Bachelor Thesis

Carbon Footprint in the Commercial Aviation Industry: Current Situation and Measures to Reduce Emissions Using the Example of Lufthansa

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Statutory Declaration

I hereby confirm that I have authored this thesis independently and I have not used other than the declared sources. To the best of my knowledge, all used sources, information and quotations are referenced as such.

Date: 30.08.17 **Signature**________________

Markus Kleiser

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List of Abbreviations

ASK	Available Seat Kilometer
ATM	Air Traffic Management
BSI	British Standards Institution
CEO	Current Engine Option
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EASA	European Aviation Safety Authority
EEA	European Environment Authority
EP	Efficiency Points
EU-ETS	European Union Emissions Trading Scheme
FAA	Federal Aviation Administration
FAB	Functional Airspace Block
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IATA	International Air Transport Association
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
l/100skm	Liters per 100 Seat Kilometers
l/100pkm	Liters per 100 Passenger Kilometers
LCC	Low Cost Carrier
LTO	Landing and Takeoff Cycle
MRO	Maintenance, Repair and Overhaul
N_2O	Nitrous Oxide
NEO	New Engine Option
PFC	Perfluorocarbons
PRC	Performance Review Commission
RPK	Revenue Passenger Kilometers
RTK	Revenue Ton Kilometers
SES	Single European Sky
SESAR	Single European Sky ATM Research
SF_6	Sulfur Hexafluoride
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

Abstract

The goal of this thesis is to give an overview of the carbon footprint of the commercial aviation industry and to introduce measures to mitigate emissions. This will be done by taking the German Lufthansa Group as an example.

In the first part, relevant theoretical background information will be given. It will be shown that the commercial aviation industry is subject to steady and relatively strong growth. Even though the global share of GHG emissions caused by air traffic is currently relatively low, it is projected to increase in accordance with overall industry growth.

In the second part, measures taken by the aviation industry to reduce its emissions are presented using the example of Lufthansa. The measures that are taken are various, reaching from fleet renewal over infrastructural improvements such as airspace management to alternative fuels. It is also shown that the efficiency of an airline depends on different things and hence leads to different performances in the industry.

Even though the reduction of emissions is typically related with a reduction of costs for the aviation industry, the progress in some areas is still relatively slow.

Exposé

Relevance and goals of this thesis

Over the last decades, sustainability has become more and more crucial for companies and nations as well as individuals. Efforts are being made nearly everywhere in order to cut greenhouse gas emissions and thus mitigate climate change. This is also done in the commercial aviation industry. Emitting the highest amounts of CO_2 per capita and per kilometer, airliners are facing a tough challenge to reduce their carbon footprint.

Being one of Europe's leading airlines, listed in DAX 30, Lufthansa is also addressing this issue. With a variety of measures, the airline aims to cut the CO_2 emissions by 50% until 2050, grow carbon neutrally from 2020 and increase energy efficiency by 1.5% per year until 2020 in accordance with overall industry goals.[1]

Building on theoretical background information and the current state of the industry concerning its environmental impact, different approaches to reduce the emissions will be presented and evaluated. The following questions shall guide this thesis:

Key questions

- What is the carbon footprint and how is it calculated?
- How is the aviation industry currently performing concerning its carbon footprint?
- What measures are undertaken to reduce the emissions in the airline industry?
- Are the measures meaningful?

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[1] Deutsche Lufthansa AG (2017e)

