Investigations on the distribution of air transport traffic and CO_2 emissions within the European Union

G. Alonso [a,*], A. Benito [a], L. Lonza [b], M. Kousoulidou [b]

[a] *E.T.S.I. Aeronáuticos, Universidad Politécnica de Madrid, E-28040 Madrid, Spain*
[b] *European Commission, Directorate-General Joint Research Centre, Institute for Energy and Transport, Sustainable Transport Unit, I-21027 Ispra, Italy*

This study analyses the structure of air traffic and its distribution among the different countries in the European Union, as well as traffic with an origin or destination in non-EU countries. Data sources are Eurostat statistics and actual flight information from EUROCONTROL. Relevant variables such as the number of flights, passengers or cargo tonnes and production indicators (RPKs) are used together with fuel consumption and CO_2 emissions data. The segmentation of air traffic in terms of distance permits an assessment of air transport competition with surface transport modes.

The results show a clear concentration of traffic in the five larger countries (France, Germany, Italy, Spain and UK), in terms of RPKs. In terms of distance the segment between 500 and 1000 km in the EU, has more flights, passengers, RTKs and CO_2 emissions than larger distances. On the environmental side, the distribution of CO_2 emissions within the EU Member States is presented, together with fuel efficiency parameters. In general, a direct relationship between RPKs and CO_2 emissions is observed for all countries and all distance bands. Consideration is given to the uptake of alternative fuels. Segmenting CO_2 emissions per distance band and aircraft type reveals which flights contribute the most the overall EU CO_2 emissions. Finally, projections for future CO_2 emissions are estimated, according to three different air traffic growth and biofuel introduction scenarios.

1. Introduction

Aviation is one of the world's great connectors of people, enhancing the prosperity of communities and facilitating world trade and tourism. According to published data (ATAG, 2012), the total value of goods transported by air represents 35% of all international trade, while regarding global tourism, 51% of international tourists in 2011 travelled by air. Today, air transport is one of the most rapidly growing transport sectors, moving more than 3 billion passengers and 670 billion revenue tonne kilometres (RTKs) in 2012. In the European Union (EU), the direct contribution of the aviation sector to the Gross Domestic Product (GDP) is €110 billion, a figure that increases to €475 billion if indirect, induced and catalytic impacts are included (ATAG, 2012). Moreover, the air transport industry supports 7.8 million jobs in the European Union and 56.6 million worldwide (ATAG, 2012).

In spite of the economic crisis, world air traffic continues to grow. However the growth is not uniform and varies from country to country. The recent traffic growth has been driven by the acceleration of demand in emerging countries like Brazil, Russia, India and China. Regarding projections for future growth, even though long-term forecasts are by their nature sensitive to a number of unforeseen factors, nevertheless there is some consensus with the forecasts given by different international organizations and aircraft manufacturers, which estimate future annual air traffic growth rates of around 4% (ICAO, 2007; EUROCONTROL, 2010; IATA, 2012; ACI, 2013; Airbus, 2012; Boeing, 2012).

Along with the growth in air transport activity and hence, in energy consumption, increased environmental impacts must also be taken into account. The environmental impact of the air transport sector largely results from its share of global warming through the greenhouse gas emissions. CO_2 is considered the most important greenhouse gas (GHG) emitted by aircraft and is included in the EU Emissions Trading System (EU ETS). Emissions from the transport sector have been estimated to contribute to 23% of the total emissions in EU-27 (ICAO, 2010). According to the same source, it has been shown that world aviation activities accounted for approximately 3.5% of anthropogenic global warming, while as reported by Lee (2010), emissions from aircraft are estimated to contribute 3.5–4.9% of anthropogenic radiative forcing. About

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* Corresponding author. Tel.: +34 913366353; fax: +34 913366363.
E-mail address: gustavo.alonso@upm.es (G. Alonso).

10,000 premature mortalities result from the degradation of air quality. In the study of Simone et al. (2013), aviation is responsible for about 3% of global fossil fuel consumption and 12% of transportation-related CO_2 emissions.

The Intergovernmental Panel on Climate Change (IPCC) in 1999 predicted that civil aviation CO_2 emissions would rise by between 60% and over 1000% between 1992 and 2050 (IPCC, 1999). More recent studies suggest that if the global economic growth continues, aviation CO_2 emissions are likely to experience a greater than three-fold increase between 2000 and 2050 (Berghof et al., 2005; Horton, 2006). It is clear that the benefits from the expected growth in the air transport sector will come at a cost, most notably a significant increase in aviation greenhouse gas emissions (Kurniawan et al., 2011). According to various studies (ATAG, 2012; EU, 2012; Macintosh and Wallace, 2009), while aviation is not currently one of the main drivers of global warming, the significant growth suggests it could become a major factor over the coming decades. ICAO (2009), forecasts that by 2050 aviation emissions could grow by a further 300–700%. Simulations suggest that aircraft emissions in the absence of any restriction will become one of the major CO_2 emissions sources covered by the EU ETS (Gudmundsson and Anger, 2012). Therefore the growth of the aviation sector and its emissions may threaten the overall efforts in GHG reductions made by other sectors and this will make it difficult to meet the EU reduction target of 20% below 1990 levels by 2020 for total EU emissions. Taking into account these statistics and predictions, there is a need to reduce CO_2 emissions related to aviation despite its currently relatively small contribution to total CO_2 emissions in the EU (Anger, 2010).

In response to concerns over the global environmental impacts of aviation, stakeholders have become committed to strategies of mitigation. Since 2012, aviation emissions have been included in the EU ETS (EU, 2008). Moreover, the International Air Transport Association (IATA) in 2009 set out goals aimed at achieving stable carbon emissions from 2020 onwards despite further growth in air traffic, to be achieved by a combination of different parameters such as fleet renewal, operational and infrastructure measures, retrofits, offset mechanisms and the use of alternative fuels (Krammer et al., 2013).

