# AN ANALYSIS OF THE CONTRIBUTION OF FLIGHT ROUTE AND AIRCRAFT TYPE IN ENVIRONMENTAL PERFORMANCE OF AIRLINES BASED ON LIFE CYCLE ASSESSMENT:
# THE LUFTHANSA CASE

13-10-2011

TICIANO COSTA JORDÃO, ERNESTO LÓPEZ-VALEIRAS SAMPEDRO, JANA ĎURIŠOVÁ

*To cite this publication as one of your references, use the following information:*
*COSTA JORDAO, T. - LÓPEZ-VALEIRAS SAMPEDRO, E. - ĎURIŠOVÁ, J. An Analysis of the Contribution of Flight Route and Aircraft Type in Environmental Performance of Airlines Based on Life Cycle Assessment: the Lufthansa Case. Scientific Papers of the University of Pardubice, Series D, Faculty of Economics and Administration, 2011, vol. 2011, no. 21, pp. 90-101. ISSN: 1211-555X.*

# AN ANALYSIS OF THE CONTRIBUTION OF FLIGHT ROUTE AND AIRCRAFT TYPE IN ENVIRONMENTAL PERFORMANCE OF AIRLINES BASED ON LIFE CYCLE ASSESSMENT: THE LUFTHANSA CASE

TICIANO COSTA JORDÃO, ERNESTO LÓPEZ-VALEIRAS SAMPEDRO, JANA ĎURIŠOVÁ

**Abstract**

In the airlines sector, the reduction of fuel consumption became a major global target due to the recent surge in oil prices. Aircraft emissions have also been gaining importance, particularly in the European Union where apart from the emissions of nitrogen oxides (NOx) and its concerns related to ground level ozone formation, measurements and reductions of carbon dioxide (CO2) became a major regional target. This major concern related to CO2 emissions is reflected on the upcoming inclusion of aviation sector into the EU Emissions Trading Scheme as of 2012 when all intra-community flights will be subject to emission restrictions. The main aim of this paper is to show by means of life cycle assessment how fuel consumption and emissions per passenger can vary significantly between the same origin and destination according to the distance flown and the use of different aircraft models. It illustrates these variations with different real offers of daily flights by Deutsche Lufthansa AG. Besides considerable reductions that can be achieved with the use of fuel-efficient aircrafts, additional improvements can be done by shortening air traffic routes and by developing technology for continuous descent approach landing patterns in collaboration between governments, regulators, airlines, airports and air navigation system providers (ANPs).

## 1. Introduction

Nowadays there are some factors that affect the global air transport industry. Reza Abdi et al. [28] point out, among others, the national tourism policies, declining yield across airline industry, consumer satisfaction, human resources policies, and technology change. Furthermore, nowadays environmental and social externalities of air transport are recognized as a fundamental aspect of business strategy and therefore are a critical factor to control for the achievement of financial success [10]. Thus air transport companies have the obligation of taking environmental impacts of their activities into account, whether due to a serious social commitment or to a desire to avoid paying fines for not adhering to existing laws. One of the most important externalities generated from commercial flights is fuel consumption and engine emissions [6]; [23] impacting on air quality and greenhouse gases.

The highly competitive global transport market requires companies to be innovative, flexible and develop, and implement adequate management systems to help them deal with these circumstances. In the last few years, the Life Cycle Assessment (LCA) has become one of the most popular tools of environmental management [33]. LCA can be defined as an information system used to measure the environmental impact caused by a business activity.

This study seeks to extend and deepen the research on the application of LCA to the air transport sector [23]; [13] in order to measure its environmental impact based on the aircraft model. For this purpose an intra-European short-haul[1] route was chosen, comparing three real cases offered by Lufthansa for flying from Prague to Munich (265 km flight distance [12]). This is one of the most popular international air routes departing from Prague's Ruzyne Airport which is the most important international airport in the Czech Republic and the second largest in Central and Eastern Europe, handling every year around 12 million passengers. Currently 50 airlines connect Prague to 134 destinations in 51 countries on direct flights, along with 5 regular cargo carriers and dozens of other companies providing charter transport [27].

In 2010, on average, 31,600 passengers passed through the airport’s gates each day. The vast majority of passengers at Prague Airport flew traditional European routes, accounting for 90.5 per cent of total operations. In the same year, the most frequented routes for passengers were Prague to Great Britain (1.2 million) and Prague to Germany (1.1 million) [26]. Prague airport has also observed a trend since 2009 of an increase in airlines aircraft occupancy. Average aircraft capacity (the so-called "load factor") was around 70 per cent for flights into and out of Prague in 2010.

The capacity of the aircrafts is correlated with the frequency of service, i.e., bigger aircrafts means less frequency [2]. The main aim of this study is to show how fuel consumption and emissions per passenger can vary significantly between the same origin and destination according to the distance flown and the use of different aircraft models. It illustrates these variations with different real offers of daily flights by Deutsche Lufthansa AG.

