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Analysis of the trends in air traffic and CO2 emissions within the European Union.

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Abstract

The rebound of air traffic after the economic crisis and the development of the emerging countries have led an increase in the CO2 emissions that the technological improvements have not been able to restrain so far. And although these emissions are reduced in comparison with the global total, if the projected growth estimates are met, air traffic would become one of the most polluting sectors in the next few years. That is why several organizations have proposed and implemented measures to counteract and reduce emissions, such as the European Union 2008/101/EC directive, the CORSIA program from ICAO or the commitment of the IATA member airlines of stabilizing the CO2 emissions from 2020.

The purpose of this study, which is a continuation of previous work from the Department of Aerospace Systems, Air Transport and Airports from the ETSIAE, is to analyse the evolution of the air traffic in the European Union and its emissions, trying to evaluate the impact of the new technologies, regulations and business strategies of the airlines and to compare them between regions and between types of flights. The methodology is bases on the analysis of the EUROCONTROL flight database, which includes all the flights from and to its territory plus Iceland and Azerbaijan, and the Eurostat statistics.

The results of the study capture the evolution of the air traffic and its emission in the EU28+2 region: they show the constant growth of the number of flights and emissions before the crisis of 2008, the speed of the following recovery, the variation of the type of flights and change of the composition of the market, including the relevance of low-cost air carriers and the consolidation of the market. The progressive change of the emissions behaviour is discussed and compared with other means of transport. The different analysis generated provide useful information for different stakeholders and the positive results reflected should serve as a motivation to continue working towards the improvement and development of new technologies to address the challenge of climate change.

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1. Introduction

Air transport has become a key element in economic development worldwide. It is a driver of cohesion between regions, leads the growth of industries such as tourism and trade. It is estimated that more than ten million people around the world are directly employed in activities related to aviation and up to sixty five and a half million jobs are related to aviation worldwide [1].

Although the contribution of air transport to the transportation-related CO2 emissions is around a 12% of the whole sector [2], the high and sustained growth rates forecasted by multiple institutions and entities could make it one of the top CO2 generators [3]. Back in 1999, the Intergovernmental Panel on Climate Change (IPCC), the United Nations body that works in the assessment of climate change issues, estimated that emissions would increase between a 60% and a 1000% in the period 1992-2050 [4]. While not very precise, these predictions are the reflect of the expectations twenty years ago, which already believed in a sustained growth of the sector. Later on, the International Civil Aviation Organization (ICAO) calculated that the growth of the aviation sector would be a 4.4% per year between 1989 and 2009, a rate that outpaced the values of the general economic growth [5].

This continuous growth, led by the developing countries, has become a topic of concern among the international community because of the high reliance on fossil fuels of the aviation sector and the lack of available technologies to contain the increase of greenhouse emissions (GHG) [6]. Several organizations have presented plans and directives to encourage technological improvements and to restrict the allowable limits of emissions:

- In 2006, ICAO members agreed on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [7], a “basket of mitigation measures” that consists on the airlines purchasing carbon offsets such as carbon reduction projects in developing countries to compensate for their increase in CO2 emissions [8]. The standards for the implementation of CORSIA have been included as an annex to the Chicago Convention, which means that the 193 member states had to start applying the program on the 1st Jan, 2019 [9].
- In 2008, the European Union (EU) introduced the Directive 2008/101/EC to include aviation in the Emission Trading System (ETS), a tool to reduce the GHG emissions in a cost-effective way [10]. The ETS forces the airlines to account for their emissions and to comply with the limits imposed by the European Commission or to compensate for the excesses.
- In parallel with the introduction of the EU Directive, leaders from across the industry signed the Commitment to Action on Climate Change [11], in which they agreed to improve the fuel efficiency a 1.5% per year between 2009 and 2020, to stabilize emissions from 2020 with a carbon-neutral growth and to work towards the reduction of a 50% in 2050 of the net emissions generated by the aviation sector in comparison with 2005 levels.

Some of the most immediate consequences of these initiatives for the airlines is the need to modify their fleets, either with the substitution of older, less-efficient aircraft with for newer ones or by introducing updates to the current ones. Some studies have analysed and compared the impact of these improvement options [12]. It has also been proven that the aircraft load factor and the cabin configuration have a remarkable impact in the emissions levels [13]. Other authors consider that the main reductions will come from the use of biofuels and other sustainable energy sources [14]. The European Commission together with Airbus and representatives from the Biofuels industry launched the European Advanced Biofuels Flightpath, an initiative that expects to achieve the use of two million tons of sustainable biofuels in the civil aviation sector by 2020 [15].

