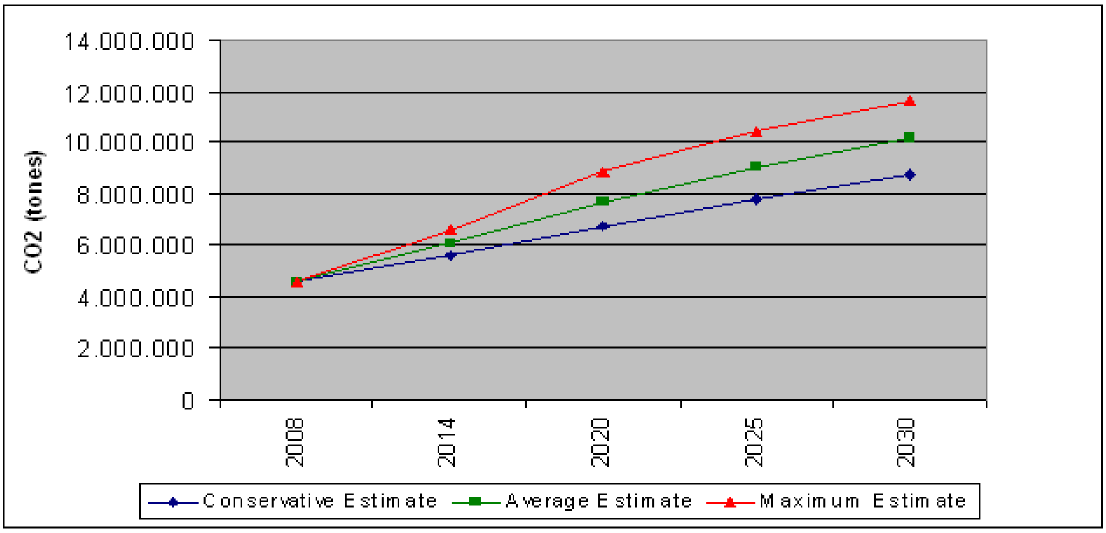

Figure 5 - Carbon emissions forecasts at the Greek airspace during 2008-2030.

Carbon emissions for domestic routes at the Greek airspace are also calculated. Table 3 presents carbon emissions for the most popular routes in Greece. It is noted that the route Athens-Thessaloniki has the largest contribution in emissions of domestic flights, with a percentage of 16%. As expected, the three main routes from Athens to Thessaloniki, Heraklion and Rhodes receive the bulk of carbon emissions (Fig 6).

Table 3 - CO_2 emissions for different domestic routes.

ROUTES	CO_2 emissions (tones)			
	WINTER	SUMMER	TOTAL	%
Athens-Thessaloniki	34,949	30,465	65,414	16%
Athens-Heraklion	23,833	26,721	50,554	12%
Athens-Rhodes	10,212	24,797	35,009	9%
Athens-Corfu	8,323	13,171	21,494	5%
Athens-Santorini	1,667	13,372	15,039	4%
Heraklion-Thessaloniki	3,825	5,780	9,604	2%
Rhodes-Thessaloniki	1,549	7,579	9,128	2%
Chania-Thessaloniki	1,271	3,139	4,410	1%