The paper is structured as follows. The next section addresses the fuel burn rates and main emissions during aircraft operations as well as their main impacts on the environment. Subsequently, authors report on how climate change has been faced by commercial aviation sector. Then, previous studies of Life Cycle Assessment involving different environmental aspects and impacts in commercial aviation are highlighted. Further, a description of the methodology adopted for calculating the fuel consumption and emissions is presented. Finally, results are illustrated with charts and commented thereafter. Final conclusions point out the importance of improving the calculation method proposed

[1] A short-haul domestic flight is commonly categorized into being no longer than 500 mi (800 km) 1.5 hours in length. A medium-haul flight is a flight between 3 and 6 hours.

by refining its input parameters and gives light to further reductions in greenhouse emissions that can be achieved with the use of fuel-efficient aircrafts.

## 2. Fuel consumption, main emissions and impacts of aviation

Fuel consumption considerations are a priority for airlines because profit margins are narrow and the price of fuel has steadily increased at a time when airfares have been decreasing in response to competition. Fuel burn rates and emissions vary according to the different modes of aircraft operation, namely idle, taxi, take-off, approach and landing. The take-off phase requires full engine thrust, and thus incur higher fuel burn rate. As the aircraft ascends to higher altitudes the drag decreases and so does the rate of fuel use. Over very long distances the fuel use per kilometre increases because of the greater amount of fuel that has to be carried during the early stages of flight [8]. Even in short-haul flights, most part of fuel is burned during the cruising stage. However, in these flights, the shares of fuel burned during the landing and take-off phases (LTO) become more significant in proportion to the total amount of fuel burned during the aircraft operations than the shares observed for medium or long-haul flights [29]. As aircraft emissions are directly proportional to fuel used, the bulk of aircraft emissions occur at higher altitudes during the cruise phase. Aircraft engine emissions are roughly composed of about 70 per cent CO2, a little less than 30 per cent H2O, and less than 1 per cent each of NOx, CO, SOx, VOC, particulates, and other trace components including hazardous air pollutants (HAPs). The main emissions from combustion process of aircraft engines are presented in Tab.1.

*Tab.1: Emissions from combustion processes of aircraft engines*

| **Gas** | **Source** |
|---|---|
| CO2 | Carbon dioxide is the product of complete combustion of hydrocarbon fuels like gasoline, jet fuel, and diesel. Carbon in fuel combines with oxygen in the air to produce CO2. |
| NOx | Nitrogen oxides are produced when air passes through high temperature/high pressure combustion and nitrogen and oxygen present in the air combine to form NOx. |
| HC | Hydrocarbons are emitted due to incomplete fuel combustion. They are also referred to as volatile organic compounds (VOCs). Many VOCs are also hazardous air pollutants. |
| H2O | Water vapour is the other product of complete combustion as hydrogen in the fuel combines with oxygen in the air to produce H2O. |
| CO | Carbon monoxide is formed due to the incomplete combustion of the carbon in the fuel. |
| SOx | Sulphur oxides are produced when small quantities of sulphur, present in essentially all hydrocarbon fuels, combine with oxygen from the air during combustion. |
| Particulates | Small particles that form as a result of incomplete combustion, and are small enough to be inhaled, are referred to as particulates. Particulates can be solid or liquid. |
| O3 | O3 is not emitted directly into the air but is formed by the reaction of VOCs and NOx in the presence of heat and sunlight. Ozone forms readily in the atmosphere and is the primary constituent of smog. For this reason it is an important consideration in the environmental impact of aviation. |

Source: [11]

Aircraft emissions are considered air quality pollutants or greenhouse gases, depending on whether they occur near the ground or at high altitude, respectively. However, aircraft are not the only source of aviation emissions. Emissions are also originated from vehicles that provide access to airports, shuttle services offered between terminals and to the aircrafts, ground equipment that provide services to aircrafts, stationary airport power sources, and auxiliary power units providing electricity and air conditioning to aircraft parked at airport terminal gates.

Aircraft emissions with an impact on air quality are estimated to be primarily released as nitrogen oxides (NOx) and to a considerably minor degree as carbon monoxide (CO), non-methane hydrocarbons (NMVOC), sulphur dioxide (SO2) and primary particulate matter (PM10). Nitrogen oxide (NOx) emissions from aviation contributes to ozone formation at ground level, and increase the deposition of oxidised nitrogen, thus increasing ecosystem exposure to acidification and eutrophication [35]. Moreover, the presence of ozone in the upper troposphere acts as a greenhouse gas, absorbing some of the infrared energy emitted by the earth [3]. Still, NOx emissions in the atmosphere also reduce the lifetimes of methane. As a result of chemical processes in the atmosphere, emissions of NOx can indirectly both damp and enhance the greenhouse effect [32].

Since the lifetime of ozone is much shorter (100-200 days) than that of methane (10-12 years), the resulting increase of ozone originated from NOx emissions is limited to a regional scale, while the reduction of methane by reactions with NOx will be perceived much long after NOx emissions were originated [32].

The International Civil Aviation Organization (ICAO) has been establishing since 1996 standards limiting the emissions of NOx and other gases from aircraft engines [25].

The impacts of gases emitted by civil aviation sector are highlighted in Tab. 2. In the subsequent sections, a particular attention is given to carbon dioxide (CO2) emissions due to its contribution to global warming.