However, some studies reflect that the improvements and the actual rhythm of introduction of new technologies are not enough to counter the increase of emissions caused by the increase on the demand. In [16], Chèze et al. estimate that a 4.7% average annual growth rate of air traffic in the period 2008-2025 will entail an average annual growth of 1.9% of CO2 emissions. The available technological improvements and the modest introduction of biofuels, which was a 0.5% in 2009 and is expected to reach 15.5% assuming a moderately optimistic scenario in 2024 [17], only achieve reductions of around a 1% [18]. Therefore, it seems necessary to introduce new policies that promote innovation in the aviation sector to ensure that technological progress occurs at a rate twice as fast as the current one.

This proceeding is a continuation of the work developed in the Department of Aerospace Systems, Air Transport and Airports from the ETSIAE, part of the Technical University of Madrid [19, 20], in which the results of a tool developed for the analysis and study of the evolution of air traffic in the European Union and the CO2 emissions produced by the civil aviation sector are going to be discussed. The tool can provide in-depth analysis per region, type of plane or airline, which allows to compare the results between entities, countries and types of flights.

2. Methodology

The main source of information used in the study is extracted from the European Organization for the Safety of Air Navigation (EUROCONTROL) Data Demand Repository. From this database it is possible to recover all the flights that took place in its list of members, up to 42, plus Iceland and Azerbaijan. The database includes the origin and destination airport codes, the date and the departure time of the flight, the company operating the flight, the aircraft model used, etc. The information was filtered to remove all the non-civil flights (military, customs, etc) as well as the general aviation ones.

Then, the countries to which airport belongs were identified, and only the flights that take-off or land in the twenty-eight countries of the European Union plus Norway and Switzerland (28+2) have been considered. The flights are segregated using the following classification:

1. Internal: when both airports are in the same country.
2. Regional: when both airports belong to the 28+2 countries of the study but not to the same country.
3. International: when one of the flights departures or lands in a non 28+2 country.

After obtaining the geographic coordinates of the airports, the orthodromic distance between each pair, d, is calculated with the great-circle formula:

$$\Delta\sigma = \arccos(sin\varphi_1 sin\varphi_2 + cos\varphi_1 cos\varphi_2 \cos(\Delta\lambda))$$
$$d = r\Delta\sigma \qquad (1)$$

Where φ and λ are the geographical latitude and longitude in radians of the two study points, Δφ and $\Delta\lambda$ are their absolute differences, $\Delta\sigma$ is the central angle between the points and r is the Earth's radius, approximately 6 371 km.

After the distance flown is calculated, the fuel consumption has been estimated using the Corinair database [21], which provides a simplified value of the consumption as a function of the distance flown per aircraft type and per flight phase. This simplification omits flight factors such as the take-off weight (TOW), the speed, the altitude, etc. Also, some aircraft models are missing so its consumption has been assimilated to the one of similar models. For the calculation of the CO2 emissions in each flight, the ICAO estimate will be used [22]. ICAO states that the emissions of CO2 are related to the fuel consumption by a 3.16 rate, which means that each kilogram of fuel burnt generates 3.16 kg of CO2.

Due to the volume of daily flights registered in the 28+2 zone, only the flights of the second week of June of each year is going to be taken into consideration, since it has been proven as an accurate approximate to the real results [23]. However, the air traffic control strike that happened between the 11^{th} and the 13^{th} of June of 2013 in France [24] altered the number of flights of that year so some adjustments have been made to compensate for it, extrapolating data from previous years.

The number of seats for each model of aircraft has been estimated using a typical dual-class configuration, business and economy, except in the case of the most relevant low-cost carriers, such as Ryanair, EasyJet or Wizz. One of the key aspects of their business model is the high capacity of their cabins and the use of only one class. For those cases, the number of seats has been sourced from their corporative websites.

Finally, the available seats per kilometer (ASK), the main production unit of the airlines, is calculated by multiplying the number of seats in each of the flights by the distance flown in kilometers. This measurement will allow the unitization of the level of emissions as per offered seat and to analyze the trends in terms of demand and emissions per seat and per distance.

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3. Results and Analysis

3.1 Traffic Data

The evolution of flights shows an increasing tendency throughout the period between 2003 and 2017, with an overall growth of a 23% in the number of flights. As it can be seen in Figure 1, the impact of the economic crisis of 2008 is reflected in the decrease of the number of flights in 2009, approximately of an 8%, which supposed a return to values of 2005. The decrease of the purchasing power of citizens and the austerity measures implemented by governments and companies were behind the decrease in the demand. The level pre-crisis was reached again in 2016, after a period of steady rise with a small decrease in 2017.