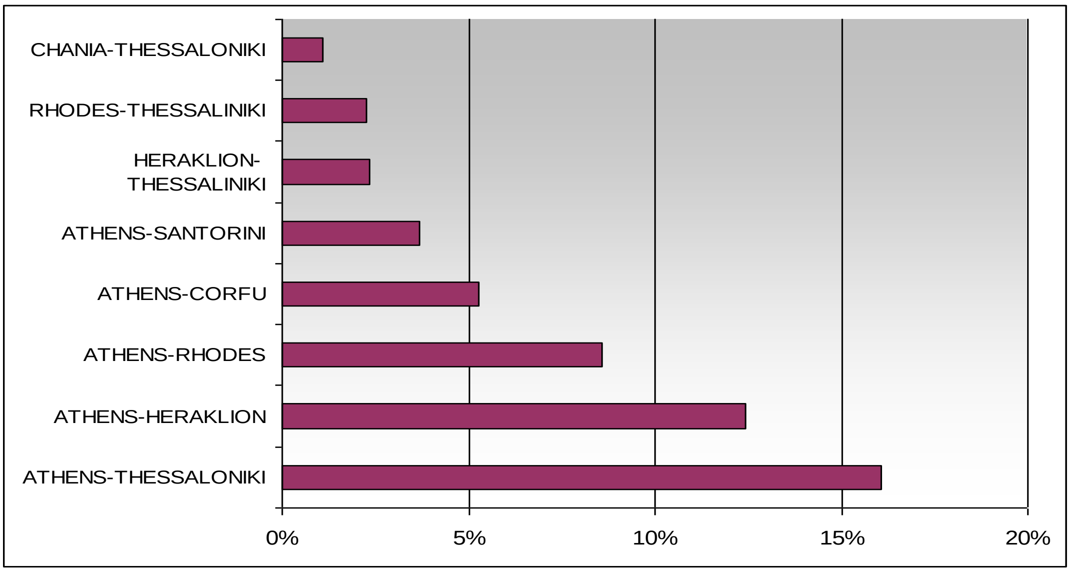

Figure 6 - Distribution of total carbon emissions along domestic routes

The seat occupancy rate of passengers on board has a direct impact on fuel consumption per passenger. Aircraft use less fuel per passenger, the more passengers are on board. The methodology developed in this paper assesses the passenger's aviation emissions for domestic flights in Greece. The additional input data include load factors which depend on date, day-time and route. Load factors for domestic flights were recorded by Hellenic Civil Aviation Authority. For example, it is calculated that 198.3 gr/passenger-km are emitted during the route Athens-Thessaloniki. Figure 7 shows the carbon emissions per passenger-km for several domestic routes as a function of load factor. We observe that the greater the load factor is, the less the emissions per passenger-km are emitted (see route Athens-Rhodes).

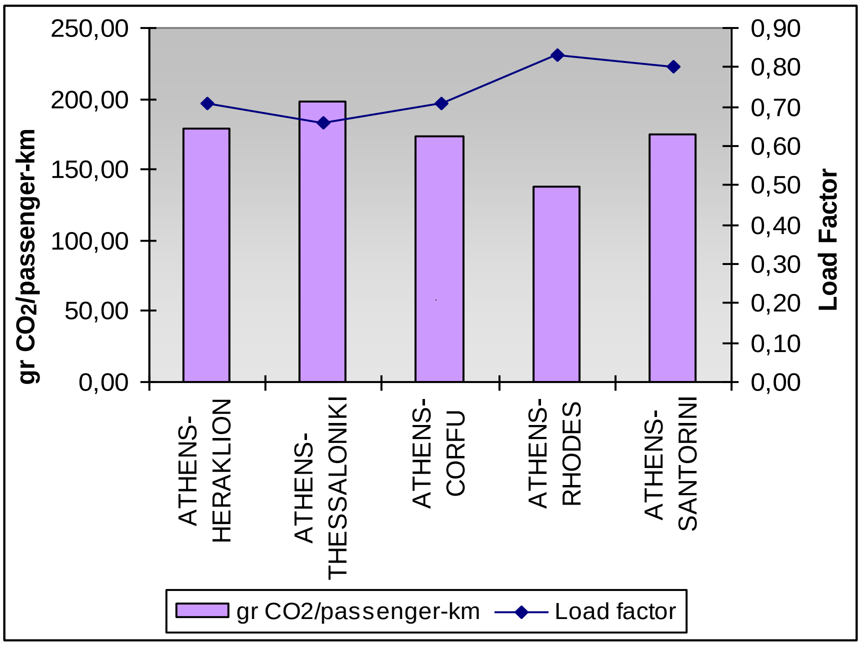

Figure 7 - Carbon emissions per passenger-km for several domestic routes as a function of load factor.

CARBON EMISSIONS AT THE GREEK AIRPORTS

Carbon emissions at airports have a strong localized impact and in addition they produce a large fraction of total emissions. Hence they require special consideration. It is estimated that 38% of the total carbon emissions generated by domestic flights are emitted at the wide area of airports during Landing/Take-off cycle (LTO).