*Tab.2: Impacts on atmosphere caused by gas emissions from aviation*

| **Gas** | **Impact** |
|---|---|
| CO2 | Long-lived GHG. Contributes to global warming. |
| O3 | Lifetime weeks to months. Product of NOx emissions plus photochemistry. The effect of O3 is high at subsonic cruise levels and causes radio-active reactions at those levels. |
| CH4 | Lifetime of ~10 years. Aircraft NOx destroys ambient CH4. |
| H2O | The effect is small because of its small addition to natural hydrological cycle. Triggers contrails, but actual contrail content is from the atmosphere. |
| Sulphate | Scatters solar radiation to space. Impact is one of cooling. |
| Soot | Absorbs solar radiation from space. Impact is one of warming. |
| Contrails | Reflect solar radiation, have cooling effect; but reflect some infrared radiation down to earth, that has a warming effect; but net effect is one of warming. |
| Cirrus | Contrails can grow to larger cirrus clouds (contrail cirrus), which can be difficult to distinguish from natural cirrus. Generally warming effects. |

*Source: [11]*

## 3. The commercial aviation in the face of climate change

The air transport sector has been increasingly placed in the environmental agenda. Commercial aircraft operate at cruise[2] altitudes of 8 to 13 km, where they release gases and particulates which alter the atmospheric composition and contribute to climate change [20]. Technological progress has been made in reducing greenhouse gas (GHG) emissions through aircraft fuel efficiency by reducing weight, improving aerodynamics performance and engine design [16].

In 2010 the air passenger transport industry has shown a good recovery from the downturn observed in the previous two years and resumed its historical trajectory of impressive growth. Global passenger traffic rose by 6.6 per cent in 2010, topping the 5 billion passenger mark for the first time and registering increases in all continents [1]. Therefore, perceived rapid growth of this sector can turn it into a significant source of greenhouse gas emissions, despite improvements in aircraft fuel efficiency.

According to IPCC [17], aviation currently accounts for about 2 per cent of human-generated global carbon dioxide emissions, the most significant greenhouse gas. This 2 per cent estimate includes emissions from all global aviation, including both commercial and military. Global commercial aviation, including cargo, accounted for over 80 per cent of this estimate. The sector also contributes to about 3 per cent of the potential warming effect of global emissions that can affect the earth's climate, including carbon dioxide. Additionally, the report also states that the amount of CO2 emissions from aviation is expected to grow around 3-4 per cent per year. Medium-range forecasts provided by IPCC estimates by 2050 the global aviation industry, including aircraft emissions, will emit about 3 per cent of global carbon dioxide emissions and about 5 per cent of the potential warming effect of all global human-generated emissions. Medium-term mitigation for CO2 emissions from the aviation sector can potentially come from improved fuel efficiency. However, such improvements are expected to only partially offset the growth of CO2 aviation emissions.

In the European Union, for example, whilst EU's total emissions controlled under the Kyoto Protocol fell by 5.5 per cent from 1990 to 2003, in the same period greenhouse gas emissions from international aviation increased by 73 per cent, corresponding to an annual growth of 4.3 per cent per year [5]. If the sector continues to grow at the current rate, by 2012 emissions will have increased by 150 per cent since 1990. Although the aviation's share of overall greenhouse gas emissions represents only 3 per cent, the rapid increase observed since 1990 may offset the progress made in other sectors. Particularly, in the European Union these increasing emissions would offset more than a quarter of the reductions required by the Community's target under the Kyoto Protocol [5].

The contribution of the aviation sector to climate change resulted in new challenges and pressures imposed by environmentalist campaigns, mainly in the European Union [34] where a directive for the inclusion of the aviation sector into the EU-ETS was published in January 2009. The EU-ETS aims at including the GHG emissions of intra-community flights as well as planes departing or landing in the European Union as of 2012. This will apply to all airlines, irrespective of nationality, which will then be allowed to sell pollution credits on the EU carbon market or buy credits if their emissions increase. Just like in the implementation of EU-ETS for industrial installations, airlines will also receive tradable

[2] Cruise altitude is an altitude or flight level maintained during the part of the flight that occurs between ascent and descent phases and is usually the majority of a journey. This is also the most fuel-efficient phase of the flight.

allowances covering a certain level of $CO_2$ emissions from their flights per year. After each year airlines must surrender a number of allowances equal to their actual emissions in that year. If their actual emissions will be lower than their allowances, they can sell their surplus allowances on the market or else "bank" them to cover future emissions. If they anticipate that their emissions will exceed their allowances, they can either take measures to reduce their emissions -for instance by investing in more efficient technologies or operational practices - or they can buy additional emission allowances on the market, whichever is cheaper. Thus, airlines may be able to buy allowances from industrial installations that have reduced their emissions. In addition, to help meet their obligations under the EU-ETS, airlines can also buy emission credits from clean energy projects carried out in third countries under the Kyoto Protocol mechanisms. Concerning the allocations of emission allowances per airlines, 82 per cent of the allowances will be given for free to airlines and 15 per cent of the $CO_2$ allowances will be allocated by auctioning. The remaining 3 per cent will be allocated to a special reserve for later distribution to fast growing airlines and new entrants into the market. The free allowances will be allocated by a benchmarking process which measures the activity of each airline in 2010 in terms of the number of passengers and freight that they carry and the total distance travelled [9].

