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Analysis of the recent evolution of commercial air traffic CO_2 emissions and fleet utilization in the six largest national markets of the European Union

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ABSTRACT

This paper presents the results of a study performed to analyze the evolution of commercial air traffic and CO_2 emissions in the European Union, from 2010 to 2013. Data sources are the European Commission's Eurostat Air Transport Statistics (Eurostat) and EUROCONTROL flight plans database. The changes in the fuel efficiency are analyzed and the potential reasons for those changes investigated. The evolution in the airline fleet composition during the last decade is presented as one of the reasons for the improvement in fuel efficiency, measured in burnt fuel per total Revenue Tonne Kilometre (RTK), as well as the different parameters depending on the airline business model (network carriers, low cost companies, etc.) and the aircraft type.

Results show a slight reduction in the traffic, both for passengers and cargo (about −0.8%), and a more important reduction in CO_2 emissions (−4.3%), thanks to an improvement in the fuel efficiency parameter (−3.5%) for the three years period. There has been a relevant change in the fleet composition in the last ten years, with the replacement of older models for more efficient ones, and a shift to larger aircraft, particularly in the regional segment. Traffic has decreased in shorter distances (internal EU traffic), but increased in more efficient long range flights (extra-EU traffic), resulting also in an improvement of the efficiency parameter as average aircraft size and stage length increases.

1. Introduction

The high growth of air transport has been accompanied by an increase in the fuel consumption and therefore CO_2 emissions growth in the last decade, despite of the improvements in the industry efficiency (Lee, 2010). Although the contribution of aviation to climate change is small in relative terms, about 3% of global fossil fuel consumption and 12% of transport-related CO_2 emissions, it is growing faster than other sources of emissions (Simone et al., 2013; Anger, 2010; Mayora, 2010; Macintosh and Wallace, 2009). The vast majority of these emissions come from international flights. By 2020, global international aviation emissions are projected to be around 70% higher than in 2005, which is the reference year for the baseline of the European Union (EU) Emissions Trading System (actual figure was the average of the yearly emissions during the 2004–2006, (Benito et al., 2010)), even if total system fuel efficiency improves by 2% per year. ICAO (2013a) forecasts that by 2050 emissions could grow up by a further 300–700%. The rapid growth in aviation emissions contrasts with the success of many other sectors of the economy in reducing emissions and it is unlikely that the ICAO goal of reaching a Carbon Neutral Growth (no CO_2 emissions increase from the sector) by 2020 could be achieved using exclusively technological measures (Chèze et al., 2013).

These concerns about the future growth of CO_2 emissions by air transport industry led to calls for additional market measures to restrict demand and encourage innovation in international aviation. A discussion of the pros and cons of the different measures can be found in Benito (2007). In this sense, the European Commission (2008) adopted Directive 2008/101/EC, to include aviation in the EU-ETS from the beginning of 2012 and have in study additional actions for the future (European Commission, 2011).

The first international action to put limits to greenhouse gas emissions was adopted in December 1997 when the Conference of the Parties (COP) approved the Kyoto Protocol, imposing

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mandatory target reduction to the emissions from developed countries. There was no agreement on the allocation of international civil flights emissions and ICAO received the responsibility of controlling them at world level. The analysis carried out by ICAO showed that technical measures were insufficient for the task, without a drastic cutting of air transport growth, and Market Based Measures (MBM) were needed. After a failed intent of launching a worldwide ETS in 2007, ICAO has initiated a dual process: on one side, a new requirement for certifying CO_2 emissions from new civil aircraft type should be approved in the 2016 General Assembly together with an additional requirement for models already in production. In the same meeting, Resolution A38-18 contains the approval of a Market based Measure (MBM) system, designed to offset emissions exceeding the 2020 level, is expected, starting by 2021 (ICAO, 2013b). At the same time States carrying at least 1% of international air transport RTKs are required to present to ICAO Action Plans for reducing civil aviation CO_2 not later than June 2015 (ICAO, 2011).

Fuel has been and still is a major component of airlines cost structure, rising up to 36% of the airlines total expenses in 2008. Even after the recent drastic fall down in oil price, the fuel is forecasted to be 21% of total expenses in 2016, as it is shown in Table 1 (IATA, 2015). Due to the rising price of oil and, in the 2006–2014 period, environmental concerns and legislations, fuel efficiency maximization has been always one of the main targets of the industry. The continuous introduction of new and more efficient airplane types such as the B787 and the A350 are the result of these improvements (Peeters, 2013). Including air transport industry in EU-ETS along with the increasing demand of air travel have motivated research and investment into sustainable fuel alternatives, more efficient airplanes and green technologies, and improvements in air traffic management (Gegg, 2014; Krammer et al., 2013; Gudmundsson and Anger, 2012). An interesting aspect is the impact of aircraft size and airlines strategies in the CO_2 emissions (Miyoshi and Mason, 2009). Some authors (Morrell, 2009; Givoni and Rietveld, 2010) have found that the utilization of larger aircraft might result in the reduction of the emissions.

This paper presents the results of a study performed to analyze the evolution of air traffic, CO_2 emissions and fuel efficiency in the European Union, from 2010 to 2013, continuing the work published in Alonso et al. (2014) that extrapolates possible scenarios of traffic and emissions in the EU, taken the 2010 year as starting point. Year 2010 was already characterized in that work, and represents an important reference in the modern evolution of air traffic in Europe: it was the first year of the recovery in airlines results after the 2008 crisis, and it was also the benchmarking year for the allocation of free allowances to aircraft operators according to the civil aviation EU-ETS. On the other hand, 2013 is the first year of growth (in yearly basis) in airlines results, after the decay in 2011 and 2012. The period 2010–2013 covers the second part of the economic crisis initiated in 2008, a complicated business environment for airlines in Europe, with rising fuel costs and a weakening demand. The objective of this paper is to analyze how the main air traffic indicators evolved during that period, reflecting how airlines adapted to the harsh environment, and resulting in the evolution of the fuel efficiency parameter. The results may serve as a base for developing new potential scenarios and give an orientation on how changes in relevant parameters affect airline behavior and civil aviation emissions in the EU and some of its larger Member States.