According to Krammer et al. (2013) and ATAG (2012), the implementation of sustainable, advanced-generation aviation biofuels will play a large role in reducing CO_2 emissions. Over 1500 passenger flights with biofuels have taken place so far and the consensus is that the lifecycle carbon saving from moving to biofuels could be up to 80% over that of the traditional jet fuel. Sgouridis et al. (2011) suggest that the proportion of biofuels in total fuel consumption by commercial aviation was 0.5% in 2009 and will rise to 15.5% in 2024 in a “moderate” scenario, and to 30.5% in an “ambitious” scenario. In the EU, the European Commission, in close coordination with aircraft manufacturers, operators and European biofuel producers, have launched the “European Advanced Biofuels Flightpath”, an industry-wide initiative to speed up the market uptake of aviation biofuels in Europe. It provides a roadmap to achieve an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020 (EC, 2011a,b).

Therefore the objective of this paper is to evaluate the current situation of the air transport sector in the EU by collecting activity and fuel/energy data, to identify differences for the various EU member states and to estimate the impact of air traffic growth to 2030. On an EU-member state level, the objective is to provide enough data for EU policy officers to analyze the situation of regions, territories, or cities, in relation to air traffic and to contribute to the assessment of various issues of accessibility and connectivity which can be related to the region's competitiveness and attractiveness.

Hence, this paper discusses the methodology employed in the data collection, together with the main findings of the study, in terms of air traffic as well as fuel consumption/CO_2 emissions structure and distribution among the 27 countries of the European Union, plus Norway and Switzerland (EU+2). Moreover, this paper presents forecasts for the growth of air transport, fuel/energy demand evolution and alternative fuels utilization. This leads to CO_2 emissions up to 2030 being projected in order to estimate the contribution of the aviation sector to climate change.

2. Methodology

2.1. Traffic data

Air transport data have been collected from the European Commission's Eurostat Air Transport Statistics (Eurostat). For each country the following information has been extracted:

- Air passenger transport between the main airports of country xx and their main partner airports (routes data) [avia_par_xx database]: total commercial passenger air flights, total passengers on board and total passenger seats available.
- Freight and mail air transport between the main airports of country xx and their main partner airports (routes data) [avia_gor_xx database]: all-freight and mail total commercial air flights and total freight and mail on board in tons.

All the above mentioned information was obtained for each airport pair, between the main airports of country xx and their main partner airports and the following parameters were derived:

- Passenger transport: number of RPKs (revenue passenger kilometres) and ASKs (available seat kilometres).
- Freight and mail transport: number of RTKs (revenue tonne kilometres).

In order to do this, the distance between airports pairs was measured with a distance calculator, using the airports reference point geographical coordinates. The distances are the shortest (orthodromic) ones between each pair of airports and cannot be directly compared with ground transportation distances. For instance, within Spain, road distances or high speed train tracks between two cities are about 25% longer than air distances as an average, and conventional train distances 35% longer. Those percentages become smaller when distances get greater (Monzon and Perez, 1996). Finally, the data were segmented, for each country between the reference country, the EU+2 countries and the non-EU countries (NO-EU). The data were also segmented per distance bands, at intervals of 500 km.

2.2. Emissions data

As discussed above, information available in the Eurostat databases provides data on the number of flights and payload (either passengers or cargo) and also on the airport pairs, so that RPKs or RTKs can be evaluated and classified per distance bands. However aircraft type information is not available for airport pairs. So it is not possible to classify this information according to aircraft types and evaluate fuel consumption and subsequently CO_2 emissions. There is another relevant source of data which is the EUROCONTROL Data Demand Repository (DDR) (EUROCONTROL) where information from the flight plans in EUROCONTROL countries is stored. It is possible to retrieve data an all flights for 365 days of a year but the amount of flights makes this unfeasible. Therefore a sample of data from two weeks (central week of June and central week of

September) was downloaded and then averaged for the overall year. This is a standard practice in the airline industry to evaluate yearly data, considering the variation in flight schedules between the high peak and other times (Garrow, 2010). The reference year for the study database was 2010 but data for the years 2011 and 2012 were used as well. The data extracted for each flight consisted of the departure airport, the arrival airport, the type of aircraft and the type of flight. Hence Eurostat data were used to derive traffic volume (flights, passengers, RPKs or RTKs) and EUROCONTROL data were used to evaluate fuel consumption and CO_2 emissions.

The EUROCONTROL DDR data were processed and segmented. First, the distance between airports pairs was evaluated with the distance calculator. Flights were filtered per type and only scheduled and non-scheduled flights were included, i.e. military, customs or police flights, general aviation flights and others have been excluded. Then the fuel consumption for every flight was evaluated using the Corinair database (EEA, 2007), which gives the fuel consumption (as a function of the distance flown) per aircraft type and per flight phase. This is, of course, a simplified procedure for the evaluation of fuel consumption as it does not take into account the dependence of the fuel consumption of a given flight on the flight actual data such as take-off weight, trajectory, altitude, speed, and meteorological conditions. Also not all aircraft types are represented, and therefore assumptions were made in order to estimate the fuel consumption of certain aircraft types based on the Corinair fuel consumption of similar types. The impact of these simplifications could be relevant in the evaluation of the fuel consumption or CO_2 emissions of a particular flight, but are far less important when we are estimating aggregated data involving thousands of flights, and furthermore if we are using this data for comparative purposes.