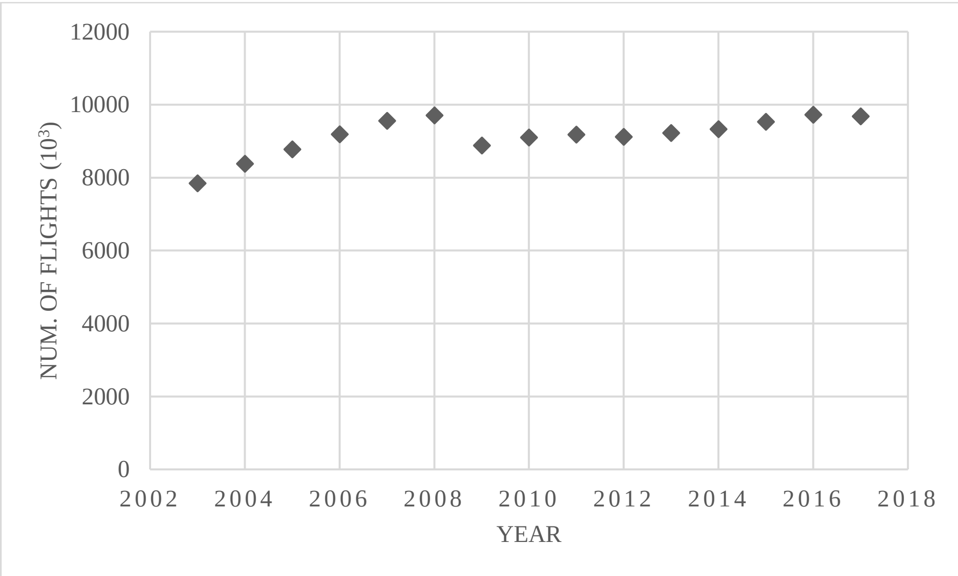

Figure 1. Evolution of the number of flights 2003-2017.

The average distance flown followed a steady growing tendency as well, as captured in Figure 2. This growth is due to an increase of the International (INT) and Intra 28+2 (EU28+2) flights against the reduction of national or domestic ones (NAT). The average distance per flight throughout the period rose almost a 30% between 2003 and 2017.

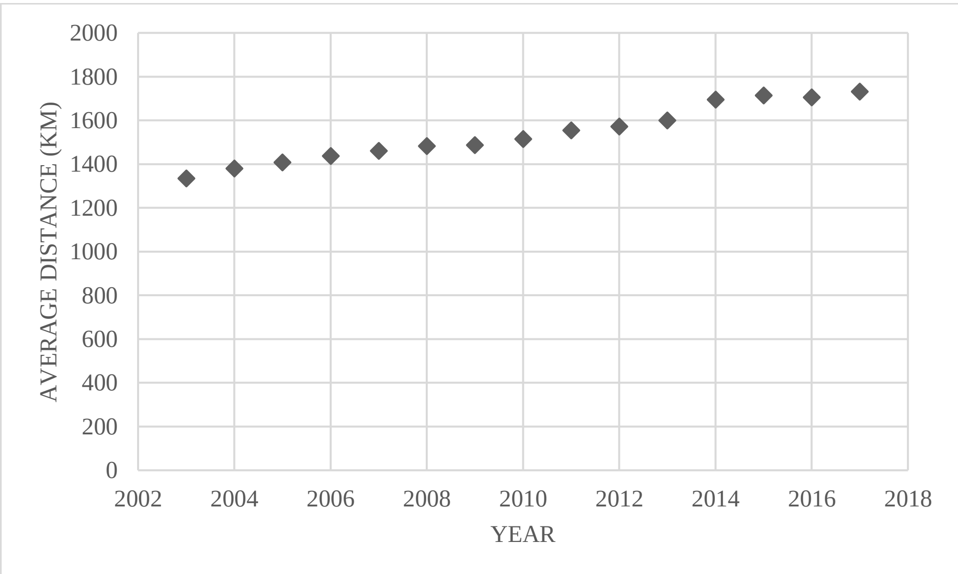

Figure 2. Evolution of the average distance flown 2003-2017.

Figure 3 represents the decrease of the proportion of domestic flights. The margin left by this category was shared between the INT and EU28+2, accounting the latter for more than half of the flights that take-off or land in the region. One of the causes for the change in the tendency is the effort of the member countries to promote and develop a wider offer in infrastructure, such as highways or high-speed railways, that compete in the distance ranges of the domestic flights. Another reason is the growth of the low-cost carriers, whose traditional market is the EU28+2 and in a smaller extent, the NAT market, but are expanding now into longer ranges. This expansion has forced more traditional airlines to reduce their costs and lower their prices, to try to avoid the loss of their market share. The consequence for passengers is that air transport has become more affordable, to the point that it is frequent to find tickets to travel to other countries for a lower price than for travelling nationally, which is another factor contributing to the increase of the number of EU28+2 flights.