In the first section of the paper the structure of air traffic evolution is investigated, both for passenger and cargo traffic, comparing the main indicators in 2013 with respect to their values in 2010. The evolution of traffic in the six largest European markets is compared, as well as the distribution of traffic in terms of flights distances and aircraft types. The second part of the paper analyzes the evolution of CO_2 emissions for the same period, and from the same perspective: comparison of the evolution per country, per distance band, and per aircraft type. Then, an efficiency parameter is defined, in terms of kg CO_2/RTK, and its evolution analyzed, trying to identify the potential reasons for the changes, particularly the fleet evolution along the last ten years, an expanded period (compared to the 2010–2013 reference period for the evolution of traffic, emissions and efficiency) because the effects of the changes in airlines' fleets usually take time to materialize.

2. Traffic evolution

Air transport data for all flights from EU and associated Member States airports have been collected from the European Commission's Eurostat Air Transport Statistics (Eurostat, 2013). The following information is extracted directly, for each airport pair: total commercial passenger flights, total passengers on board and total passenger seats available for passenger transport; all-freight and mail total commercial air flights and total freight and mail on board in tons for freight and mail air transport. The following parameters are derived: number of RPKs (revenue passenger kilometers) and ASKs (available seat kilometers) for passenger transport; number of FRTKs (freight revenue ton kilometers) for freight and mail transport and total RTKs for both passenger and cargo. Finally, data were segmented by country and per distance bands, at intervals of 500 km, which is the EU scale for classifying the activities of the different transportation modes. See Alonso et al. (2014) for a detailed description of the methodology.

From the study performed about traffic and emissions in 2010 (Alonso et al., 2014), the concentration of traffic in the EU was apparent: the 6 largest countries in terms of traffic (France, Germany, Italy, The Netherlands, Spain, United Kingdom) represented 79.7% of the total RTKs in 2010 for passenger traffic and 82.3% for cargo traffic. Therefore, in the present study about the evolution of 2013 air traffic, preferential attention is given to these six largest markets as a good representation of the traffic evolution in the whole EU.

The results showing the evolution of passenger traffic are shown in Table 2, where the main figures in 2013 are given and compared to the 2010 corresponding ones: number of flights, passengers, RPKs, Load Factor and the average number of passengers per flight. Analyzing those results, it can be seen that the UK remains the largest market by far in terms of RPKs, representing 29% of the total for the six countries, followed by Germany (21%), France (19%) and Spain (15%). With the exception of Italy and The Netherlands, both the number of flights and the number of passengers grew in all countries, resulting in an overall increase in the number of flights

Table 1
Evolution of the fuel expenses of airlines (IATA, 2015).

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015(f)	2016(f)
Brent (USD/b)	65.1	73.0	99.0	62.0	79.4	111.2	111.8	108.8	101.4	55.0	51.0
Fuel expenses (BUSD)	127	146	205	135	152	192	227	228	226	180	135
% of expenses	28	30	36	28	28	31	33	33	32	27	21

(f) forecast; USD/b US Dollars per oil barrel; BUSD billions of US Dollars.

Table 2
Passenger traffic per country in 2013. In brackets, change with respect to 2010 in percentage.

Country	Flights (thousands)	Passengers (millions)	RPK (billions)	Load factor (%)	Passengers per flight
Germany	1462 (+11%)	165 (+16%)	320 (+4%)	80 (−2%)	113 (+5%)
Spain	1118 (+6%)	138 (+6%)	230 (−3%)	78 (+2%)	124 (+0%)
France	1108 (+12%)	128 (+18%)	284 (+9%)	74 (−6%)	116 (+4%)
Italy	883 (−17%)	104 (−10%)	116 (−19%)	75 (−2%)	118 (+8%)
The Netherlands	348 (−6%)	44 (−1%)	125 (−7%)	85 (+2%)	128 (+5%)
United Kingdom	1435 (+12%)	179 (+8%)	445 (−1%)	79 (−2%)	124 (−3%)
Total	6353 (+5%)	758 (+7%)	1520 (−1%)	78 (−2%)	119 (+2%)

(5% more in 2013 than in 2010) and in the number of passengers (7% more in 013 than in 2010). Despite of the growth in terms of flights and passengers, there is a reduction in the number of RPKs (1% less in 2013 than in 2010) indicating a slight average stage length decrease. Only in Germany and France there is growth in terms of RPKs but lower than the growth in passengers, with the corresponding reduction of the average flight length as well. It is interesting to note that the 2010 traffic was affected by the air space closure following the eruption of the Eyjafjallajökull volcano in Iceland, but the 2013 traffic is still slightly lower in terms of RPKs, indicating that the effects of the difficult economic conditions in Europe have had a greater impact on air traffic. There is a slight reduction in the average Load Factor (2% less), indicative of the commercial difficulties of airlines, and an increase in the number of passengers per flight (2% more). Both the reduction in the average Load Factor and the increase in the number of passengers per flights, together with the reduction in terms of RPKs can be explained by an increase in the average size of the aircraft used by airlines, as it can be seen in Table 6, and it will be shown in Section 5 of this paper.

The distribution of commercial passenger traffic, segmented per distance band, is presented in Table 3. It is interesting to note how the average load factor grows with the distance, from the 67% for distances below 500 km, where there is a high presence of regional aviation flights, to the 80% for distances longer than 2500 km. It is also noticeable the average number of seats per flight: 123 for distances less than 500 km. It means than an important part of these low range flights are performed by single aisle jets, instead of smaller regional jets or more efficient turboprops, as the airlines try to simplify their fleet composition reducing the number of different aircraft types, selecting models capable to operate in a variety of routes.

As it was the case in 2010 (Alonso et al., 2014), there is a clear concentration in both the number of flights and the number of passengers in the distance range below 1000 km (respectively 64% and 51% of the total), representing intra-EU flights, highly competitive and exposed to competition with surface modes, particularly high speed train (European Commission, 2010; Duarte et al., 2008). However, most of the RPKs are in distances longer than 2500 km (75% of the total, while just 17% for the range below 1000 km). The interval between 2000 km and 2500 km shows the smallest number of flights (3%), passengers (also 3%) and even RPKs (4%).

In terms of cargo (Table 4) there is growth from 2010 to 2013 in terms of FRTKs in all countries except The Netherlands and the UK. As it was the case in 2010, the ranking is different than for passenger traffic. Countries with more cargo volume are: Germany, UK, The Netherlands and France. Airports in The Netherlands move more cargo than those in France, Spain and Italy (countries with more passenger traffic). This result is consistent with the ranking of airports in Europe in terms of cargo, being the top four Frankfurt, Paris Charles de Gaulle, Amsterdam Schiphol and London Heathrow (ACI, 2015).