When considering the impacts of the inclusion of aviation sector into the EU-ETS, Scheelhaase, Grimme, and Schaefer [34] expect that network carriers based outside the EU and with a moderate growth of emissions between 2006 and 2012 will most likely gain a significant competitive advantage compared to EU network carriers. This prognosis is applicable when comparing the EU network carriers competing with non-EU network carriers on markets for long-haul[3] air services. The disadvantage of EU network carriers relies mainly on the fact that not only all long-haul flights arriving at and departing from airports in the EU will be included into the EU-ETS, but also all short-haul flights, which are less eco-efficient than long-haul flights (calculated on the basis of emissions per RTK[4] or RPK[5]). All feeder services from short-haul flights needed to achieve and surpass the break-even seat load factor on the long-haul flights of EU network carriers are subject to the EU-ETS. On the other hand, non-EU network carriers operate its own feeder network outside the EU and therefore this part of their operations is not included in the EU-ETS.

## 4. Previous studies of Life Cycle Assessment in commercial aviation

The airlines are showing an increasing awareness on the environmental impacts of their operations by introducing new components related to these impacts in their accounting frameworks [24]. “Life Cycle Assessment was the first, and has been the most frequently adopted approach to environmental information management” [33].

Despite the considerable interest in the application of waste management and LCA in air transport sector [21]; [22]; [4], the environmental management literature has dedicated slight concentration to the study of airline’s choice of aircraft size and model on short-haul high density routes. Givoni and Rietveld [13] run an empirical examination that concluded that the service frequency in airlines’ competition is key factor that explains the choice of size and frequency.

[3] Long-haul flights are journeys typically made by wide-body aircraft that involve long distances, typically beyond six and a half hours in length, and often are non-stop flights.
[4] Revenue Tonne-kilometre (RTK) is the utilized (sold) capacity for passengers and cargo expressed in metric tonnes, multiplied by the distance flown.
[5] Revenue passenger kilometres (RPK) is a measure of the volume of passengers carried by an airline. A passenger for whose transportation an air carrier receives commercial remuneration is called a revenue passenger.

There has been several publications focused on the estimation and reporting of emissions by aircraft engines in different modes of flight, which in turn can provide a valuable support for the development of benchmarking of airlines within the framework of EU-ETS and can also be used by airlines to find more efficient alternatives to reduce its emissions based on fuel consumption and flight path designs [31]; [7]; [18]; [30].

## 5. Methodology of the study

This paper analyses the life cycle of air passenger transportation sector. The study aims at identifying the differences in fuel consumption and emissions among different aircraft models and flight routes for the same origin and destination currently offered by a major European airline. This comparison is illustrated by simple real case involving the daily offer of flights from Prague to Munich by Deutsche Lufthansa AG. Two flight routes were considered: a direct flight route from Prague Ruzyne airport to Munich International airport and a flight route with connection in Frankfurt international airport. For the direct flight route (265 km) two different aircraft models are used: AVRO RJ85 and DHC-8 400. For the indirect flight route Lufthansa uses Airbus A321-100 from Prague to Frankfurt (500 km) and from Frankfurt to Munich (374 km). In each case, the fuel consumption and emissions released were estimated in order to identify the most eco-efficient way of transporting the passengers from Prague to Munich.

Tab. 3 provides the main characteristics of aircrafts and routes currently offered by Lufthansa from Prague to Munich. According to Givoni and Rietveld [14] “in general, airlines opt for high frequency and small aircraft rather than lower frequency and larger aircraft when demand is relatively high on short-haul routes”.

Flowcharts processes and calculations in this study were made with the support of software UMBERTO v5.0. However, in order to obtain a more realistically model, more updated information was gathered for UMBERTO’s database. For inventory procedure, additional data related to resources used and emissions released was obtained through a research based on the following sources of information:

- Lufthansa environmental reports.
- Technical data brochures of aircraft manufacturers.

In Umberto, transitions are represented by a square symbol and places are represented by circles. The calculation using Umberto software contains a series of simplifications. In particular it assumes that all aircrafts have a load factor of 100 per cent and does not contain any dependence on special running conditions (e.g., speeds, short-haul flights/long-haul flights) and on holding delays resulting from congestion at airports or weather variations. It is therefore only suitable for rough calculations and should not be used for detailed transport emission calculations. Material pre-inputs, for instance provision of the transport infrastructure or the aircraft are not taken into consideration. On the input side, kerosene is the only energy considered as jet fuel. On the output side, the following emissions were estimated: CO2, NOx, SO2, VOC, particles and CO. As this study focuses on the contribution of aviation sector to global warming, only the levels of CO2 emissions per passenger are reported in the results. Moreover, as previously noted, most part of aircraft emissions occur at high altitudes. Almost 30 per cent of hydrocarbons and CO are emitted at ground level, while 70 per cent are emitted at higher altitudes. For other gases, 90 per cent of their emissions occur at higher altitudes [11]. Therefore, the calculations performed for the amount of produced emissions (output) of aircraft engines are based in the emission indices (EI) of jet fuel at typical cruise conditions as shown in Tab. 4. The EI represents the mass of a substance in grams per kilogram of fuel burned.

The functional unit used in this LCA is 1 passenger with an average of 70kg weight.

