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

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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 (NO_x) and its concerns related to ground level ozone formation, measurements and reductions of carbon dioxide (CO_2) became a major regional target. This major concern related to CO_2 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).*

Keywords: *Life Cycle Assessment, Environmental Impacts, Material Flow, Airlines, Air Transport, Greenhouse Gas Emissions, Climate Change.*

JEL Classification: *Q56, M14.*

Introduction

Nowadays there are some factors that affect the global air transport industry. Reza Abdi et al. [23] 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 [7]. 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 [4]; [19] 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 [27]. 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 [19]; [10] 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 [9]). 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 [22].

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% 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) [21]. 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% 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 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.

1 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

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[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.

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 [6]. 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 [24]. 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% CO_2, a little less than 30 % H_2O, and less than 1% each of NO_x, CO, SO_x, VOC, particulates, and other trace components including hazardous air pollutants (HAPs). 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.

The impacts of gases emitted by civil aviation sector are highlighted in Tab. 1. In the subsequent sections, a particular attention is given to carbon dioxide (CO_2) emissions due to its contribution to global warming.

Tab. 1: Impacts on atmosphere caused by gas emissions from aviation

Gas	Impact
CO_2	Long-lived GHG. Contributes to global warming.
O_3	Lifetime weeks to months. Product of NO_x emissions plus photochemistry. The effect of O_3 is high at subsonic cruise levels and causes radio-active reactions at those levels.
CH_4	Lifetime of ~10 years. Aircraft NO_x destroys ambient CH_4.
H_2O	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 of data: [8]

2   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 [16]. Technological progress has been made in reducing greenhouse gas (GHG) emissions through aircraft fuel efficiency by reducing weight, improving aerodynamics performance and engine design [12].

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% 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 [13], aviation currently accounts for about 2% of human-generated global carbon dioxide emissions, the most significant greenhouse gas. This 2 % estimate includes emissions from all global aviation, including both commercial and military. Global commercial aviation, including cargo, accounted for over 80% of this estimate. The sector also contributes to about 3% of the potential warming effect of global emissions that can affect the earth's climate, including carbon dioxide.

The contribution of the aviation sector to climate change resulted in new challenges and pressures imposed by environmentalist campaigns, mainly in the European Union [28] 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.

When considering the impacts of the inclusion of aviation sector into the EU-ETS, Scheelhaase, Grimme, and Schaefer [28] 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

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[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.
[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.

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.

3 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 [20]. "Life Cycle Assessment was the first, and has been the most frequently adopted approach to environmental information management" [27].

Despite the considerable interest in the application of waste management and LCA in air transport sector [17]; [18]; [3], 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 [10] run an empirical examination that concluded that the service frequency in airlines' competition is key factor that explains the choice of size and frequency.

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 [26]; [5]; [14]; [25].

4 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. 2 provides the main characteristics of aircrafts and routes currently offered by Lufthansa from Prague to Munich. According to Givoni and Rietveld [11] "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".

Tab. 2: 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 of data: authors

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 % 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: CO_2, NO_x, SO_2, VOC, particles and CO. As this study focuses on the contribution of aviation sector to global warming, only the levels of CO_2 emissions per passenger are reported in the results. Moreover, as previously noted, most part of aircraft emissions occur at high altitudes. Almost 30% of hydrocarbons and CO are emitted at ground level, while 70% are emitted at higher altitudes. For other gases, 90% of their emissions occur at higher altitudes [8]. 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. 3. 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.

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[6] Kerosene consumption per 100 passenger – kilometres.

Tab. 3: Emission indices of jet fuel at typical cruise conditions

Substance	Emission Index (g/kg)
Carbon Dioxide, CO_2	3 150
Water, H_2O	1 240
Sum of nitric oxide and nitrogen dioxide (NO_x)	14.0
Carbon Monoxide, CO	1.9
Sum of Hydrocarbons, HC	0.6
Sulphur Dioxide, SO_2	0.6
Soot	0.015

Source of data: [5]

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:

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

(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.
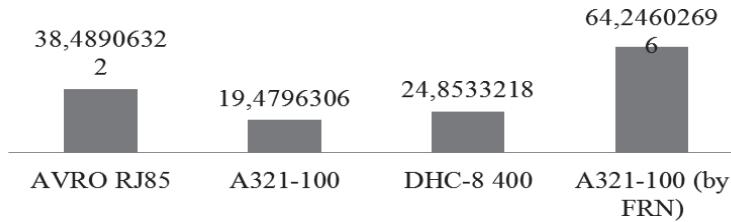
5 Results

Fig.1 and Fig. 2 present respectively, the differences in fuel consumption and in levels of CO_2 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 emissions were also calculated, such as: NO_x, SO_2, VOC, particles and CO. Although their amounts in Kg are considerably lower in comparison to CO_2, 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 CO_2 emissions per passenger are reported.

Fig. 1: Difference in fuel (kerosene) consumption per passenger (kg/pers.)
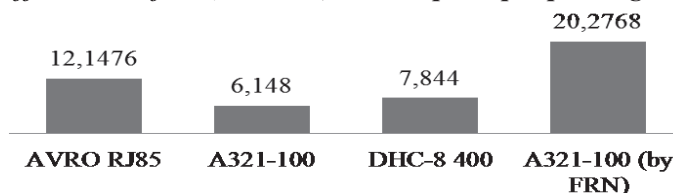
Source of data: authors

Fig. 2: Difference in levels of CO_2 emissions per passenger (kg/pers.)

Results show that when using DHC-8 400 for a direct flight from Prague to Munich, the fuel consumption per passenger is 35% 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% lower than that expected by DHC-8 400. Total kerosene consumption in Kg per direct flight from Prague to Munich would be roughly: 1 130 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 CO_2 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% for all direct flights, total CO_2 emissions per flight would be roughly: 3 559 Kg (AVRO RJ85), 3 680 Kg (A321-100), 1730 Kg (DHC-8400). All substances listed in Tab. 3, except water vapour (H_2O) and soot, were calculated using Umberto model. Among those substances, CO_2 and NO_x are most important due to reasons previously stated. The emissions of NO_x calculated were roughly: 15.70 Kg (AVRO RJ85), 16.24 Kg (A321-100), 7.63 Kg (DHC-8400).

6 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 [25] 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

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[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.

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 CO_2 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 [15].

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, CO_2 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 CO_2 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.

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