The distribution of cargo traffic is presented in Table 5, classified per distance band. The results support the conclusions from the 2010 study. Most of cargo flights (66%) correspond to short distances, with less than 1000 km, typical of courier services and feeders of large cargo hubs. The bulk of the cargo (68%) is transported to long distances, larger than 2500 km, but those flights only represent 19% of the total. This is due to the much larger size of these aircraft transporting cargo to long distances (average 151 tons per flight). In fact, 94% of the FRTKs correspond to distances longer than 2500 km.

Finally, the distribution in terms of distance band and aircraft type of all flights in the EUROCONTROL airspace has been analyzed, with the intention of deriving conclusions on the evolution of the airlines industry in Europe. The study covers the so called EU+2 countries, including all the present EU members but Croatia, plus Norway and Switzerland. The distribution of flights given in Table 6 has been obtained from EUROCONTROL DDR 2013 data, which allows the classification per aircraft type. From the figures in Table 6 it can be observed that about 78% of the flights are performed with short and medium range jets. This percentage has increased with respect to 2010 figures (75.6%), reflecting the progression of the development of the low cost model in Europe which, as a reference, has passed from a 20% market share in 2008 to a 26% in 2013 (EUROCONTROL, 2014). According to OAG (2013), the number of seats offered by low-cost carriers (LCCs) in Europe has increased by an average of 14% per year over the last decade, compared to a 1% average annual rise in capacity among legacy carriers. LCCs are exclusively operating medium range aircraft and their growth has influence in this size aircraft inventory.

There is a reduction in the number of flights in the short range distance (below 500 km), and also in the range between 500 km

Table 3
Passenger traffic in 2013 for the six largest countries segmented per distance band.

Distance band (km)	Flights (thousands)	Passengers (millions)	RPK (billions)	Seats (millions)	ASK (billions)	Load factor (%)	Seats per flight
<500	1863	153	57	229	85	67	123
500–1000	2205	233	166	316	224	74	143
1000–1500	939	123	153	162	200	77	172
1500–2000	471	68	118	87	150	79	184
2000–2500	177	25	56	32	71	79	180
>2500	698	155	970	195	1218	80	279
Total	6353	758	1520	1020	1948	78	119

Table 4
Cargo traffic per country in 2013. In brackets, change with respect to 2010 in percentage.

Country	Flights (thousands)	Tons (thousands)	FRTK (millions)	Tons per flight
Germany	77 (+12%)	3925 (+7%)	18,235 (+6%)	51 (−4%)
Spain	33 (+26%)	576 (+5%)	2584 (+4%)	17 (−19%)
France	51 (+30%)	1609 (+15%)	8001 (0%)	32 (−11%)
Italy	24 (−7%)	726 (−3%)	3265 (+10%)	30 (+3%)
The Netherlands	14 (−19%)	1308 (−14%)	8710 (−11%)	94 (+7%)
United Kingdom	50 (+44%)	2245 (−2%)	11,974 (−3%)	45 (−32%)

Table 5
Distribution of cargo traffic main data in 2013 (six largest countries).

Distance band (km)	Flights		Tons		FRTK		Tons per flight
	Thousands	%	Thousands	%	Millions	%	
<500	87	35	1030	10	389	1	12
500–1000	78	31	1293	12	925	2	17
1000–1500	22	9	413	4	508	1	19
1500–2000	11	4	266	3	471	1	24
2000–2500	5	2	307	3	654	1	61
>2500	47	19	7079	68	49,822	94	151
Total	250	100	10,388	100	52,769	100	42

Table 6
Number of flights in EU+2 classified per distance band and aircraft type in 2013.

Distance band (km)	Aircraft type (MTOW in tons)				Total band		
	<7	7–136		>136	2013		2010
		Turboprop	Jet	Wide body	Total n^{er} of flights	% Of total	% Of total
<500	50	671	1436	26	2182	25.3%	29.0%
500–1000	12	154	2013	31	2209	25.6%	26.8%
1000–1500	2	20	1243	26	1290	15.0%	14.3%
1500–2000	1	4	886	25	916	10.6%	10.1%
2000–2500	0	1	518	37	556	6.5%	5.3%
>2500	0	0	608	852	1461	17.0%	14.6%
Total type	64	850	6705	996	8614		8439
2013	0.7%	9.9%	77.8%	11.6%			
2010	0.9%	13.0%	75.6%	10.4%			

and 1000 km, compatible with the already mentioned intensification of the competition with surface modes, like high speed train, and consistent also with the decrease in the domestic traffic consequence of the economic crisis, especially acute in some countries like Greece or Spain. The large reduction of the number of flights with turboprop shown in Table 6 supports this conclusion.

On the other hand, there is an increase in the number of flights in the medium range (from 1000 km to 2500 km), which can be explained again by the continuous development of the low cost business model, with routes of 2–3 h of flight, concentrated in the intra-EU network, a liberalized area with no need of bilateral agreements for traffic rights. The long range flight (distances longer than 2500 km) number increases as well, indicating the air traffic growth outside the EU (ICAO, 2013a) to and from countries less affected by the financial crisis. Again, this conclusion is supported by the growth in the number of flights performed with jets (single aisle) and wide bodies (see Table 6). It is worth noting (thinking of CO_2 emissions) that there are more wide body flights than turboprops ones.

Overall, there is an increase of 2.1% in the total number of flights in the EU+2 perimeter in 2013 compared to 2010 (this increase was larger, 5%, just for the six largest markets, Table 2).

3. CO_2 emissions evolution

In order to evaluate fuel consumption and subsequently CO_2 emissions by country and to classify this information according to aircraft type and distance band, data from the EUROCONTROL Data Demand Repository (DDR) (EUROCONTROL) have been used. There, information from the flight plans in EUROCONTROL countries is stored. For each individual flight fuel consumption is evaluated using the Corinair database (EEA, 2007), which gives the fuel consumption for every aircraft type as a function of the distance flown. See Alonso et al. (2014) for a detailed description of the methodology. The objective is to evaluate CO_2 emissions in 2013, and to relate these emissions with the traffic structure and evolution from 2010 already described in the previous Section.

The CO_2 emissions in the 29 countries in 2013 are presented in Table 7, together with the evolution from 2010. Overall, there is a reduction of 3.1% in the CO_2 emissions in 2013 (209.1 Mtons) compared to 2010, i.e. slightly more than a 1% average yearly decrease in the period. For comparison, from 2005 (reference year for the EU-ETS) to 2010 the overall increase in CO_2 emissions was 10%, i.e. a 2% average yearly increase (Alonso et al., 2014).