*Tab. 3: Main characteristics of aircrafts and routes analyzed*

| Aircraft | AVRO RJ85 | De Havilland DHC-8 400 | Airbus A321-100 |
|---|---|---|---|
| **Manufacturer** | British Aerospace (UK) | De Havilland Aircraft Comp. (UK) | Airbus (France) |
| **Seating capacity** | 93 | 70 | 190 |
| **Kerosene cons.[6]** | 5.73 litres | 3.7 litres | 2.9 litres |
| **Route** | PRG-MNH | PRG-MNH | PRG-FRN, FRN-MNH |
| **Distance** | 265 Km | 265 Km | 874 Km |
| **Flight number** | LH1697 | LH1689 | LH1403, LH104 |
| **Duration** | 0h50 | 1h00 | 1h15, 0h55 |

*Source: Authors*

*Tab.4: Emission indices of jet fuel at typical cruise conditions*

| Substance | Emission Index (g/kg) |
|---|---|
| Carbon Dioxide, CO2 | 3150 |
| Water, H2O | 1240 |
| Sum of nitric oxide and nitrogen dioxide (NOx) | 14.0 |
| Carbon Monoxide, CO | 1.9 |
| Sum of Hydrocarbons, HC | 0.6 |
| Sulphur Dioxide, SO2 | 0.6 |
| Soot | 0.015 |

*Source: [7]*

Individual calculations were done for each aircraft used by Lufthansa from Prague to Munich. The kerosene consumption in litres per passenger per 100 km was established as follows:

$$\text{Kerosene consumption} = \frac{fuel\ capacity}{maximum\ range \cdot passenger\ capacity} \cdot 100 \qquad (1)$$

Considering that 1 litre of kerosene weighs approximately 0.8 kg, fuel consumption is then converted in terms of kg per passenger per 100 km. By knowing the flight distance, it is possible to estimate the fuel consumption and the emissions per passenger for each flight.

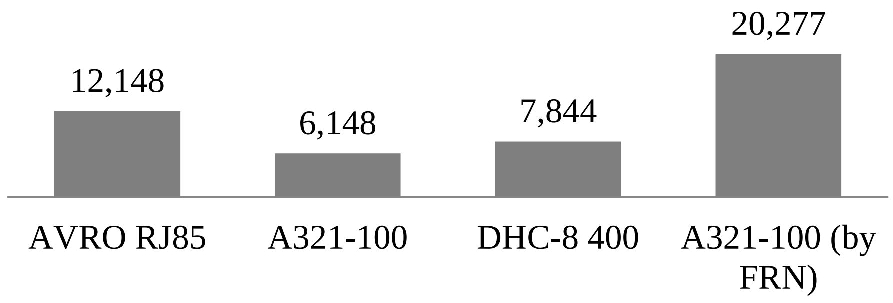
## 6. Results

Fig.1 and Fig. 2 present respectively, the differences in fuel consumption and in levels of CO2 emissions per passenger, both in kg. Additional calculation was done considering the case in which Lufthansa would offer an airbus A321-100 for a direct flight from Prague to Munich. Other

[6] Kerosene consumption per 100 passenger - kilometres

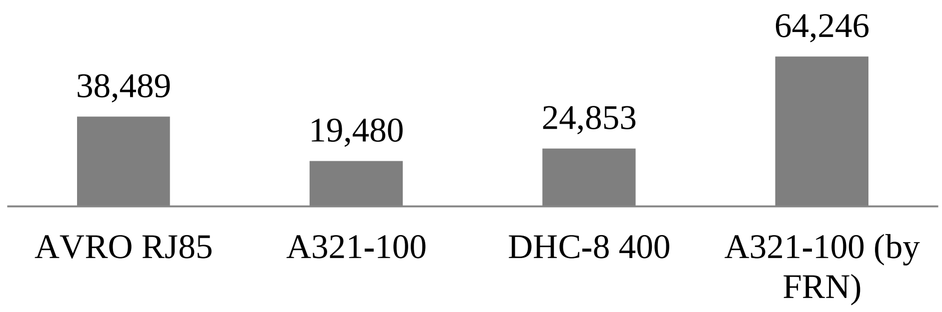
emissions were also calculated, such as: NOx, SO2, VOC, particles and CO. Although their amounts in Kg are considerably lower in comparison to CO2, it does not mean, however that these emissions are not of concern and shall not be controlled. As previously explained, this study focuses on the contribution of aviation sector to global warming and therefore, only the levels of CO2 emissions per passenger are reported.

*Fig. 1: Difference in fuel (kerosene) consumption per passenger (kg/pers.)*




*Source: Authors*

*Fig. 2: Difference in levels of CO2 emissions per passenger (kg/pers.)*




*Source: Authors*

Results show that when using DHC-8 400 for a direct flight from Prague to Munich, the fuel consumption per passenger is 35 per cent lower than that expected when operating AVRO RJ85. Moreover, when flying from Prague to Munich through Frankfurt with airbus A321-100, the total fuel consumption per passenger is approximately 2.5 times higher than that expected when operating DHC-8 400 in a direct flight. Interestingly, if Lufthansa would use an airbus A321-100 for a direct flight from Prague to Munich, the fuel consumption per passenger would be even 21.6 per cent lower than that expected by DHC-8 400. Total kerosene consumption in Kg per direct flight from Prague to Munich would be roughly: 1130 Kg (AVRO RJ85), 1168 Kg (A321-100) and 549 Kg (DHC-8400).