From the fuel consumption, CO_2 emissions were calculated, by multiplying the fuel consumption times 3.15, which is the value selected for the EU ETS Directive (EU, 2008). Other sources, for instance ICAO (2013) use a value of 3.16. Therefore, the information for each flight was: departure airport, arrival airport, type of aircraft, fuel consumption in LTO cycle (approach, landing, taxiing, take-off and climb, below 3000 feet over the airport), fuel consumption in climb/cruise/descent, total flight fuel consumption, and total flight CO_2 emissions. This was segmented for the EU+2 countries plus the NO-EU countries and presented by pairs for every country (departure) and the rest of the countries (destination). The data were segmented according to the same distance bands, at 500 km intervals, and per aircraft type, taking into account the MTOW (Maximum Certified Takeoff Weight) and the propulsion type. The following aircraft type categories were considered:

- MTOW less than 7 tons (aircraft typically up to 19 seats in passenger configuration)
- MTOW between 7 and 136 tons
  - Turboprops
  - Turbofans
- MTOW larger than 136 tons (aircraft larger than 240 seats)

3. Results

3.1. Traffic data

Data for the baseline year 2010 for commercial passenger flights are presented in Table 1, segmented per distance band. It is interesting to note that almost 60% of the flights and 46% of the passengers correspond to distances below 1000 km, and are therefore susceptible to competition from high speed trains (excluding connections with islands, remote regions, etc.). This consideration should be complemented by further analysis of global transport demand, because high speed trains need a significant demand level to be competitive, due to the very high investment per track kilometre, which needs to be depreciated over a large number of transport units (De Rus, 2008). Obviously, these percentages are much smaller in terms of RPKs: only 13% of the RPKs correspond to the segment below 1000 km. Roughly 20% of the passengers fly distances longer than 2500 km, representing 60% of the total RPKs. It is noticeable that there are a small number of flights in the distance interval between 1500 and 2500 km, just 13% of the total.

Table 1
Commercial passenger flights data.

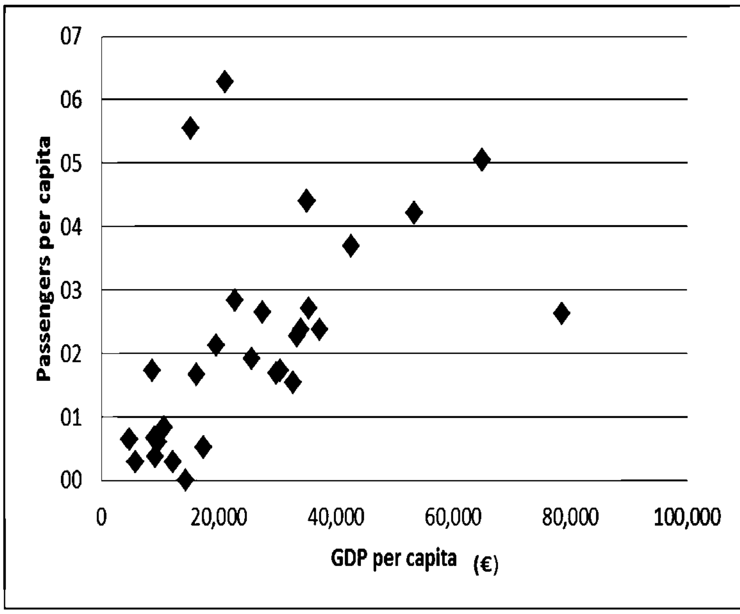
Distance band (km)	Flights (10^3)	Passengers (10^6)	RPKs (10^9)	Seats (10^6)	ASKs (10^9)	L/F	Seats/ flights
<500	2360	174	64	262	98	65%	111
500–1000	2877	271	197	380	278	71%	132
1000–1500	1479	176	220	230	291	76%	156
1500–2000	796	106	182	129	231	79%	162
2000–2500	340	46	103	52	132	78%	152
>2500	933	195	1160	234	1416	82%	251
Total	8785	967	1926	1286	2445	79%	146

The number of average seats per flight in the distance interval below 500 km is 111, which indicates that an important number of these short range flights are performed using aircraft with more than 100 seats, and therefore are at least medium range aircraft. The consequence, as shown in Section 3.2 (Fig. 2), is that the efficiency in terms of fuel consumption (or CO_2 emissions) per RPK is very poor in this distance segment (Morrell, 2009; Givoni and Rietveld, 2010). The same consideration can be applied to the distance interval from 500 to 1000 km, with just 132 seats per flight. At intermediate distances, from 1000 to 2500 km, the seat per flight value is very similar, around 150–160 seats per flight. The average aircraft size grows significantly at distances beyond 2500 km, 251 seats per flight, which indicates a mixed fleet of single-aisle and wide-body jets (see Section 3.2). The average load factor grows steadily with the distance of the flight, from a minimum value of 64.7% for distances below 500 km, to a maximum value of 82.0% for distances larger than 2500 km. The average load factor for all flights is 79%.

Data for the baseline year 2010 for total commercial flights (all-freight and mail) are represented in Table 2, segmented per distance band. Although most of the cargo flights (62%) take place with distances below 1000 km, it is significant that 94% of the RTKs are flown in distances larger than 2500 km. These figures confirm the intense competition that air cargo suffers from surface transport modes in the intra-EU market, because of the short-medium distances involved. It is in the long distance range where air transport competes much better with other modes. The average load per flight grows steadily with the distance flown, but with generally small values up to 2500 km. For distances longer than 2500 km the average load per flight changes order of magnitude to 138 tonnes.

The distribution of the commercial passenger flights among the EU+2 countries is shown in Table 3. This shows a clear concentration of traffic in five large countries (France, Germany, Italy, Spain and UK). These five countries account for approximately two thirds of the EU+2 traffic with any of the traffic measures (flights, passengers or RPKs). The values of these variables are consistent for France, Germany and Spain representing approximate values of 12%, 15% and 13% respectively. However Italy, with a 12% share of flights and passengers, accounts for just 7% of the RPKs, while the UK, on the contrary, shows a completely inverted distribution with 23% of the RPKs, 15% of the flights and 17% of the passengers.