Data show a big concentration of CO_2 emissions in the selected six countries, consistent with the concentration in the traffic distribution among countries. CO_2 emissions from the 6 largest countries represent 76.8% of the total of the EU+2 CO_2 emissions.

Table 7
CO2 emissions in EU+2 countries in 2013 compared to 2010.

Ranking	Country	CO_2 emissions (Mton)	Change w.r.t. 2010 (%)
1	UK	47.36	−2.6%
2	Germany	37.62	−4.2%
3	France	26.92	−4.3%
4	Spain	17.49	−11.5%
5	The Netherlands	16.12	−0.6%
6	Italy	15.05	−4.3%
7	Switzerland	6.56	9.0%
8	Belgium	5.38	−4.9%
9	Greece	4.69	0.6%
10	Portugal	4.21	0.0%
11	Denmark	3.44	5.5%
12	Norway	3.26	18.5%
13	Sweden	3.16	2.6%
14	Austria	2.99	−9.7%
15	Ireland	2.85	9.2%
16	Finland	2.56	5.8%
17	Poland	2.07	−8.4%
18	Czech Republic	1.30	−4.4%
19	Cyprus	1.14	2.7%
20	Bulgaria	1.03	19.8%
21	Luxembourg	0.90	−30.2%
22	Romania	0.84	−10.6%
23	Hungary	0.59	−32.2%
24	Latvia	0.46	9.5%
25	Malta	0.37	12.1%
26	Lithuania	0.24	20.0%
27	Estonia	0.17	41.7%
28	Slovakia	0.17	−15.0%
29	Slovenia	0.14	−12.5%
Total		209.1	−3.1%

Just the UK represents 22.5% of the total EU+2 CO_2 emissions.

The evolution of the CO_2 emissions per distance band is analyzed in Table 8. Results show a reduction in the emissions in all the distance ranges (comparing 2013 to 2010), with the exception of the 1500 km–2500 km interval. The largest reduction is in the short range interval (distance below 500 km), with a significant increase in the range between 2000 km and 2500 km. The evolution of emissions classified per distance is different than the evolution of traffic already described in Section 2. It is especially relevant the emissions reduction in the largest distances interval (longer than 2500 km), responsible for most of the emission, because the number of flights grew in that band.

The distribution of the CO_2 emissions per aircraft type and distance band is shown in Table 9. As it could be expected, most of the CO_2 emissions (73%) correspond to long distance flights (longer than 2500 km). It is worthwhile highlighting again the relevance of the long range traffic in the six largest markets analyzed, comparing the results in Tables 8 and 9. It can be observed in Table 9 that the distribution of the share of the six largest countries varies between 58% and 70%, depending on the distance band, except in the more than 2500 km band, where the share reaches 83%. This fact has an impact in the efficiency figures, as it will be shown in Section 4, because long range flights are usually more efficient in terms of fuel consumption.

Table 9
CO_2 emissions in the 6 largest EU aviation markets in 2013 classified per distance band and aircraft type.

Distance band (km)	Aircraft type (MTOW in tons)				
	<7	7–136		>136	Total band
		Turboprop	Jet		
<500	–	0.5	4.6	0.2	5.2
500–1000	–	0.2	10.7	0.4	11.4
1000–1500	–	–	10.0	0.5	10.5
1500–2000	–	–	9.0	0.5	9.5
2000–2500	–	–	6.1	0.5	6.6
>2500	–	–	10.7	106.7	117.4
Total type	–	0.7	51.1	108.7	160.8

4. Fuel efficiency evolution

Once the traffic and CO_2 emissions evolution has been analyzed, it is possible to investigate the fuel efficiency (or CO_2 emissions efficiency) evolution. The evolution of the efficiency parameter, measured in terms of emitted CO_2 per RTK (or burnt fuel per RTK) is shown in Table 10 for the six largest EU aviation markets. There is a reduction of 4.3% in the CO_2 emissions, only partly explained by a modest decrease in the traffic (0.8% in terms of RTK). Overall, there is a 3.5% improvement in the efficiency parameter, which corresponds to an average 1.2% yearly improvement between 2010 and 2013. The reduction in the CO_2 emissions for the six largest countries (−4.3%) is larger than for the whole EU+2 (−3.1%), in the three years period.

From data in Table 11, it can be seen that longer distance routes (>2500 km) account for 73% of total CO_2 emissions, consistent with carrying 72% of the RTKs. Shorter distances (below 500 km) are responsible for just 3.3% of the CO_2 emissions, but move 20% of the passengers. Most of the efficiency gain comes from the shorter distance range (distances below 1000 km) and especially from the long distance range (longer than 2500 km).

The methodology that has been followed to analyze the evolution of traffic and CO_2 emissions is also useful to derive the same type of information at airline level, and investigating for instance the differences in terms of energy efficiency among the various airline business models. The results are shown in Table 12, where the average efficiency is presented for a subset of network carriers (Lufthansa, 1st European airline and 6th of the world in terms of traffic, Air France, KLM, British Airways, Iberia, SAS and Alitalia), low cost carriers (Ryanair, largest European low cost carrier and 2nd of the world in this category, Easyjet, Air Berlin, Norwegian, Vueling and Wizz), Regionals (Air Nostrum, Air Dolomiti and BEE) and Inclusive Tour (IT) or charter carriers (TUI, Thomas Cook and Monarch), a category still important in the intraeuropean traffic.

Table 8
CO_2 emissions in EU+2 countries in 2013 classified per distance band (Mtons are millions of CO2 tons; w.r.t. means with respect to).

Distance band (km)	CO_2 2013		CO_2 2010		2013 w.r.t 2010 (%)
	Mtons	% Of total	Mtons	% Of total	
<500	7.9	3.8	9.9	2.6	−20.2
500–1000	16.3	7.8	18.1	8.1	−9.2
1000–1500	15.7	7.5	16.2	8.8	−3.1
1500–2000	15.5	7.4	15.4	7.3	0.6
2000–2500	11.3	5.4	10.6	4.3	6.6
>2500	142.3	68.1	145.6	68.7	−2.3
Total	209.1		215.8		−3.1%

Table 10
Efficiency parameter per country. Comparison between 2013 and 2010.