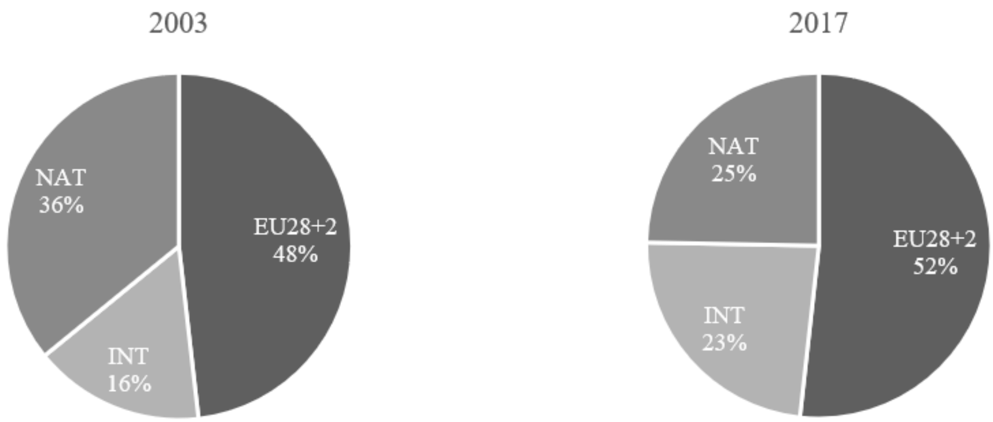

Figure 3. Comparison of the proportion of flights per type in 2003 and 2017.

It is also interesting to compare the variation of the average distance flown per flight between the years 2003 and 2017. The results gathered in Table 1 show an increase of the distance in the domestic and EU28+2 flights whereas the variation in the distance of INT flights is negligible. There are several reasons for these changes. The first one is the introduction in the market of new narrow-body aircraft such as the Airbus neo family or the Boeing MAX models that have notably increased their flight ranges [25]. The second one is the use of those aircrafts in shorter routes, which has contributed to their development by increasing the number of available seats and hence, decreasing the price of tickets, stimulating the demand for those routes.

Table 1. Variation of the average distance per type of flight between 2003 and 2017

	2003	**2017**	**Variation**
NAT	418.29	457.65	9%
EU28+2	1,054.09	1,198.20	14%
INT	4,242.26	4,241.43	0%

The number of available seats per kilometre (ASK), which is calculated by multiplying the number of seats available in each of the flights by the distance flown in kilometres, is an indicator of the offer given by the carriers in each of the routes. Table 2 collects the average values of ASK in 2003 and 2017 as well as the variation between those years. There is an increase throughout all the types of flights, but the higher variations come from the NAT and EU28+2 categories, a consequence of the raise of the average distance per flight, the introduction of bigger planes for shorter routes and newer models with higher capacity and maximum range.

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Table 2. Variation of the average ASKs per flight between 2003 and 2017.

	2003	2017	Variation
NAT	47,522.35	59,858.13	26%
EU28+2	147,326.85	188,289.89	28%
INT	1,134,872.65	1,207,596.73	6%

The evolution of the percentage of ASK per type of flight in 2003 and 2017 in Figure 4 reflects the decrease of the contribution of national flights, that the increase of the average distance has not been able to compensate. It is important to note that as per the values in Table 1, the average distance of a national flight is half of the EU28+2 and ten times less of the INT. In the case of the EU28+2 flights, their average distance is four time less that of the INT ones, and even the increase in both the average distance flown and the number of flights is not enough to maintain the contribution to the total ASKs.