Based on the EI provided in Tab. 4, it is expected similar difference in terms of emissions of CO2 per passenger during the aircraft operations. Considering a possible use of A321 for a direct flight from Prague to Munich and assuming a passenger load capacity of 100 per cent for all direct flights, total CO2 emissions per flight would be roughly: 3559 Kg (AVRO RJ85), 3680 Kg (A321-

100), 1730 Kg (DHC-8400). All substances listed in Tab. 3, except water vapour (H2O) and soot, were calculated using Umberto model. Among those substances, CO2 and NOx are most important due to reasons previously stated. The emissions of NOx calculated were roughly: 15.70 Kg (AVRO RJ85), 16.24 Kg (A321-100), 7.63 Kg (DHC-8400).

## 7. Discussion

The total fuel consumption of DHC-8400 is about 50% less than that of AVRO RJ85, while the fuel consumption of A321-100 if used for a direct flight would be almost the same of AVRO RJ85.

Ross [30] highlights that the overall weight of a passenger aircraft is determined primarily by the airframe and amount of fuel carried. Therefore the number of passengers on board has a smaller impact on total fuel consumption. On the other hand, aircraft use less fuel per passenger the more passengers there are on board. The use of more fuel-efficient aircraft engines and the introduction of larger aircraft accommodating more seats per aircraft in combination with an increase in the average stage distances[7] have reduced the fuel use per available seat kilometre (ASK). The improvement in the specific fuel consumption has furthermore reduced the necessary amount of fuel that has to be carried on flights of comparable distances leading to additional fuel savings. Furthermore, the operation at higher passenger load factors has contributed to reduce the fuel use per revenue passenger kilometre (RPK).

Although the capacity of A321 is almost 100 passengers more than the capacity of AVRO RJ85, the total CO2 emissions of A321 would be just slightly higher than the emissions of AVRO RJ85 during the same flight route but still would have additional revenues from the sale of flight tickets for 97 passengers. Thus, the RPK would be significantly increased and the fuel use per RPK would be considerably reduced.

The calculations presented in this study are subject to several uncertainties and as previously stated, provide only a rough picture on the differences in terms of fuel consumption and emissions per passenger. Apart from the aircraft model, flight distance, cargo on passenger flights and seat occupancy rate, other important factors may affect the GHGs emissions released by commercial flights on a per person basis, such as flight profile and seating configuration [19].

Currently, Lufthansa offers eight flights per day to Munich being four of them direct flights. An eventual increase in the share of direct flights to Munich over total flights offered with Munich as a final destination would depend on the passenger demand departing from Prague. That means, more passengers willing to go to Munich departing from Prague would be needed. This increase does not depend solely on the airlines initiatives. On the other hand, the use of more fuel-efficient and sometimes even larger aircrafts can be faced as an interesting alternative to reduce fuel consumption per RPK but this would require an increase in awareness of passengers concerning their contributions to climate change. Initiatives of the airlines to promote these eco-efficient flights might vary from awarding bonus miles to charging discounted fares to passengers opting for these flights. For the first alternative, a survey among current members of their miles programme would be convenient to identify what would be their reaction to such policies. For the second alternative, the estimation of price elasticity of demand in aviation would be recommended, although it can be a difficult process, given the various problems concerning data availability on prices, number of passengers, etc. The majority of studies with this respect report estimated price elasticity (passenger kilometres with respect to ticket prices) of from –0.4 to –1.2 for business flights and from –1.1 to –

[7] The average distance flown per aircraft departure, measured in statute kilometres. The measure is calculated by dividing total aircraft kilometres flown by the number of total aircraft departures performed.

2.7 for holiday flights [15]. Considering that for the route Prague-Munich, a significant share of passengers are flying for business purposes, a discounted fare might not be the most appropriate measure. However, for flights to destinations conventionally sought by tourists this alternative might be convenient. In this case, another challenge arises related to the estimation of the size of the discount in the air fares for eco-efficient flights.

## 8. Conclusion

The air transport companies have to consider not only the maximum efficiency in economic terms, but also if the chosen alternative is the more eco-efficient. One of the most popular tools to evaluate eco-efficiency is the Life Cycle Assessment.

The main aim of this paper is to show how fuel consumption and emissions per passenger can vary significantly for different flight routes between the same origin and destination according to the distance flown and the use of different aircraft models. It illustrates these variations with different real offers of daily flights by Deutsche Lufthansa AG.

For airlines, the reduction of fuel consumption and consequently, CO2 emissions is a major target due to the major oscillations in oil prices and the inclusion of the aviation sector in the EU Emissions Trading Scheme as of 2012 when all intra-community flights will be subject to emission restrictions. Conventionally, the initiatives taken by airlines to minimize their CO2 emissions are mainly based on the optimization of fuel consumption (e.g., maximizing efficient use of the cruising speed) and in the renewal of aircraft fleet with more fuel-efficient aircrafts.

Additional operational initiatives are being discussed with government authorities and airport service management in order to ensure optimized air traffic (e.g., Single European Sky), more airport runways (fewer approach manoeuvres) and shorter taxiways. Besides improvements in operational performance, marketing strategies aimed at attracting passengers to more eco-efficient flights can also emerge as noteworthy adaptation measures to the EU-ETS. All these initiatives become essential for short-haul flights in the European Union in the light of the EU-ETS, since they are commonly known as less eco-efficient than long-haul flights due to their higher emissions per RTK or RPK.

A further study will be conducted by authors focused on the alternatives for engaging the passengers in using more eco-efficient flights and on estimating the possible financial gains for airlines from the investment into eco-efficient aircrafts.