Country	RTK (millions, passengers + cargo)			CO_2 (Mtons)			kg CO_2/RTK		
	2013	2010	Var. (%)	2013	2010	Var. (%)	2013	2010	Var. (%)
Germany	50,235	47,842	+5.0	37.62	39.25	−4.2	0.75	0.82	−8.7
Spain	25,584	26,373	−3.0	17.49	19.76	−11.5	0.68	0.75	−8.8
France	36,401	34,089	+6.8	26.92	28.14	−4.3	0.74	0.83	−10.4
Italy	14,865	17,367	−14.4	15.05	17.73	−4.3	1.01	0.91	11.8
The Netherlands	21,210	23,342	−9.4	16.12	16.21	−0.6	0.76	0.69	9.1
United Kingdom	56,474	57,382	−1.6	47.36	48.6	−2.6	0.84	0.85	−1.0
Total 6	204,769	206,395	−0.8	160.56	167.69	−4.3	0.78	0.81	−3.5

Table 11
Efficiency parameter for the six largest EU aviation markets in 2013 classified per distance band. In brackets, percentage with respect to the total.

Distance band (km)	RTK (millions, passengers + cargo)	CO_2 (Mtons)	CO_2/RTK (kg/RTK)	
			2013	Change w.r.t. 2010
<500	6089 (3%)	5.24 (3.3%)	0.86	−14.0%
500–1000	17,525 (9%)	11.37 (7.1%)	0.65	−11.0%
1000–1500	15,808 (8%)	10.54 (6.6%)	0.67	1.5%
1500–2000	12,271 (6%)	9.48 (5.9%)	0.77	8.5%
2000–2500	6254 (3%)	6.57 (4.1%)	1.05	19.3%
>2500	146,822 (72%)	117.36 (73.1%)	0.80	−1.3%
Total	204,769	160.56	0.78	−3.5%

Table 12
Airlines emissions and efficiency.

Airline type	Average efficiency (kg CO_2/RTK)	Difference w.r.t. Network carriers (=100)
Network carriers	1.06	100
Low Cost Carriers	0.83	78
Regionals	1.84	1.73
IT's or charter	0.60	57

According to this analysis, the average efficiency of the low cost carriers represents 78% of the value for the network carriers, a very important difference that explains partly the cost advantage of this type of companies. IT's or charter carriers are even more efficient (60% of the efficiency of the network carriers). On the other hand, Regionals show the worst behavior, with an efficiency 73% higher than that of the network carriers. These results are consistent with the analysis of Mason and Miyoshi (2009) for the period 1997–2006.

In order to investigate the reasons of those differences in the efficiency for each airline business model, the efficiency of the various aircraft types, depending on how they are utilized by each airline, have also been analyzed. The results are shown in Table 13 and Fig. 1. As the Corinair database has a relatively wide definition of aircraft type, putting together models with different weights and engines, these figures should be considered as approximate but give a good first order of magnitude of the comparative results.

A relevant aspect of this comparison is the higher efficiency (in terms of kg CO_2/RTK) of the low cost carriers compared with the traditional airlines when operating the same type of aircraft (Airbus A320 or B737NG family aircraft). Analyzing (Table 13) the dependency of the efficiency parameter with the average stage length, it can be appreciated how the improvement in the efficiency parameter of the low cost carriers compared to the network carriers flying the same type of aircraft is larger for longer values of the average stage length, but it is also the case even for smaller values of the average stage length, as a proof of a more modern fleet composition in the case of the low cost carriers.

Another interesting output of this analysis is the different aircraft utilization that airlines obtain from the aircraft they operate. It can be observed from data in Table 14, how the daily utilization of the same aircraft type is quite higher for low cost companies compared to network carriers due to the differences between their network structure (point to point instead of hub&-spoke) and operation procedures (short time airport turnaround, no connections, no cargo).

5. Fleet evolution 2004–2013

In order to explain the improvement in the efficiency previously shown, the evolution of the fleet composition of airlines operating in the EUROCONTROL airspace has been performed for the last decade. The evolution of the number of aircraft of each category is shown in Fig. 2, where the percentage of the number of flights operated by each aircraft type with respect to the total number of flights is shown from 2004 to 2013. As it was explained in the Introduction, even if the period covered by this investigation of traffic and efficiency evolution is 2010–2013, the changes in airlines' fleet composition are analyzed for a longer time frame to show the trend in this important parameter for the airlines efficiency.

The share of flights operated by wide bodies is relatively stable, being the same at the end of the period than at the beginning (12%), with a slight decrease during 2008 (10%) and the interval 2009–2012 (11%). Probably the most relevant result is the sustained increase in the share of the single aisle type, growing continuously from 62% in 2004 to 67% in 2013. This increase matches very well with the reduction in the share of regional aircraft, decreasing from a 26% share in 2004 to a 22% in 2013, where the decrease in the smaller segment (below 50 seats), from

Table 13
Efficiency of aircraft operated in 2013.

Family	Model	Network carriers		Low cost carriers	
		Mean leg (km)	kg CO_2/RTK	Mean leg (km)	kg CO_2/RTK
A320	A318	590	1.13		
	A319	966	1.12	862	1.12
	A320	1034	0.95	1261	0.76
	A321	1247	0.78	1419	0.68
Single aisle Airbus		**959**	**0.99**	**1181**	**0.86**
B737-classic	B737-300	592	1.20	868	1.04
	B737-400	1117	1.08		
	B737-500	532	1.47		
B737-NG	B737-600	657	1.18		
	B737-700	785	1.13	507	1.33
	B737-800	2000	0.73	1253	0.69
	B737-900	2108	0.75		
Single aisle Boeing		**1113**	**1.08**	**876**	**1.02**
Total single aisle		**1057**	**1.05**	**1028**	**0.94**
A330	A330-200	5548	1.10		
	A330-300	5514	0.99		
A340	A340-300	6416	1.05		
	A340-600	7984	0.94		
A380	A380	8462	0.78		
Wide body Airbus		**6794**	**0.97**		
B767	B767-300	3760	0.82		
B777	B777-200	8020	1.04		
	B777-LR	6327	0.78		
	B777-W	8400	0.84		
B747	B747-400	7592	1.09		
Wide body Boeing		**8004**	**0.99**		
Total wide body		**7284**	**0.98**		
Regionals		**588**	**1.61**		