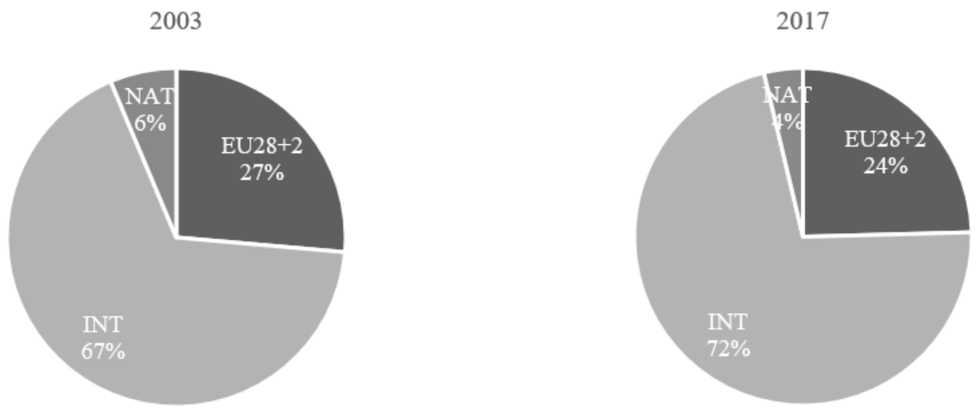

Figure 4. Comparison of the proportion of ASK per type in 2003 and 2017

Another important analysis is the presence of the airlines in the market, their share, the type of business model that they are leading and the evolution throughout the years. With the data obtained from EUROCONTROL, it is possible to segregate the number of flights of each carrier and to calculate the average distance.

Table 3 is the compilation of these values in the year 2003. Flag airlines occupy the first eight positions of the table, with a combined market share of 27.82%. The market share of the first airline in the ranking, Lufthansa, is almost twice as big as the one from its immediate competitor, Alitalia and three times as big as the one from the last airline in the list, EasyJet.

As for the average distance, the airline with the longer average flights is Air France, an airline that has traditionally been the connection between mainland France, and specially its principal hub, Paris Charles de Gaulle airport, with all the overseas departments and territories and the old colonies, mainly in Africa. The relevance of long-haul flights for the carrier and its decision to limit their involvement in shorter routes, to avoid competition with low-costs and railways, are the reason behind the longer average distance flown of their fleet. British Airways follows a similar pattern than Air France, but with its focus on the US.

An example of an opposite business model to the one of Air France can be found in Ryanair, which occupies the 9th position of the list in terms of market share. This airline has the shorter average distance per flight in 2003, 760.23 km, which falls in between the average distances for domestic and EU28+2 as shown in Table 1. The focus of the carrier is the point-to-point connection of mainly secondary airports in Europe and hence, the distances flown by their aircraft.

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Table 3. Top ten airlines per market share in 2003 and the average distance flown in km.

Position	Airline	Number of flights	Market Share	Average Distance (km)
1	Lufthansa	538,044	6.86%	1,235.52
2	Alitalia	283,452	3.61%	1,000.69
3	SAS	261,144	3.33%	863.46
4	British Airways	258,232	3.29%	2,131.91
5	Iberia	232,856	2.97%	1,171.26
6	Air France	224,588	2.86%	2,247.47
7	Swiss	194,428	2.48%	1,141.58
8	KLM	189,436	2.42%	1,668.23
9	Ryanair	175,500	2.24%	760.23
10	EasyJet	157,612	2.01%	921.55

In the rest of the cases, the average distance is very close to the EU28+2 average one, 1,054.09 km, as represented in Figure 5. These results are aligned with the fact that the biggest proportion of flights are among the EU28+2 countries as shown in Figure 3.

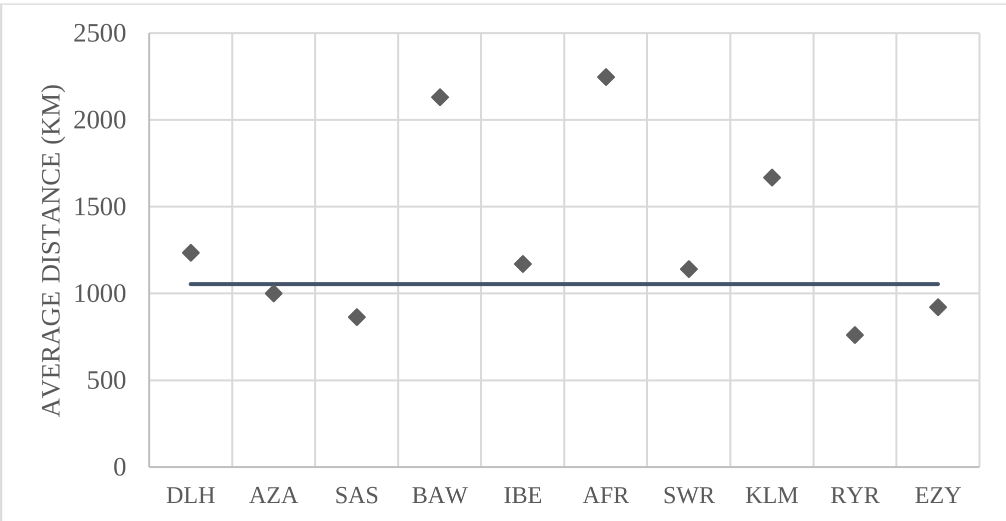

Figure 5. Comparison of the average distance flown by the top ten airlines in market share against the average distance of the EU28+2 flights in 2003.