Regarding the distribution of cargo flights per country (Table 4), the concentration is somewhat different. Countries such as Italy or



country	GDP per capita	passengers per capita
Austria	34.100	2.4
Belgium	32.700	1.5
Bulgaria	4,800	0.6
Cyprus	21.000	6.3
Czech Repub	14.300	0.0
Denmark	42,600	3.7
Estonia	10,700	0.8
Finland	33.300	2.3
France	29.900	1.7
Germany (inc	30.500	1.7
Greece	19,600	2.1
Hungary	9,700	0.6
Ireland	35.000	4.4
Italy	25.700	1.9
Latvia	8.600	1.7
Lithuania	8.900	0.7
Luxembourg	78.600	2.6
Malta	15.200	5.5
Netherlands	35.400	2.7
Norway	65,000	5.1
Poland	9,200	0.4
Portugal	16,200	1.7
Romania	5,800	0.3
Slovakia	12,100	0.3
Slovenia	17,400	0.5
Spain	22.800	2.8
Sweden	37.300	2.4
Switzerland	53,400	4.2
United Kingd	27.500	2.6
average	26.114	1.9

Fig. 1. Passengers per inhabitant (capita) as a function of country's GDP per capita (in €).

Spain account for a lesser share of the cargo traffic than with passenger traffic, while smaller countries, like Belgium or The Netherlands, have larger shares. However the case of Italy and Spain is not similar for the other EU largies countries as, with the exception of The Netherlands which is a small country, the group composed of France, Germany, The Netherlands and the UK represents 74% of the total RTKs of the EU+2, showing the importance of specific airports such as Paris Charles de Gaulle, Frankfurt, Schiphol and London Heathrow airports as worldwide cargo hubs.

To complete the traffic analysis by country, the ratio between the number of passengers per citizen and the country's GDP per capita is shown in Fig. 1. The average for the EU+2 countries is almost 2 passengers per citizen, well above the world average of approximately 1.4. The well-known relationship between the two variables is apparent, with the passengers per citizen growing with the GDP per capita almost linearly. Remarkable exceptions are Luxembourg, with the largest by far GDP per capita but an average value of flights per citizen, or on the other side Malta and Cyprus, with poor GDP per capita but around 6 passengers per citizen, showing the importance for these small countries of air transport for their tourism industry. This is also noticeable in the case of Ireland, again showing an above-average number of passengers per citizen and a GDP per capita in line with the EU average, emphasizing the significance of air transport for an island.

Finally, an analysis of the distribution of flights per aircraft type and size, in addition to the distance bands, is given in Table 5. 76% of the flights are flown by single-aisle jets, which are used in all distance bands, even below 500 km. In fact one fourth of the flights performed by single-aisle jets correspond to distances shorter than 500 km. Turboprops represent 13% of the flights, as expected, concentrated in the distance bands shorter than 500 km with almost all remaining capacity in the adjacent distance band (500–1000 km). Turboprops are not used much in the 1000–1500 km band, representing only 1.3% of the flights. 10% of the total number of flights is performed by wide-body jets, with 14% of the wide body jets flying distances shorter than 2500 km. This distribution has been obtained from EURCONTROL DDR data. It has also been used to check the consistency of both data sources used in this study, by comparing with the number of flights given in Table 1, obtained from the Eurostat data. There is a difference of just 3.9% in the total number of flights.

3.2. Emissions data

CO_2 emissions are shown in Table 6 and the total value obtained for 2010 is 216 million tonnes. This figure can be compared with the reference value used by the European Commission in the inventory performed to implement the Emissions Trade Scheme in the

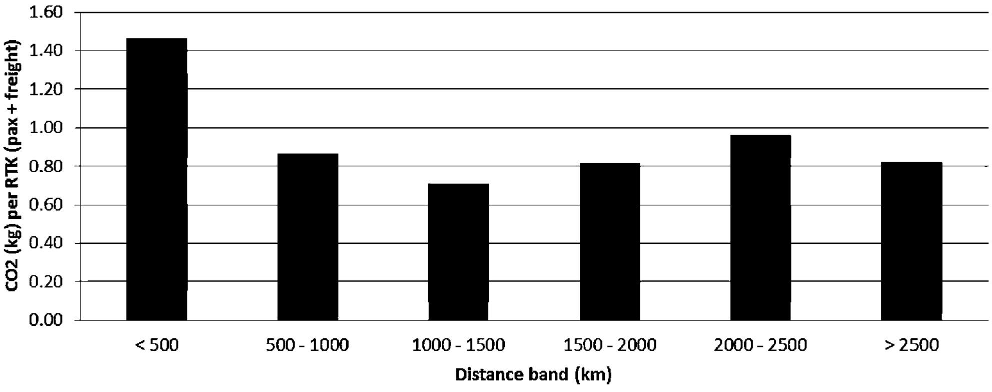


Fig. 2. CO_2 emissions per RTK.

Table 2
Cargo flights data.

Distance band (km)	Flights (10^3)	Freight (tons × 10^6)	RTKs (10^6)	Tons/flight
<500	119	1077	399	9
500–1000	112	1703	1176	15
1000–1500	38	625	731	16
1500–2000	22	372	635	17
2000–2500	12	385	773	31
>2500	67	9183	60586	138
All bands	370	13345	64301	36

aviation sector. The average value for the 2004–2006 period was also 216 million tonnes (Benito et al., 2010). The difference is to be found in the flight inventory as for the purpose of the ETS other non-airline flights (business flights, sport aviation, utility, general aviation) have been included. The emissions from this sector are about 22 million tonnes, accounting roughly for the emissions growth from commercial flights between 2005 and 2010, thus showing a good consistency.

The CO_2 emissions distribution shows how most of the CO_2 emissions (67.5%), correspond to flights longer than 2500 km (transporting 20% of the passengers, see Section 3.1), while short range flights, with less than 1000 km, transporting almost half of the total passengers (46%), emit just 13% of the total CO_2. This is an interesting conclusion from the point of view of CO_2 emission reduction potential through short distance flights replacement by other more CO_2 efficient surface transport modes.