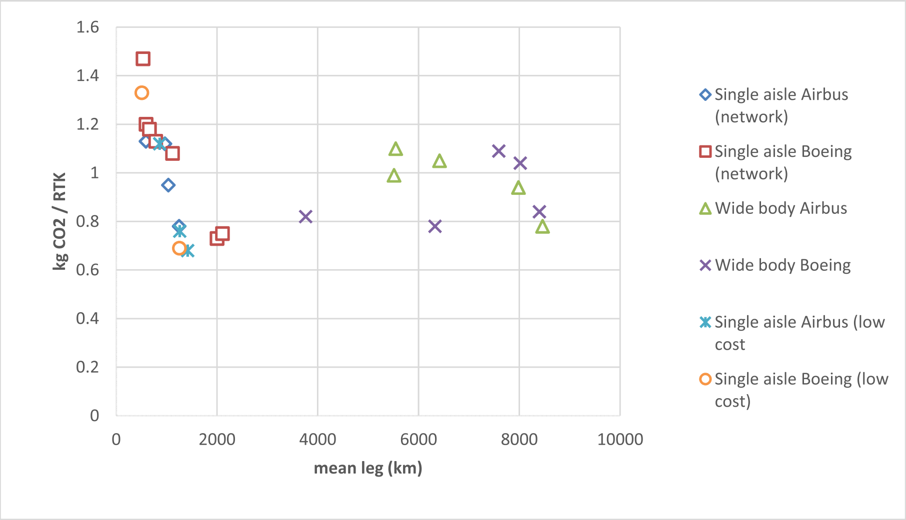

Fig. 1. Efficiency of different aircraft type and airline business model.

Table 14
Aircraft utilization.

Model	Airline	Daily utilization (block hours)
A319	British Airways	6.3
	Iberia	9.0
	Easyjet	10.1
A320	British Airways	7.1
	Iberia	8.3
	Easyjet	10.4
	Wizz	10.2
B737-800	KLM	9.5
	Ryanair	11.5

16% to 5% does not compensate the increases in the 70 seats category (from 8% to 10% and in the more than 90 seats category (from 2% to 7%). The result is an overall increase in the average size of the aircraft flying these routes, where regional models are reducing their participation in the total of the flights, while larger jets, both single aisle and wide body, are increasing theirs. These figures are consistent with the results of the traffic evolution described in Section 2, and with the changes in the business model of the airline industry in Europe in the last decade, with the continued growth of low cost companies, typical users of single aisle aircraft, and the difficulties of regional airlines caused at a great extent by the poor economy of small size jets in an expensive fuel environment and

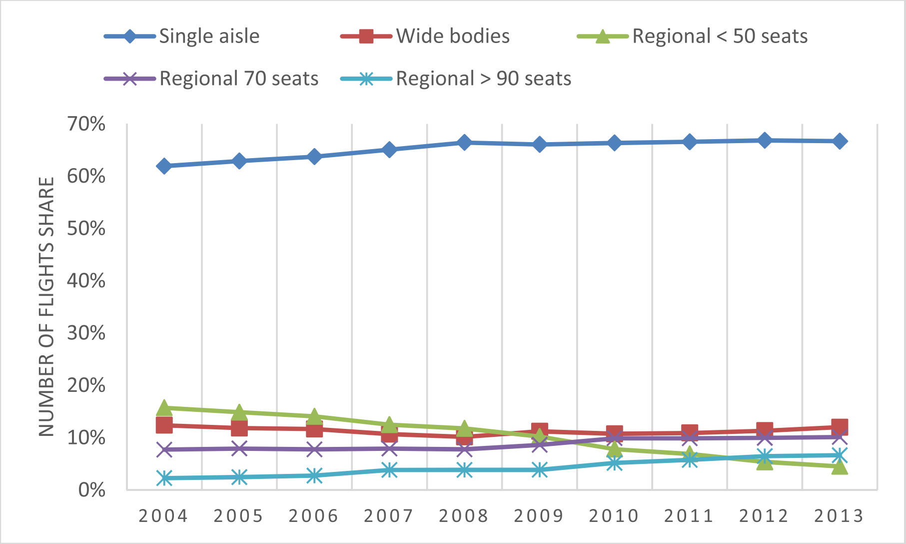

Fig. 2. Fleet evolution 2004–2013 per aircraft category.

the competition of fast surface transportation modes.

The improvement in the industry fuel efficiency shown previously, can be partly explained by the evolution of the number of flights operated by aircraft of each category shown in Figs. 3–7, where the percentage of flights operated by each aircraft model with respect to the total of the corresponding category is plotted. Concerning single aisle aircraft, the replacement of the classic B737 family by the newer B737 NG family is clearly appreciated in Fig. 3, as well as the reduction in the share of the B757 and the practical disappearance of the MD80/MD90 series, both replaced by a mix of B737NG and A320 families. All replacements are made with more energetic efficient models and collaborate to reduce CO_2 emissions per RTK.

Concerning wide bodies (Fig. 4), there is a continuous increase in the share of the two most modern long range twin types, the A330 and the B777, reaching each of them 25% of the total number of flights of this category in 2013, starting in both cases also with a 13% in 2004. Only the A340-500/600 and the newest A380, B747-8 and B787 increase their share. There is a strong reduction in the relative number of flights of old models such as the A300/A310, the DC10/MD11 and the older versions of the B747 and A340-200/300, all of them out of production nowadays. The share of the B767 shows a slow decline from 18% to 16%.

It can be concluded that along the full period 2004–2013 (and also between 2010 and 2013), there has been an important renovation in the commercial jet (single aisle and wide bodies) fleet operating in the EUROCONTROL airspace. This fleet renewal can explain the improvement in fuel efficiency described in Section 4.

In the regional aircraft segment with up to 50 seats (Fig. 5), there has been a strong increase in the share of turboprops, from 38% in 2004 to 49% in 2014, reflecting the need for efficiency improvement of regional airlines during the decade. It is particularly noticeable the increase in the share of the Dash8 family and the strong decrease of the share of the CRJ100/200, good example of jet-powered 50 seaters, affected by the high price of fuel and being partially replaced by more fuel efficient turboprop models.