Methodology and Approach

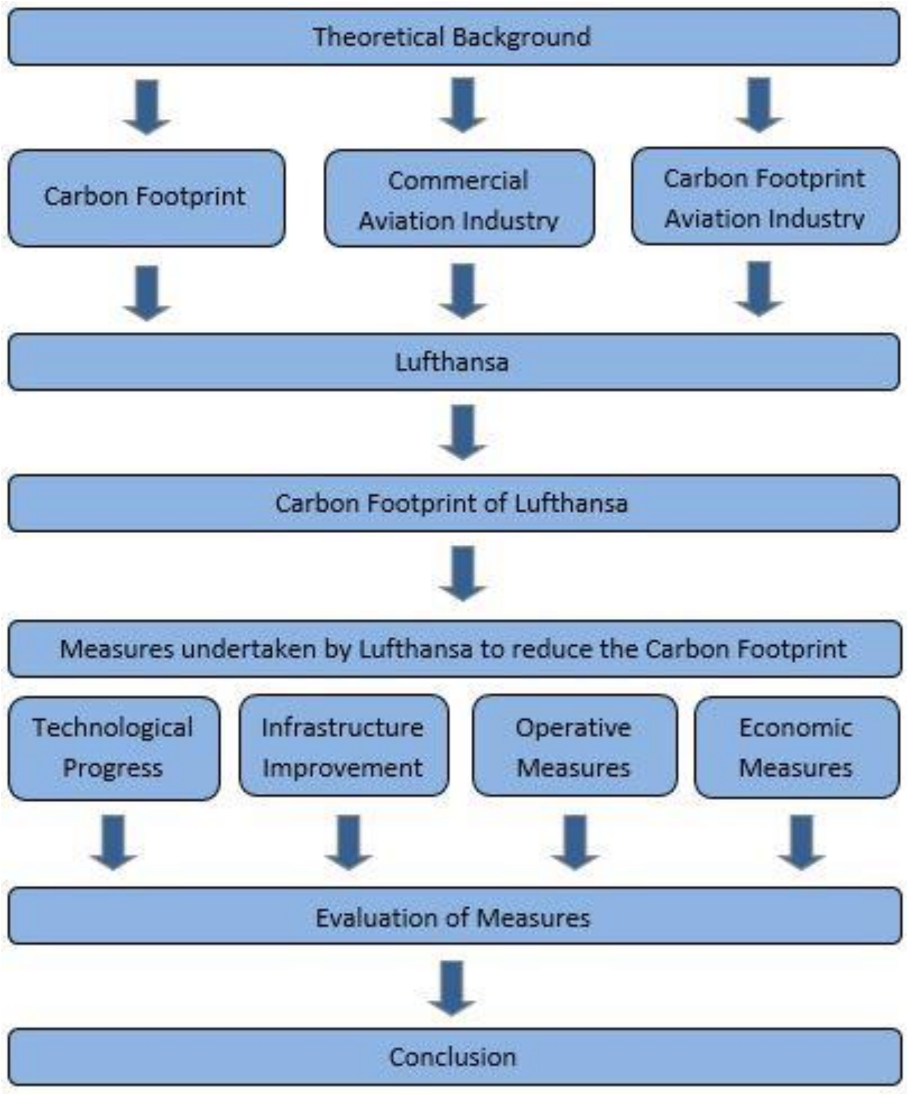

Figure 1: Methodology and Approach[2]

For these questions to be answered, the reader will be given an overview of the carbon footprint and its calculation. Further focus will be dedicated to the way Lufthansa measures and records its CO_2 emissions. This will be followed by a presentation of the commercial aviation industry and an introduction to the carbon footprint in the commercial aviation industry including a benchmark with other industries. These steps will serve as a basis for the main part of the thesis which will introduce and evaluate the measures undertaken by Lufthansa to cut its CO_2

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[2] Own Illustration

emissions. A presentation of the airline group Lufthansa and a CO_2 benchmark with other airlines will serve as an introduction to this part of the thesis.

As Lufthansa has set up a four-pillar strategy to cut its CO_2 emissions, which is a common approach in this industry, each pillar will be focused on separately. In a first step, measures that are undertaken will be introduced, followed by an evaluation of the measure. The final stage of this thesis will conclude its findings.

Limits

As the measures taken by Lufthansa are various, not each single measure can be introduced and evaluated. In addition, many of these measures are not specific to Lufthansa but can be applied in the entire industry and are also initiated comprehensively. Besides, the focus of this thesis will be on the primary CO_2 emissions caused by the flight operations of Lufthansa. Insignificant amounts, for instance coming from the heating of office buildings, will be neglected as they barely contribute to the carbon footprint and are not industry specific.

2. Theoretical Background

This chapter will build the theoretical foundation and give relevant background information. First of all, some information will be given about the related topic sustainability, followed by an introduction of the carbon footprint. Afterwards, an overview of the commercial aviation industry and its carbon footprint will be given.

2.1. Sustainability

The term sustainability is widely used these days; almost all companies around the globe include sustainability in their corporate strategies. Yet, there is no uniform definition of it. One of the most important definitions is given by the Brundtland report from 1987 which was published by the World Commission on Environment and Development. It considers sustainability as a process of development and defines it as follows: *"sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*[3] Even though sustainability is often only seen as "being green" it is more than mere environmentalism. In order to achieve sustainable development, social and economic factors have to be taken into account as well. Figure 2 shows the three components of sustainable development.