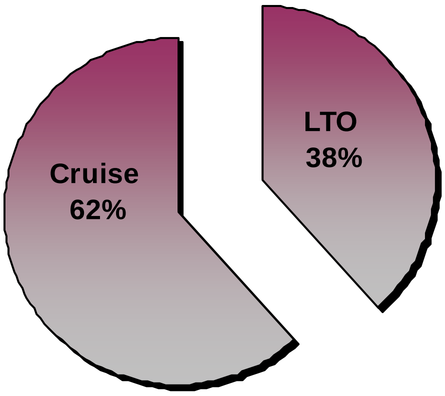

Figure 8 - Carbon Emissions at Greek airports (LTO) and during cruising.

The carbon emissions at Greek airports are calculated during the five operation modes: taxi-out, take-off, climb-out, approach landing and taxi-in.

Table 4 shows domestic, international and total CO_2 emissions related to LTO cycles for the major Greek airports. The Athens International Airport, which acts as the hub airport for most domestic and international flights, has the largest contribution in emissions (37%) as the last column indicates.

Table 4 - Carbon emissions in major Greek airports in 2008.

CO_2 emissions (tones) in 2008				
GREEK AIRPORTS	**DOMESTIC FLIGHTS**	**INTERNATIONAL FLIGHTS**	**TOTAL**	**%**
ATHENS	67,316	109,265	176,582	37%
HERAKLION	14,696	44,756	59,452	12%
THESSALONIKI	19,573	25,323	44,896	9%
RHODES	9,986	28,059	38,045	8%
KOS	4,900	15,351	20,251	4%
CORFU	4,828	13,323	18,151	4%
CHANIA	6,247	11,892	18,139	4%
SANTORINI	4,999	4,824	9,823	2%
ZAKYNTHOS	539	8,079	8,618	1.8%
MYKONOS	4,401	3,177	7,578	1.6%
MYTILENE	4,290	1,265	5,555	1.2%

International flights form the most significant source of pollution in the majority of Greek airports.
The above findings can be used to obtain a first order estimate of the negative environmental externalities caused by tourist as international flights serve mostly tourist traffic.

CONCLUSIONS

Greek airports are of great national importance. They constitute a major accessibility mode for the Greek islands and serve high volumes of tourism, a major sector of the Greek economy. On the other hand, emissions of aviation are a critical negative externality with an increasing future impact. They affect both the communities around Greek airports and the entire Greek airspace with adverse effect on climate change. Total CO_2 emissions at the Greek airspace were estimated to be approximately 4.5 millions of tones in 2008. Over-flights produce a considerable fraction of total emissions at the Greek airspace (56%). Furthermore, carbon emissions are expected to double by 2030. For example, it is calculated that 198.3 gr/passenger-km are emitted during the route Athens-Thessaloniki.
The proposed method estimates carbon emissions at Greek airports where a large fraction of total emissions is produced. Greek airports contribute to total emissions producing 500,000 tones in 2008. The Athens International airport, which provides connections to most domestic destinations and serves a major share of international flights, ranks first in pollutant production (37%).
The results of this study provide quantifiable indicators of the environmental impact of tourist air travel. Furthermore, the calculation of the passenger’s aviation emissions for domestic flights can be used for a comparative assessment of the different modes of transportation (ship, train and road vehicle) in terms of environmental impact. Finally, the calculation of carbon emissions at the Greek airspace could be used in the context of the European Emissions Trading Scheme. According to this scheme,

2010 has been defined as base-year when aircraft operators flying to and from EU are required to monitor their emissions.
Future work will study the effect of other pollutants such as nitrogen oxide and carbon monoxide. It will further look at the impacts of aviation on the climate change taking into account the radiative forcing from aircraft emissions (IPCC, 1999; Sausen et al, 2005).

ACKNOWLEDGMENTS

The authors would like to thank the Hellenic Civil Aviation Authority for their help in obtaining the airport statistics. We would also like to thank the reviewers of the present paper for their helpful and valuable comments.

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