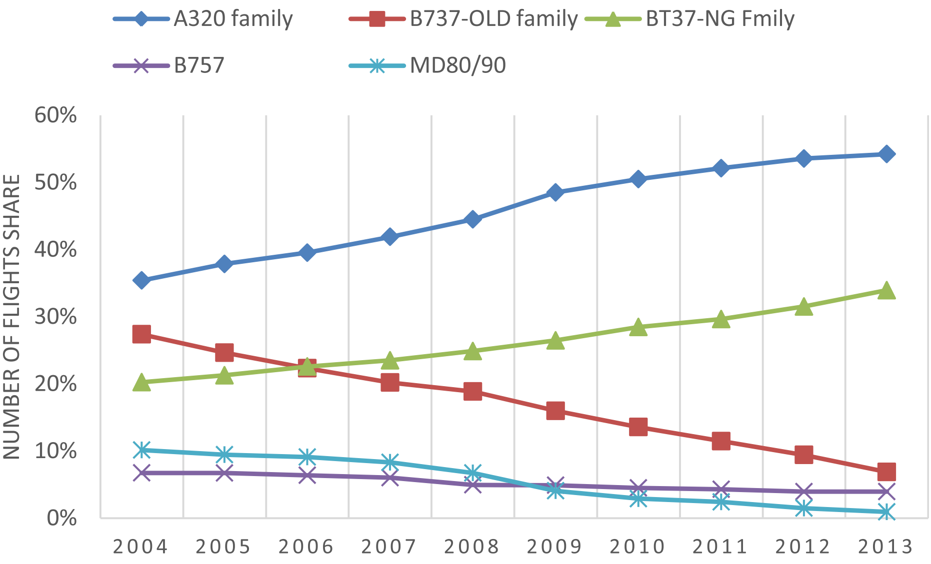

Fig. 3. Fleet evolution 2004–2013. Single aisle.

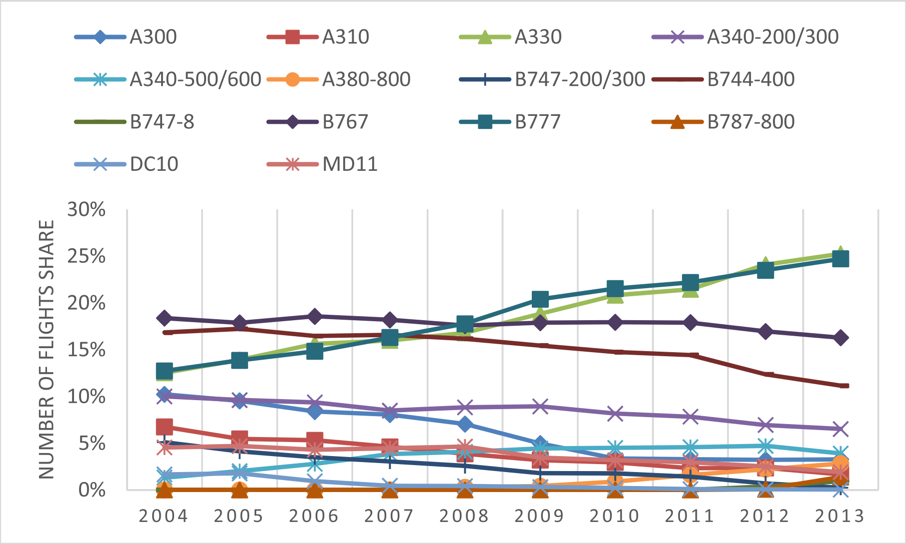

Fig. 4. Fleet evolution 2004–2013. Wide bodies.

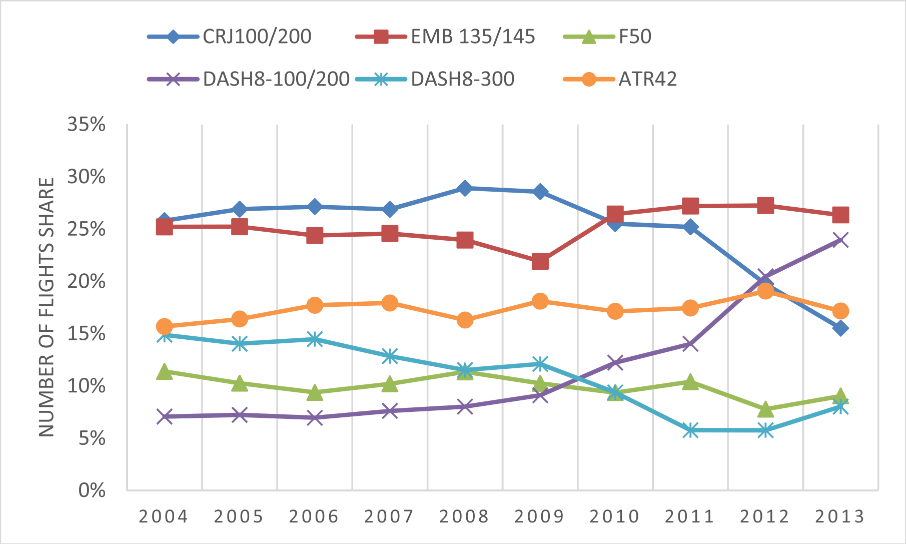

Fig. 5. Fleet evolution 2004–2013. Regional aircraft with up to 50 seats.

The share of turboprops have remained more stable in the regional aircraft segment with 70 seats (Fig. 6), varying around 70% for the whole period (adding the ATR42 and Dash8-400Q). From the jet side, there is a replacement of the CRJ700 and especially the older Fokker F70 by the Embraer E170.

Finally, in the larger regional jets segment (Fig. 7), again the Embraer model (E190) has the largest share, more than 54%, followed by the similar size Bombardier models CRJ900 (26%, and decreasing), and the CRJ1000 (8%). All of them replace the old (and far less efficient in terms of fuel consumption) Fokker F100, which had 100% of the share in terms of number of flights in 2004, and keeps just 11% in 2013.

Summarizing, there has also been an improvement in fuel efficiency in the regional segment, coming from different sides:

- Replacement of jets by turboprops in the smaller segment (less than 50 seats).
- Replacement of old models (Fokker F70 and F100) by newer models (E170/190, CRJ900/1000) in the large regional aircraft segment.
- Overall, an increase in the aircraft size, with a net reduction in the number of flights operated by aircraft with less than 50 seats and an increase in the flights with aircraft with more than 90 seats.

6. Conclusions

The investigation of the commercial passenger traffic evolution in the six largest markets in the European Union (representing some 80% of the total EU RTKs) shows a slight reduction in traffic, almost 1% from 2010 to 2013, as a consequence of the financing crisis in Europe. This is unevenly distributed according to the evolution of the local economies in those years: growth in Germany and France, decrease in the UK, Spain, Italy and The Netherlands.