The percentage of total RTKs (passenger flights plus cargo flights) per distance band is also shown in Table 6, in order to be compared with the distribution of emissions per distance band. There is a direct correction between both measures at distance bands. Longer distances flights (>2500 km) are by far the largest contributors to RTKs and emissions, representing approximately 68% of both total RTKs and CO_2 emissions. It is remarkable the relevance of the segment between 500 and 1000 km in the EU with more RTKs and CO_2 emissions than larger distances, notably more than the segment 2000–2500 km which represents less than 5%. The significance of the 500–1000 km segment is also observed in Table 1, where it can be seen that the largest number of passengers (28% of the total) are in this segment. In addition, the efficiency of turboprops in terms of fuel consumption and therefore CO_2 emissions is apparent, representing less than 1% of the total CO_2 emissions, having 13% of the flights. This is due to the dual effect of a better fuel efficiency and shorter distances flown.

Fuel consumption or CO_2 emissions efficiency is measured using the standard parameter of the kilograms of fuel burnt or CO_2 emitted per total RTK (ICAO, 2011). The CO_2 emissions per total RTK values are shown in Fig. 2, classified per distance band. In Fig. 2,

Table 3
Distribution of passengers flights per country.

Country	Passenger flights							
	Flights (10^3)		Passengers (10^6)		RPKs (10^9)		L/F	Pass/ flight
Austria	229	2.6%	19.9	2.1%	27.0	1.4%	75.7%	87
Belgium	172	2.0%	16.8	1.7%	31.1	1.6%	75.2%	97
Bulgaria	45	0.5%	4.7	0.5%	7.2	0.4%	75.8%	104
Cyprus	38	0.4%	5.2	0.5%	12.5	0.6%	83.1%	137
Denmark	217	2.5%	20.4	2.1%	29.2	1.5%	77.5%	94
Estonia	19	0.2%	1.1	0.1%	1.1	0.1%	71.6%	60
Finland	148	1.7%	12.2	1.3%	25.2	1.3%	76.1%	82
France	987	11.2%	109.1	11.3%	261.1	13.6%	78.9%	111
Germany	1315	15.0%	141.9	14.7%	306.9	15.9%	80.9%	108
Greece	230	2.6%	24.0	2.5%	37.3	1.9%	74.2%	104
Hungary	65	0.7%	6.0	0.6%	6.9	0.4%	73.9%	91
Ireland	154	1.8%	19.7	2.0%	26.9	1.4%	79.4%	128
Italy	1065	12.1%	115.8	12.0%	144.4	7.5%	75.9%	109
Latvia	52	0.6%	3.9	0.4%	4.8	0.2%	77.4%	75
Lithuania	29	0.3%	2.2	0.2%	2.8	0.1%	74.4%	75
Luxembourg	30	0.3%	1.3	0.1%	1.1	0.1%	68.8%	44
Malta	20	0.2%	2.3	0.2%	3.8	0.2%	74.9%	115
Netherlands	370	4.2%	45.0	4.7%	134.9	7.0%	83.1%	122
Norway	292	3.3%	24.7	2.6%	22.3	1.2%	66.2%	85
Poland	159	1.8%	14.1	1.5%	19.6	1.0%	74.7%	88
Portugal	159	1.8%	17.7	1.8%	30.7	1.6%	76.7%	111
Romania	73	0.8%	6.3	0.7%	8.6	0.4%	79.1%	86
Slovakia	17	0.2%	1.6	0.2%	2.0	0.1%	80.4%	93
Slovenia	22	0.2%	1.1	0.1%	0.9	0.0%	69.8%	49
Spain	1050	12.0%	130.2	13.5%	237.7	12.3%	77.1%	124
Sweden	226	2.6%	22.2	2.3%	30.6	1.6%	77.7%	99
Switzerland	323	3.7%	33.0	3.4%	59.4	3.1%	81.5%	102
UK	1279	14.6%	164.9	17.1%	449.9	23.4%	79.9%	129
Total	8785	100.0%	967.3	100.0%	1925.7	100.0%	78.8%	110

Table 4
Distribution of cargo flights per country.

Country	Cargo flights						
	Flights (10^3)		Freight (10^3)		RTKs (10^6)		Tons/ flight
Austria	5.2	1.4%	234.2	1.8%	1118	1.7%	45
Belgium	30.6	8.3%	975.6	7.3%	1746	2.7%	32
Bulgaria	2.4	0.6%	17.5	0.1%	23	0.0%	7
Cyprus	1.1	0.3%	35.8	0.3%	76	0.1%	31
Denmark	4.9	1.3%	149.2	1.1%	672	1.0%	31
Estonia	1.5	0.4%	8.9	0.1%	11	0.0%	6
Finland	7.3	2.0%	158.2	1.2%	764	1.2%	22
France	39.4	10.7%	1399.4	10.5%	7989	12.4%	36
Germany	68.9	18.6%	3677.0	27.6%	17,142	26.7%	53
Greece	10.2	2.8%	82.5	0.6%	188	0.3%	8
Hungary	4.2	1.1%	44.4	0.3%	155	0.2%	10
Ireland	4.7	1.3%	110.4	0.8%	263	0.4%	23
Italy	25.9	7.0%	748.5	5.6%	2967	4.6%	29
Latvia	0.5	0.1%	10.3	0.1%	15	0.0%	19
Lithuania	2.0	0.5%	7.3	0.1%	7	0.0%	4
Luxembourg	6.9	1.9%	536.5	4.0%	3235	5.0%	78
Malta	0.7	0.2%	14.8	0.1%	25	0.0%	21
Netherlands	17.3	4.7%	1518.1	11.4%	9842	15.3%	88
Norway	9.2	2.5%	46.3	0.3%	115	0.2%	5
Poland	8.0	2.2%	54.4	0.4%	151	0.2%	7
Portugal	8.8	2.4%	95.4	0.7%	308	0.5%	11
Romania	29.0	7.8%	19.2	0.1%	21	0.0%	1
Slovakia	1.1	0.3%	17.2	0.1%	22	0.0%	15
Slovenia	0.0	0.0%	6.9	0.1%	4	0.0%	6851
Spain	26.2	7.1%	549.7	4.1%	2573	4.0%	21
Sweden	15.6	4.2%	174.6	1.3%	510	0.8%	11
Switzerland	3.5	0.9%	369.3	2.8%	1976	3.1%	106
UK	34.8	9.4%	2284.1	17.1%	12,382	19.3%	66
Total	370.0	100.0%	13,345.4	100.0%	64,301	100.0%	36

Table 5
Flight distribution per distance band and aircraft type. (Number of flights lower than 500 are given the value 0).