Moving forward to 2017, the picture is completely changed. The results summarized in Table 4 observe the growth of Ryanair and EasyJet, that moved to the first and second position respectively, displacing Lufthansa to the third one. Apart from the raise in market share, the number of low-cost airlines in the top ten list doubled, from two in 2003 to four in 2017 with the entrance of Vueling (part of IAG group together with Iberia and British Airways) and WizzAir. The top four low-cost airlines accounted for the 17% of the market share and in total, the top ten airlines added a 36.61%, which is a 32% increase in comparison to 2003.

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Table 4. Top ten airlines per market share in 2003 and the average distance flown in km.

Position	Airline	Number of flights	Market Share	Average Distance (km)
1	Ryanair	754,936	7.80%	1,260.95
2	EasyJet	516,412	5.33%	1,151.10
3	Lufthansa	499,720	5.16%	1,648.72
4	Air France	347,672	3.59%	2,037.50
5	SAS	334,516	3.46%	964.91
6	British Airways	261,976	2.71%	2,912.11
7	KLM	252,200	2.61%	1,896.82
8	Vueling	214,968	2.22%	983.86
9	Alitalia	202,228	2.09%	1,272.44
10	WizzAir	159,588	1.65%	1,422.37

This increase is a symptom of the consolidation of air traffic in a smaller number of airlines or groups, such as the mentioned before, IAG, the formed by Air France and KLM or the one formed between Lufthansa and SWISS. This phenomenon which started in the US after the deregulation of 1978, is expected to affect the European market even more in the upcoming years.

In 2017, the airline with the longest average distance flown was British Airways, with 2,912.11 km. This came as the consequence of the restructuring that followed the merge with Iberia, in which British Airways operated some of the traditional Iberia long haul routes to South America. The other two airlines that drift from the average EU28+2 distance are Air France and KLM, as presented in Figure 6.

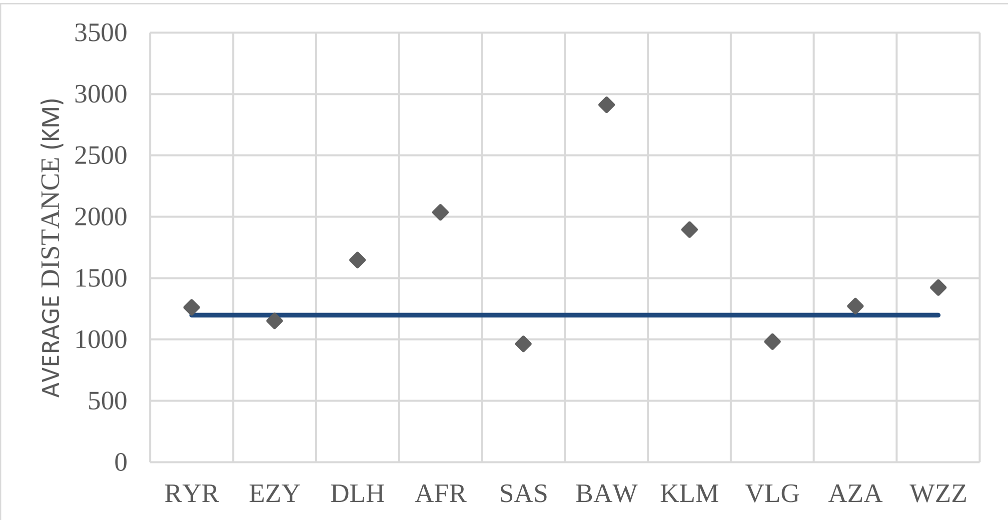

Figure 6. Comparison of the average distance flown by the top ten airlines in market share against the average distance of the EU28+2 flights in 2017.

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A noticeable change is the increase of the average distance of Ryanair, which in 2003 was 760.23 km and in 2017, 1,260.95km, an increase of almost a 66%. The company followed an expansion strategy that lead to the opening new routes to destinations outside of Europe such as Jordan or Israel thanks in part to the acquisition of Laudamotion.

The configuration of the European aviation sector has change without any doubt in the fourteen years period subject of study. The dynamism of this industry, together with the fluctuations of the local and international financial situation will bring more changes. What seems clear is that the sector will continue growing in Europe with the development of the Eastern Europe and Balkan countries, incorporating new markets and routes.

3.2 Emissions Data

The evolution of the CO2 emissions in the period 2003-2017 shows a continuous growth similar to the number of flights. However, is at the end of the period, between 2015 and 2017, where the trend starts changing, and even though the number of flights continues growing, the average emission per operation decreases, as can be seen in Figure 7.