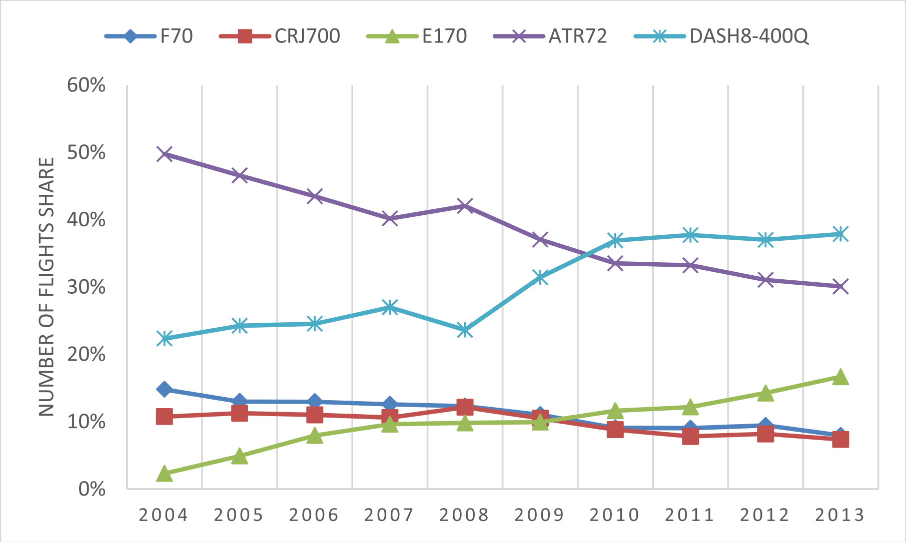

Fig. 6. Fleet evolution 2004–2013. Regional aircraft with 70 seats.

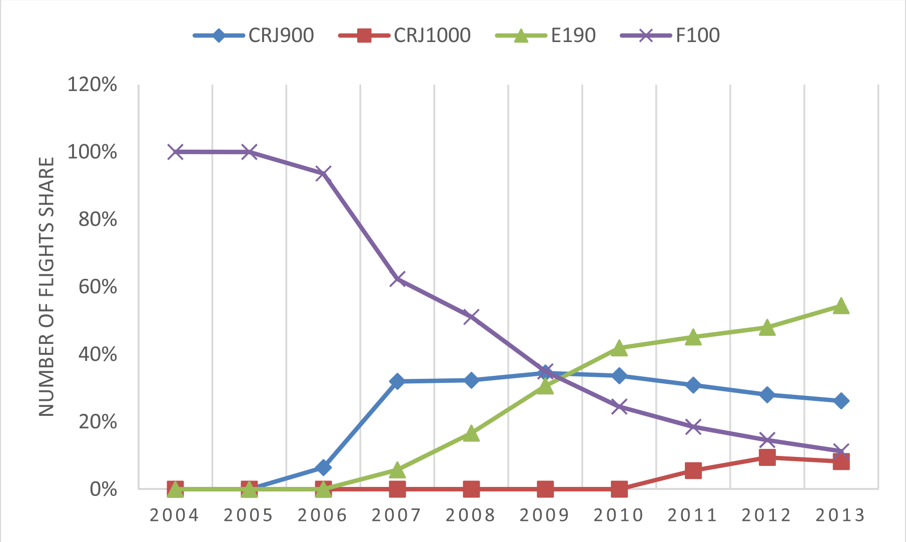

Fig. 7. Fleet evolution 2004–2013. Regional aircraft with more than 80 seats.

Most of the flights are operated in the distance range below 1000 km, although most of the RPKs are flown in distances longer than 2500 km.

The number of flights performed with short and medium range jets (78%) has increased with respect to 2010 figures (75.6%), as well as the number of flights in the medium range (from 1000 km to 2000 km), reflecting the progression in the development of the low cost model in Europe. There is on the other side a reduction (in relative terms) in the number of flights performed with turboprop and in the number of flights in the short range distance (below 500 km). It corresponds to the reduction in the domestic traffic and may be also an indication of an escalation of the competition with surface modes, like high speed train. Largest growth in traffic comes in the long range (distances longer than 2500 km), and in the number of flights performed with single aisle and wide body jets, indicating the air traffic growth outside the EU, less affected by the weak economy.

The CO_2 emissions have been reduced by 4.3% in the three years period considering only the six largest markets. Considering the overall EU+2 perimeter, the reduction in the CO_2 emissions is smaller, 3.1%, corresponding to lower levels of fleet renewal in less wealthy economies.

The reduction in the CO_2 emissions is larger than the decrease in traffic (RTKs), resulting therefore in a 3.5% improvement in efficiency (kg of CO_2 per RTK), coming from efficiency improvements in shorter-range flights (less than 1000 km) and long-range flights (longer than 2500 km). This latter segment explains the overall improvement in the efficiency parameter, as it accounts for 73% of the total CO_2 emissions.

That global figure for the three year period (2013-2010) is 3.1% and represents a 1.2% average efficiency improvement per year, a number being lower than the 1.5% voluntary commitment adopted by IATA and much lower than the 2% aspirational target established by ICAO (2013b). However, it is in line with the most recent analysis (Kharina and Rutherford, 2015) which have found an improvement of 1.1% per year in the same period, considering only the evolution of the world fleet composition. As the calculation in the present investigation covers fleet composition but also real operation and network evolution, the 10% difference may be considered acceptable for those two additional factors.

Taking a representative sample of airlines from the different business models (network, low cost, regionals, Inclusive Tour), the differences in their corresponding efficiencies are highlighted, with important efficiency variations among them. Charter type carriers with high density interior configuration, medium to long range routes, high load factors and large aircraft are the most efficient, while regional carriers, with standard interiors, medium to short range routes, modest load factors and small aircraft are the worst. The results show that Inclusive Tour operators are three times more efficient that regionals in CO_2 emissions. A clear consequence is that fuel efficiency increases as load factor and seating density get higher and an advanced policy of emissions reduction should make clear distinction among different passenger accommodation and on the cargo effect as well. An additional conclusion may led us to show that the freighter version of a passenger aircraft is always more energetically efficient than the original, at similar load factor.

In order to try an explain the improvement in the efficiency parameter, an analysis of the fleet composition has been performed, showing an important fleet renewal in the last ten years, implying the replacement of old models by newer ones and an increase of the average size of aircraft, especially in the regional routes segment. While passenger preference leans towards high frequency service with small aircraft, low frequency with larger aircraft is much more efficient in terms of energy use and in airport capacity use as well.

As the technological efficiency increase does not seem enough to compensate the traffic growth, the only way of stabilizing air transport CO_2 emissions (as it is planned, starting in 2020) seems to be the application of MBMs. This may have a dual effect: moderate the demand growth by doing the flight more expensive (an effect to be compared with the fuel price evolution) and collect money to apply compensatory mechanisms, investing in reducing CO_2 emissions in other sectors with a more affordable cost per suppressed ton.

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