## Acknowledgement

The article was supported by the “Student Grant Competition” at University of Pardubice - the project “Science and research activities supporting the program Economic Policy and Administration” (SGFES01/2011) and the project “Science and research activities supporting the program Economics and Management” (SGFES03/2011).

## References


[1] AIRPORTS COUNCIL INTERNATIONAL. ACI: Press Releases [online]. 2011, 01.08.2011 [cit. 2011-10-12]. World Airport Traffic Report 2010 - Strong traffic rebound demonstrates industry's resiliency. Available at WWW: <http://www.aci.aero/cda/aci_common/display/main/aci_content07_banners.jsp?zn=aci&cp=1-7-46%5e43915_725_2__>.

[2] ARANDA, A.; ZABALZA, I. Y SCARPELLINI, S. Economic and Environmental Analysis of the Wine Bottle Production in Spain by Means of Life Cycle Assessment. In International Journal of Agricultural Resources, Governance and Ecology, 2005, Vol. 4, No. 2, pp. 178-191. ISSN: 1741-5004.

[3] BECK, J. P.; KRZYZANOWSKI, M.; KOFFI, B. EEA [online]. 8. European Environment Agency, 1998, 13th April 2011 [cit. 2011-10-15]. Tropospheric Ozone in EU - The consolidated report. Available at WWW: <http://www.eea.europa.eu/publications/TOP08-98/page004.html>. ISBN 92-828-5672-0.

[4] CHESTER, M.; HORVATH, A. Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas, and Criteria Pollutant Inventories of Automobiles, buses, Light Rail, Heavy Rail and Air. University of California, Berkeley. California, 2008.

[5] COMMISSION OF THE EUROPEAN COMMUNITIES. Communication from the Commission to the Council, the European Parliament, the EESC and the Committee of the Regions: Reducing the Climate Change Impact of Aviation COM (2005) 459 final. *In Official Journal of the EU* [online]. 27.9.2005, Brussels, [cit. 2011-09-30]. Available at WWW: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2006:185:0097:0101:EN:PDF>.

[6] COOK, A.; TANNER, G.; WILLIAMS, V. Y MEISE, G. Dynamic cost indexing – Managing airline delay costs. In Journal of Air Transport Management, 2009, Vol. 15, No. 1, pp. 26-35. ISSN: 0969-6997.

[7] DOPELHEUER, A. Aircraft emission parameter modelling. In Air & Space Europe, May-June 2000, Vol. 2, Iss. 3, pp. 34-37. ISSN 1290-0958. DOI: 10.1016/S1290-0958(00)80060-X.\

[8] ENVIRONMENTAL PROTECTION AUTHORITY, Victoria, Australia. Carbon Offset Guide Australia [online]. 2007 [cit. 2011-10-11]. Calculating Airline Emissions and Offsets. Available at WWW: <http://www.carbonoffsetguide.com.au/aviation_offsets>.

[9] EUROPEAN COMMISSION: Climate Action [online]. 09 Mar 2011 [cit. 2011-09-29]. Reducing emissions from the aviation sector. Available at WWW: <http://ec.europa.eu/clima/faq/transport/aviation/index_en.htm>.

[10] FAWCETT, A. The sustainability of airports and aviation: depicturing air travel impacts and opportunities for sustainable change. In Transport Engineering in Australia, 2000, Vol. 6, pp. 33-39. ISSN: 1324-1591.

[11] FEDERAL AVIATION ADMINISTRATION. Aviation & Emissions: A Primer. Office of Environment and Energy, USA, 2005. Available at WWW: <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/aeprimer.pdf>.

[12] FLIGHTPEDIA [online]. c2009 [cit. 2011-09-30]. Flight distance from Prague to Munich. Available at WWW: <http://www.flightpedia.org/distance-prague-czech-republic-to-munich-germany.html>.

[13] GIVONI, M.; RIETVELD, P. Airline's choice of aircraft size – Explanations and implications. In Transportation Research Part A: Policy and Practice, 2009, Vol. 43, No. 5, pp. 500-510. ISSN: 0965-8564.

[14] GIVONI, M.; RIETVELD, P. The environmental implications of airlines' choice of aircraft size. In Journal of Air Transport Management, 2010, Vol. 16, No. 3, pp. 159-167. ISSN: 0969-6997.

[15] HOF, A.; DINGS, J.; DIJKSTRA, W. Price elasticities in aviation and marine shipping: literature study. In. Delft, Netherlands: CE Delft, 2001. s. 28. Available at WWW: <http://www.cedelft.eu/?go=home.downloadPub&id=287&file=01_4112_27.pdf>.

[16] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). In: Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., and McFarland, M. (Eds.). Aviation and the Global Atmosphere: A Special Report of IPCC Working Groups I and III in Collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer. Cambridge Un. Press: Cambridge, UK, 1999. Available at WWW: <http://www.grida.no/climate/ipcc/aviation/064.htm>.

[17] IPCC Fourth Assessment Report: Climate Change 2007 (AR4).

[18] JARDINE, C.N. Calculating the Carbon Dioxide Emissions of Flights. In Final report by the Environmental Change Institute, 2009.

[19] KOLLMUSS, A.; LANE, J. SEI working paper, Carbon offsetting and air travel, part 1: CO2-Emissions Calculating, Stockholm Institute, Stockholm, 2008.