The total increase in the period 2003-2017 is approximately a 19% of the average emissions per flight, which is linked to the growth in the average distance discussed in the previous paragraphs. However, the increase in the average distance (30%) is almost double the increase of the CO_2 emissions per operation (19%). It is remarkable as well the decrease that happened between 2015, the year with the peak level of average emissions per flight, and 2017. The decrease in this period, although small since it is around 2%, represent and actual decrease in the emissions and not a slowest trend as in the period as a whole.

The loss of parallelism between the growth of both indicators and the actual reduction of emissions are good news, since the measures taken by the airlines to control the level of emissions are giving results.

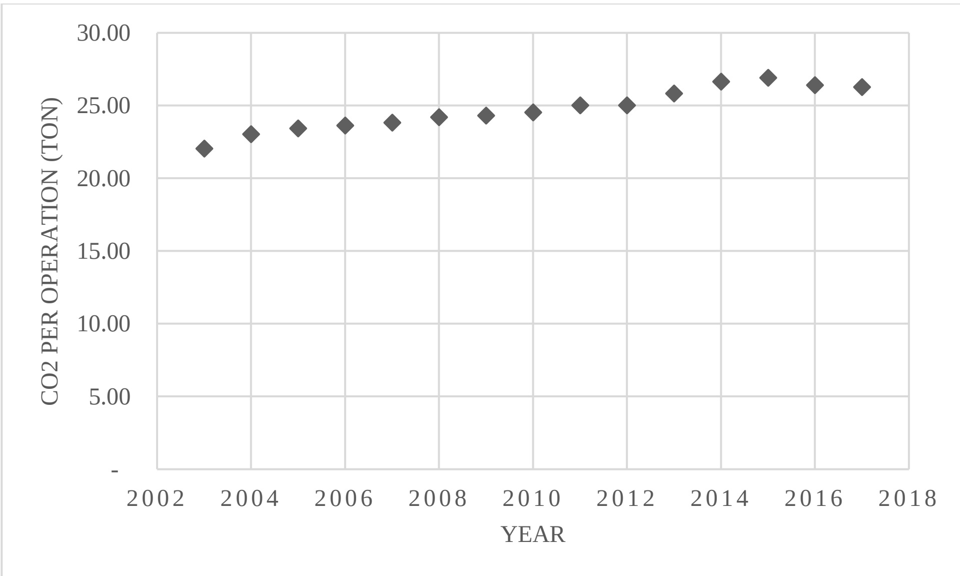

Figure 7. Evolution of the average emissions per operation between 2003 and 2017.

In the case of the contribution of each type of flights to the total emissions, the changes between 2003 and 2017 have not been drastic. As seen in Figure 8, there is a slight increase in the contribution of the international flights and the EU28+2 ones against the reduction of the domestic ones, led by the decrease of the number of these flights.

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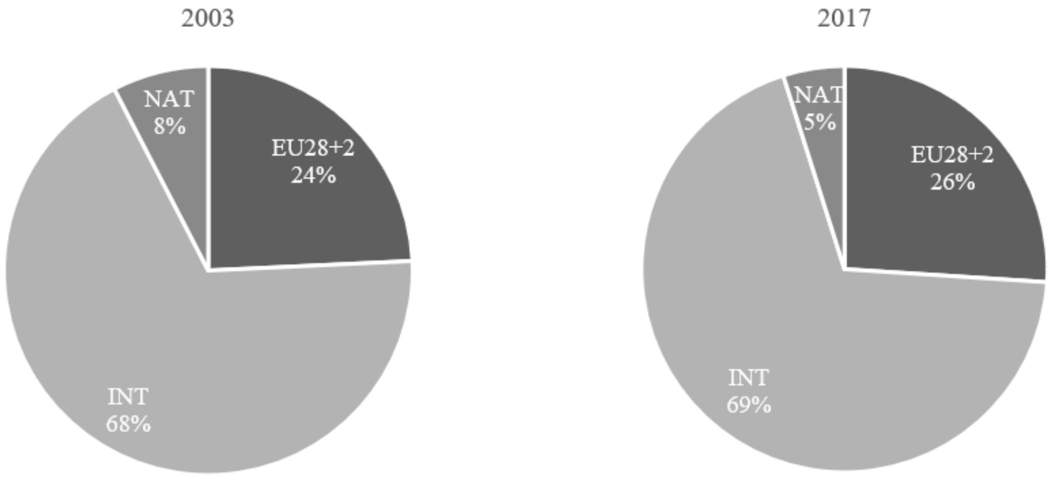

Figure 8. Percentage of emissions per type of flight in 2003 and 2017.