Distance band (km)	Flights (thousands)					
	Aircraft type (MTOW range in tons)					
	<7	7–136		>136	Total band	
		Turboprop	Jet			
<500	64	866	1487	28	2445	29.0%
500–1000	12	214	2010	27	2263	26.8%
1000–1500	2	16	1163	23	1204	14.3%
1500–2000	0	3	827	19	850	10.1%
2000–2500	–	1	427	17	445	5.3%
>2500	–	1	470	761	1232	14.6%
Total type	78	1100	6384	876	8439	100.0%
	0.9%	13.0%	75.6%	10.4%	100.0%	

Table 6

CO_2 emissions distribution per distance band and aircraft type. (Emissions lower than 0.1 million tonnes are given the value 0).

Distance band (km)	CO_2total (Mtons) Aircraft type (MTOW range in tons) <7	7–136 Turboprop	Jet	>136	Total band		Total RTK (passengers + cargo)
<500	0	1.2	8.3	286.3	9.9	4.6%	2.6%
500–1000	0	0.6	17.0	507.4	18.1	8.4%	8.1%
1000–1500	0	0	15.4	665.3	16.2	7.5%	8.8%
1500–2000	0	0	14.7	679.3	15.4	7.1%	7.3%
2000–2500	–	0	9.6	975.1	10.6	4.9%	4.3%
>2500	–	0	16.1	129.4	145.6	67.5%	68.7%
Total type	0	2.0	81.2	132.5	215.8	100.0%	100%
	0.0%	0.9%	37.6%	61.4%	100.0%		

RTKs correspond to all flights (passenger and freight). The fuel efficiency of short flights (less than 500 km) is very poor, 1.47 kg/RTK. This efficiency improves with the distance up to 1500 km (0.71 kg/RTK). From 1500 km the efficiency degrades somewhat, showing the poor efficiency of the mixed fleet used in these distances. It was shown in Table 5 that for distances between 1500 and 2500 km, there is a certain portion of the flights flown by wide-body jets, clearly operating far from their maximum range (much longer than 2500 km) and therefore also far from their optimum energetic efficiency.

The distributions of the fuel consumption and CO_2 emissions per country, together with the values of the intensity parameter are given in Table 7. This again shows a large concentration of the CO_2 emissions in a few countries, with the outstanding case of the UK emitting 22.5% of the total EU+2 air transport CO_2. Again, the correlation between the emissions and the production parameter is observed, because in Table 3 it can be seen that UK represents also 23.4% of the total RPKs. This correlation appears for most of the countries, comparing the RPKs for each country as a percentage of the total shown in Table 3 and the CO_2 emissions for that country as a percentage of the total shown in Table 7. The five largest countries (France, Germany, Italy, Spain and UK) account for approximately two thirds of the EU+2 CO_2 emissions as with the traffic. It should be notes that the values of CO_2 efficiency that are presented in Table 7 and Fig. 2 compare well with the 0.896 kg/RTK value obtained from worldwide CO_2 emissions and RTK data in the ICAO Environmental Report (ICAO, 2013).

Table 7

CO_2 emissions and efficiency per country.

Country	Fuel consumption (million tonnes)	CO_2 (m tonnes)		CO_2 (kg)/RTK
Austria	1.05	3.31	1.5%	0.87
Belgium	1.80	5.66	2.6%	1.17
Bulgaria	0.27	0.86	0.4%	1.16
Cyprus	0.35	1.11	0.5%	0.83
Czech Republic	0.43	1.36	0.6%	
Denmark	1.04	3.26	1.5%	0.91
Estonia	0.04	0.12	0.1%	1.01
Finland	0.77	2.42	1.1%	0.74
France	8.93	28.14	13.0%	0.83
Germany	12.46	39.25	18.2%	0.82
Greece	1.48	4.66	2.2%	1.19
Hungary	0.28	0.87	0.4%	1.02
Ireland	0.83	2.61	1.2%	0.88
Italy	4.99	15.73	7.3%	0.90
Latvia	0.13	0.42	0.2%	0.84
Lithuania	0.06	0.20	0.1%	0.69
Luxembourg	0.41	1.29	0.6%	0.39
Malta	0.11	0.33	0.2%	0.83
Netherlands	5.14	16.21	7.5%	0.69
Norway	0.87	2.75	1.3%	1.17
Poland	0.72	2.26	1.0%	1.07
Portugal	1.34	4.21	2.0%	1.25
Romania	0.30	0.94	0.4%	1.07
Slovakia	0.06	0.20	0.1%	0.90
Slovenia	0.05	0.16	0.1%	1.72
Spain	6.27	19.76	9.2%	0.75
Sweden	0.98	3.08	1.4%	0.86
Switzerland	1.91	6.02	2.8%	0.76
UK	15.43	48.61	22.5%	0.85
Total	68.50	215.79	100.0%	0.84

4. Projections

Data for traffic activity, fuel demand and emissions have been projected on a year by year basis up to 2030, using 2010 as the baseline. Different growth scenarios have been used, as described hereafter. Since the reference year is 2010, but 2011 and 2012 (provisional) data are already available, actual growth rates for these years are included in all scenarios with projections starting from the year 2013 onwards.

4.1. Historical air traffic growth

After the Second World War, air transport experienced a fast and continuous growth in every geographical area, at rates dictated by the prevalent socio-economic conditions in each country. In the 50s and 60s decades, growth rates were double digit. The oil price shocks of the 70s and 80s tempered the air transport increase and aligned it to the cyclic fluctuations of the world economy, with a typical elasticity (Air transport growth/world GDP growth) between 1.5 and 2 (Benito, 2007). In spite of many contingencies, all specialized forecasts (ICAO, 2007; EUROCONTROL, 2010; IATA, 2012; ACI, 2013; Airbus, 2012; Boeing, 2012) extrapolate the idea of a growing industry in the coming years, based on a number of related socio-economic trends that explain the direct relationship between air transport and the economy, both in international trade patterns and in the leisure travel sectors.