[20] KOMALIRANI, Y., GAURAVKUMAR, J. Carbon Dioxide Emission Reduction. Potential from Civil Aviation Sector. A Case Study of Delhi–Mumbai Air Route. In India Infrastructure Report 2010.

[21] LI, X.D.; POON, C.S.; LEE, S.C.; CHUNG, S.S. Y LUK, F. Waste reduction and recycling strategies for the in-flight services in the airline industry. In Resources, Conservation and Recycling, 2003, Vol. 37, No 2, pp. 87-99. ISSN: 09213449.

[22] LOFTUS, J.; PURCELL, J. Product Life Cycle Analysis in the Airline Industry. In Journal of the Asia Pacific Centre for Environmental Accountability, 2006, Vol. 12, No. 3, pp. 11-18.

[23] LU, C. The implications of environmental costs on air passenger demand for different airline business models. In Journal of Air Transport Management, 2009, Vol. 15, No. 4, pp. 158-165.

[24] LYNES, J.K.; ANDRACHUK, M. Motivations for corporate social and environmental responsibility: A case study of Scandinavian Airlines. In Journal of Intern. Management, 2008, Vol. 14, No. 4, pp. 377-390. ISSN: 1075-4253.

[25] OFFICE OF TRANSPORTATION AND AIR QUALITY, U.S. ENVIRONMENTAL PROTECTION AGENCY. U.S. Environmental Protection Agency: Nonroad Engines, Equipment, and Vehicles [online]. U.S. : EPA, 2005, 10.1.2011 [cit. 2011-10-16]. Regulatory Announcement: New Emission Standards for New Commercial Aircraft Engines. Available at WWW: <http://www.epa.gov/otaq/regs/nonroad/aviation/420f05015.pdf>.

[26] PRAGUE AIRPORT [online]. 1/31/2011 [cit. 2011-09-29]. Prague Airport evaluates 2010 Operating Results. Available at WWW: <http://www.prg.aero/en/prague-airport/press-center/press-releases/prague-airport-evaluates-2010-opearting-results/>.

[27] PRAGUE AIRPORT [online]. July 2010 [cit. 2011-09-29]. Company profile 2009 - 2010. Available at WWW: <http://www.prg.aero/Files/cs/O_letisti/vyrocni_zpravy/profil-2010.pdf>.

[28] REZA ABDI, M.; SHARMA, S. Strategic/tactical information management of flight operations in abnormal conditions through Network Control Centre. In International Journal of Information Management, 2007, Vol. 27, No. 2, pp. 119-138. ISSN: 0268-4012.

[29] ROMANO, D.; GAUDIOSO, D.; DE LAURETIS, R. Aircraft Emissions: A Comparison of Methodologies Based on Different Data Availability. Environmental Monitoring and Assessment. 1999, 1, 56, s. 51-74. Available at WWW: <http://extranet.regione.piemonte.it /ambiente/aria/dwd/emissioni/aircraft_emissions.pdf>.

[30] ROSS, D. GHG emissions resulting from aircraft travel. Sydney: Carbon Planet, 2007.

[31] RYPDAL, K. Aircraft Emissions in Background Papers IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2000. Available at WWW:
http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf.

[32] S. FUGLESTVEDT, J., et al. Climatic effects of NOx emissions through changes in tropospheric O3 and CH4: A global 3-D model study. In. 3. Oslo, Norway: CICERO, 1997. s. 64. Available at WWW:
<http://www.cicero.uio.no/media/94.pdf>. ISSN 0804-4562.

[33] SCHALTEGGER, S.; BURRIT, R. Contemporary environmental accounting: issues, concepts and practice. New edn. Sheffield: Greenleaf, 2000. 462 p. ISBN: 1874719357

[34] SCHEELHAASE, J.; GRIMME, W. Y; SCHAEFER, M. The inclusion of aviation into the EU emission trading scheme - Impacts on competition between European and non-European network airlines. In Transportation Research Part D: Transport and Environment, 2010, Vol. 15, No. 1, pp. 14-25. ISSN: 1361-9209.

[35] TARRASÓN, L., et al. Study on air quality impacts of non-LTO emissions from aviation. In. 3. Oslo, Norway: Norwegian Meteorological Institute, 2004. s. 64. Available at WWW:
<http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/aeprimer.pdf>. ISSN 1503-8025.

[36] VINOT, S; COUSSY, P. Greenhouse gas emissions and the transport sector. IFP: Panorama 2009 [online]. December 2008 [cit. 2011-09-30]. Available at WWW: <http://www.ifpenergiesnouvelles.com/publications/notes-de-synthese-panorama/panorama-2009>.

## Contact address

**Ticiano Costa Jordão**
Institute of Administration and Social Sciences
Faculty of Economics and Administration
University of Pardubice
Studentská 84, 532 10, Pardubice, Czech Republic
E-mail: ticiano.costajordao@upce.cz
Executive Director
The Sustainability Crusade Observatory
E-mail: tcjordao@crusus.org

**Ernesto López-Valeiras Sampedro**
Faculty of Business and Tourism
University of Vigo
Campus Universitario, 32004, Ourense, Spain
E-mail: elvaleiras@uvigo.es

**Jana Ďurišová**
Institute of Economy and Management
Faculty of Economics and Administration
University of Pardubice
Studentská 84, 532 10, Pardubice, Czech Republic
E-mail: Jana.Durisova@upce.cz