In order to unitize the measurement of emissions, the average CO2 emissions per flight in kg have been divided over the average ASKs per flight, getting an idea of how much each seat or potential passenger contributes per kilometre flown in each of the flight types. The results from Table 5 show remarkable decreases in all categories, being especially steep in the case of the international flights. It is interesting to notice that between 2003 and 2017, there was a shift in the contamination patterns, since the international flights became the least contaminating ones.

Table 5. Evolution of the CO2 kg per seat per kilometre between 2003 and 2017.

	2003	**2017**	**Variation**
NAT	0.098	0.087	-12%
EU28+2	0.075	0.070	-7%
INT	0.083	0.064	-23%

The period has brought as well a noticeable percentual increase in the range of emissions. In 2003, the difference between the domestic and the EU28+2, the least and most pollutant, was a 30%. In 2017, this difference rose to the 35% as a consequence of the difference in the variation of the national and international flights. These values are still far from other means of transport traditionally pollutant such as cars. The European Union estimated that in 2016, road transport was responsible for 21% of the CO2 emissions, from which 15% corresponded to light-vehicles or cars [26].

The introduction of new policies and the development of new technologies have contributed to the reduction of emissions of standard cars from values of 0.163kg CO2/km in 2004 [27] to values of 0.119 kg CO2 /km in 2017 [28], a decrease of a 27%. Since the average car has five seats, the amounts are equivalent to 0.033 and 0.024 CO2 kg/seat·km. Air transport and conventional cars are competitors mainly in short distances, so it is adequate to compare the emissions of cars against those of domestic flights as done in Table 6.

Emissions of conventional cars are way lower than the ones of domestic flights per unit km·seat. A passenger flying a domestic route is polluting three times more than a passenger riding a car. However, if the occupation of the vehicles is taken into consideration, the margin between both means of transports shrinks. Assuming that the occupancy rate values estimated by the European Environmental Agency (EEA) [29] for 2016 of 1.5 passengers per trip for cars and 70% occupation rate for air transport can be extrapolated to 2017, the emissions for cars become 0.079 and 0.102 kg of CO2 per km per passenger. The emissions of the car passenger are now 1.29 times the emissions of an aircraft passenger, almost half the first estimate of 3.625.

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Table 6. Comparison of the evolution of CO_2 emissions of domestic flights and conventional cars in 2003-2017.

	2003	**2017**	**Variation**
Domestic flights	0.098	0.087	-12%
Conventional cars	0.033	0.024	-27%
Difference factor	2.97	3.625	

The first idea that can be extracted from this analysis is that small changes in the efficiency of cars and other light-vehicles will have a bigger impact in the big picture than equivalent changes in air traffic due to the bigger magnitude of the contribution of road transport to the global emissions. The second one, is that the relatively small share of air transport against road traffic in short routes compensates the difference in the level of emissions.

4. Conclusions and future work

This work is a compilation of the analysis of the evolution of air transport and the CO_2 emissions that it produces in the period 2003 – 2017. Several indicators such as the number of flights, the average distance flown, the distribution of flights per category (NAT, EU+28, INT) and the number of available seats have been discussed as part of the analysis of the traffic data. For the emissions, other indicators such as the evolution of the average emissions per operation, the contribution of each of the flight types and the emissions per seat and per kilometre were analysed. It is not possible to deny that air transport has an impact in the environment, but the results obtained show promising reductions in the levels of emissions that have to be developed in the upcoming years.

Further measures need to be implemented by all the involved stakeholders. Apart from policies and other types of restrictive measurements to complement those already in place, government and authorities need to work towards the improvement of airports and air traffic management. More efficient airports and air routes will lead to shorter flights and hence, less consumption of fuel. Investment in public centres of Research and Development can bring in the longer-term solutions to some of the problem of the GHG.

Airlines on their side need to push for change. The reduction of burnt fuel has a direct impact in the financial results of the companies, since it implies a direct reduction in operational costs. That is why carriers are the first interested in the improvement of efficiency. The renewal of fleets in favour of more efficient models and the redesign and optimization of routes seem to be giving positive results, as discussed in previous paragraphs. Finally, manufacturers need to be encouraged to perfect their technologies and to develop new ones, taking into account the needs of their clients and the complete life cycle of the products, paying attention to all the environmental aspects that are impacted by the operation of the aircraft.

Future works will include more in-depth analysis of the data, obtaining results at country level that could provide useful information for different authorities since it would be possible to assess the effect of economic factors, the geopolitical situation or the investment in the sector. Tools for the forecasting of relevant indicators will de developed as well.

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