There are negative factors as well, that are becoming more significant as the dimension and repercussions of commercial aviation gain importance. The most relevant ones are likely to be:

- The cost of the kerosene fuelling commercial aircraft. Until alternative fuels are developed, air transport suffers from a strong dependence on the oil price that is likely to increase in the near future.
- The maturation of the air travel market in the most developed countries.
- Public opinion worries about environmental conditions which have a considerable relevance to air transport development.

The different evolution of the above mentioned factors in the European Union and in other parts of the world seems to recommend using different growth scenarios for the traffic growth within European borders and the flights beyond them. This is the philosophy adopted in this study in order to evaluate the evolution of air transport in the European Union. Long term scenarios, covering the period 2013–2030, have been prepared. A central or most likely scenario is followed by two additional ones, the first assuming a number of credible negative trends that may appear during that period and the second following the hypothesis of more optimistic conditions.

4.2. *Central scenario*

A survey of available forecast by specialized bodies has been performed, including international organizations (ICAO, 2007; EUROCONTROL, 2010; IATA, 2012; ACI, 2013; Airbus, 2012; Boeing, 2012). As the intention of the paper is to take as the baseline the most likely scenario, the previous six sources have been compared, taking out the highest and lowest value and adopting the statistical mode of the other four. The baseline of this scenario considers an initial period (2013–2016) of slow economic growth within the European Union countries, followed by a gradual recuperation in the 2017–2020 period and a steady growth in the following decade (2021–2030). As the air transport demand varies in parallel to the economy growth, traffic to and from EU is assumed to have different levels of development in each decade, but in any case higher than domestic EU demand, due to integrating the higher developing pace of emerging economies (Table 8).

The application of these values to the traffic is not immediately translated to the fuel consumption because there are several factors improving the energetic efficiency of air transport:

- Fleet replacement, substituting some aircraft models by new, more efficient ones as they enter into the market.
- Use of larger aircraft, as the average commercial aircraft size is continuously increasing.
- Increased density seating inside the aircraft. With the development of low cost carriers, the number of seats has been rising, not only with these airlines but also with the incumbents.
- Improvements in air traffic control and navigation procedures, allowing the optimization of flight profiles and trajectories.

The calculation of the practical consequences of all those elements is rather complicated. During the last 15 years IATA has been comparing the values of the RTKs with fuel consumption. The results show an average annual improved efficiency, measured in tonnes of fuel per RTK, of around 1.9% (IATA, 2013) for the IATA members, although other studies indicate lower figures. A good recollection of different analysis in the 1997 to 2012 period can be found in Peeters (2013). Meanwhile ICAO, in its climate change mitigation program, has set an aspirational target for the world air transport sector of 2.0% annual improvement until 2020, with a possible stretch until 2030 if the national action plans prepared by contracting States prove to be adequate (ICAO, 2011). In addition, IATA has considered an efficiency improvement of 1.5% per year in future years and adopted this as a voluntary commitment.

Considering that information, the annual figure of 1.5% efficiency improvement has been used in the Central Scenario for the full 2013–2030 period. The appearance of a number of new more efficient models in all size and range categories (A350, B777X, A320NEO, B737MAX, C919, MS21, C-Series, E2Jet and CRJ re-engined) in the next five years and the promised improvements in the use of the air space (SESAR, NextGEn) seem to support the credibility of this number.

With respect to the biofuel usage, most of the specification and operational questions have been already answered and no technological show-stopper seen in the considered period. However, the economic viability is still far from being made secure. For this study, an assumption has been used that up to 2017 the introduction of biokerosene is 1% of the total fuel usage, with this percentage progressively increasing, achieving 5% in 2021 and remaining at this level until 2030. In the projections made, the CO_2 emissions coming from biokerosene are not included. This decision of taking a zero emission factor for aviation biofuels is congruent with the European ETS Directive (EC, 2008) although assessments of life-cycle CO_2 emissions typically show a reduction potential compared to fossil jet fuel in the order of 30–90%, depending on the feedstock and production processes (Stratton et al., 2010).

Table 8
Central Scenario traffic growth.

Period	2013–2016	2017–2020	2021–2030
EU domestic traffic	2.8%	3.2%	3.5%
Traffic to and from EU	4.0%	4.0%	4.5%

Table 9
Pessimistic Scenario traffic growth.

Period	2013–2016	2017–2020	2021–2025	2026–2030
EU domestic traffic	0.8%	1.0%	1.5%	2.0%
Traffic to and from EU	2.0%	2.0%	2.5%	2.5%

4.3. *Alternative scenarios*

The Pessimistic Scenario (Table 9) is based on the hypothesis of a prolongation of the EU economic crisis until the end of the present decade with a dual situation of high-deficit countries sunk in the economic recession or its sequels, and better-off countries carefully moving their budget control with strong limitations on expenditure. This bleak forecast would be improving at a slow pace during the second decade. Moderate US economic recovery, inflationist pressures in China and fast rising oil prices would reduce by a couple of percentage points the demand growth for air traffic outside the EU.

The Optimistic Scenario (Table 10) assumes a fast and robust recovery of the EU economy, returning to pre-crisis growth rates in the middle of the present decade, partially thanks to the stabilization of oil prices. International markets would gain from a high consumer expenditure increase in the United States and a soft landing of the overheated Chinese economy. Intra-EU demand will always increase less than external traffic.

In both alternative scenarios, the efficiency improvement and the percentage of bio-kerosene usage are kept at the same levels than in the Central Scenario. The projections for CO_2 emissions in all three scenarios are shown in Fig. 3. CO_2 emissions in 2030 result in a baseline value of 293 million tonnes, ranging between 207 and 334 million tonnes respectively for the pessimistic and optimistic scenarios. These projections result in average annual growth rates of CO_2 emissions of 1.8% in the Central Scenario, −0.2% in the Pessimistic Scenario and 2.7% in the Optimistic Scenario. Similar growth rates are given in Chèze et al. (2013). In terms of total fuel consumption (including biokerosene), the projections give values for 2030 of 93, 66 and 106 million tonnes respectively for the baseline, pessimistic and optimistic scenarios (Fig. 4).

5. Conclusions

This study analyses the structure of air traffic and its distribution among the different countries in the European Union, as well as traffic with an origin or destination in non-EU countries. The findings will be useful for researchers but also for policy makers in

Table 10
Optimistic Scenario traffic growth.

Period	2013–2016	2017–2020	2021–2025	2026–2030
EU domestic traffic	2.8–3.0%	3.4–3.6%	4.0%	4.0%
Traffic to and from EU	4.5%	5.0%	5.5%	5.5%

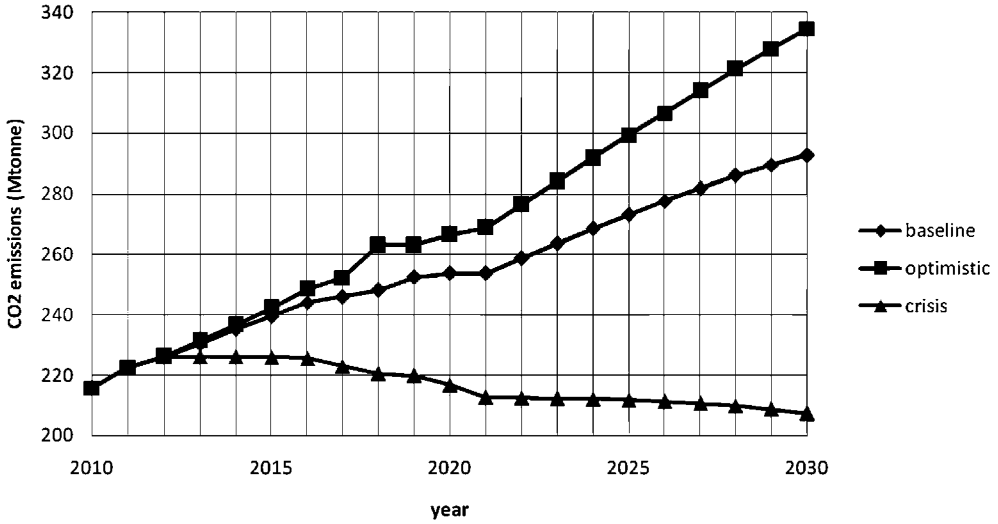


Fig. 3. CO_2 emissions projections for the three scenarios.

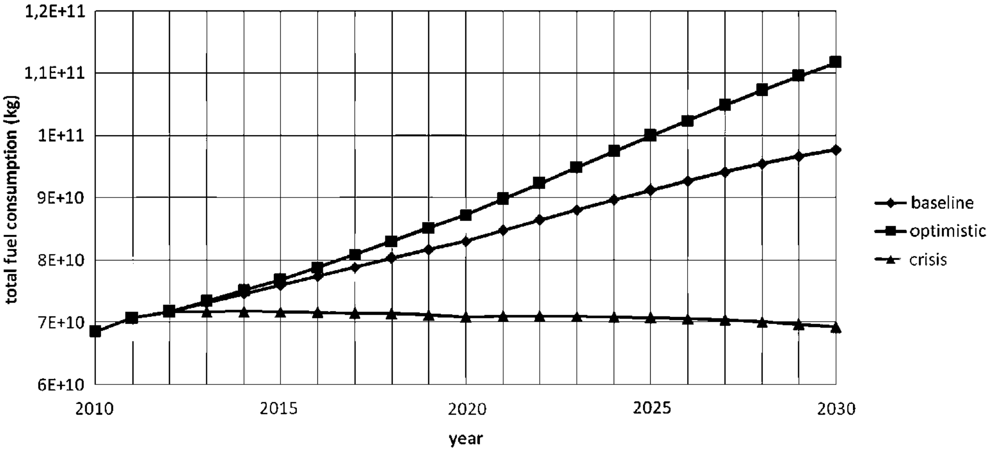


Fig. 4. Total fuel consumption projections for the three scenarios.

their evaluation of different issues related to a specific region such as accessibility, connectivity and competitiveness, or in considering the potential for global integration.

The analysis of passenger flights shows that the traffic is very concentrated on short distances below 1000 km (almost 60% of the flights and 46% of the passengers), despite the broad availability of surface transport alternatives. Air transport cargo is concentrated on long distances, with 69% of the cargo tonnes and 94% of the RTKs flown in distances larger than 2500 km. Passengers' flights are concentrated in the five larger countries of the EU: France, Germany, Italy, Spain and UK. Two thirds of the EU+2 traffic volume correspond to those countries. The distribution of cargo flights is different showing an even larger concentration. France, Germany, The Netherlands and the UK represent together 74% of the total RTKs of the EU+2.

Concerning CO_2 emissions, a total value of 216 million tonnes has been calculated for 2010, in line with the EU inventory. The values again show a large concentration of emissions in a few countries. The UK alone emits 22.5% of the total CO_2 emissions generated by air transport in EU+2. CO_2 emissions per RTK are also given, showing the dependency of this parameter with the distance band, and therefore with the fleet composition used per distance band.

Finally, the projections for CO_2 emissions are given for three different scenarios. They result in a baseline value of 293 million tonnes for 2030, with a band between 207 and 334 million tonnes for the Pessimistic and Optimistic Scenarios, respectively. These projections result in average annual growth rates of CO_2 emissions in the order of 1.8%, −0.2% and 2.7% for the Central, Pessimistic and Optimistic Scenarios, respectively.

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