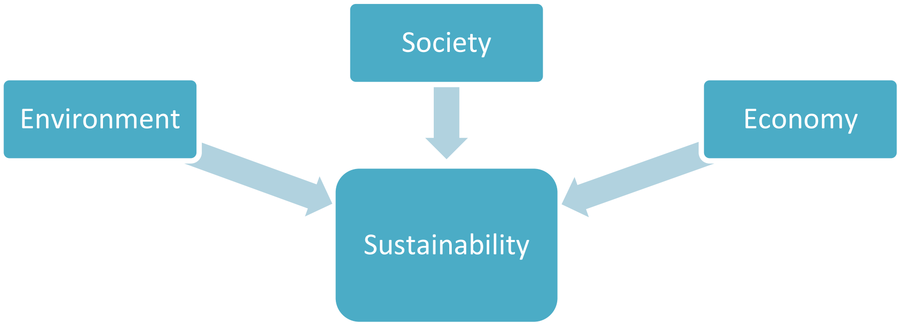

Figure 2: Components of sustainability[4]

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[3] World Commission on Environment and Development (1987)

[4] Own illustration based on United Nations General Assembly (2005)

Environmental sustainability means that mankind consumes natural resources at a rate at which they are able to reproduce themselves and thus maintaining the environmental systems in balance.[5]

Social sustainability describes a state where all people can enjoy universal human rights, fulfill basic necessities and have access to sufficient recourses allowing them to keep their families and communities healthy and clear. Furthermore, for social sustainability to be guaranteed, healthy communities need to have leaders who are fair and ensure that personal, labor and cultural rights are appreciated and no one suffers from discrimination.[6]

Finally, economic sustainability can be achieved if people have access to sufficient resources, be it financial or other, which enable them to satisfy their elementary needs and ultimately, to remain independent. Economic sustainability also assumes the intactness of the economic systems and the availability of secure sources of livelihood.[7]

As this thesis focuses on the reduction of the carbon footprint in the airline industry, environmental sustainability will be the relevant component. Besides, environmental sustainability is also most and directly impacted by carbon dioxide emissions. Global warming is only one example which proves the negative effects of CO_2 emissions and the interference with this component of sustainability as the emissions disrupt the balance of the environmental systems.

2.2. Carbon Footprint

2.2.1. Terminology

Since public awareness about climate change and environmental protection has grown and since it has become clear that mankind is influencing or even causing climate change, the need for a framework that measures the impact which anthropogenic activities have on the environment has risen, as such frameworks make it easier to tackle the related problems in a comprehensive way. As a result,

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[5] University of Alberta Office of Sustainability (2013)
[6] University of Alberta Office of Sustainability (2013)
[7] University of Alberta Office of Sustainability (2013)

solutions to these problems can also be designed in a more customized and precise way. The ecological footprint is a framework that existed before the carbon footprint which also includes some carbon measurements.[8] The carbon footprint can be traced back to a subset of this concept which was introduced by Mathis Wackernagel and William Rees in 1996.[9] Whereas the carbon footprint focuses on the emission of greenhouse gases, mainly due to the burning of fossil fuels, the ecological footprint relates the resources consumed by humans with the areas of water and land that would be needed to replace these resources. It could thus be said that the ecological footprint depicts in what way carbon emissions compare with other components of human demand such as e.g. resources of food. The carbon footprint, however, is a metric to measure the amount of carbon that is emitted in the course of a process, by an organization or an entity. To make it short, it aims to quantify the atmospheric pollution which results from human activity[10]. Both, the ecological footprint and the carbon footprint include calculations on greenhouse gas emissions, yet, they are used in different ways.

2.2.2. Measurement

The goal of the carbon footprint is to identify all carbon emissions which are caused by an activity over its entire lifecycle. This activity will result in a product or service, all sub processes and activities that can be derived from the primary activity are included.[11] However, there is no standardized and generally recognized definition of the carbon footprint yet and thus, there is also no standardized way of measuring the carbon footprint. This is at the same time a criticism of the carbon footprint. Some calculations are merely based on carbon dioxide emissions, others might as well include carbon-based greenhouse gases such as methane. The selection of greenhouse gases to be included in the calculation can depend on different things, such as what the carbon footprint is actually needed for, which guidelines for greenhouse gas accounting are followed and what type of activity is being analyzed.

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[8] Harkiolakis (2013)
[9] Pandey et al. (2011)
[10] Harkiolakis (2013)
[11] Harkiolakis (2013)

For instance, in the case of a coal-fired power plant where most of the greenhouse gas emitted is CO_2 it is reasonable to only measure the CO_2 emissions, whereas in the meat industry and in agriculture it also makes much sense to include CH_4 and N_2O.[12] In relation with this it should be mentioned that the Kyoto Protocol from 1997 encompasses six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).[13]

To correctly account for the amounts of GHGs emitted over the lifecycle of an activity or product, there are some common guidelines available for GHG accounting. First of all, there are some ISO standards that relate to the carbon footprint. ISO 14064 defines how boundaries are determined correctly, how to quantify GHG emissions and it can also serve as a guideline on how to design GHG mitigation projects. ISO 14025 is a standard that helps to correctly determine the lifecycle of an activity or product and finally, ISO 14067 gives a guideline on the carbon footprint of a product. The British Standard Institution (BSI) has released the PAS 2050 standard in 2008 that gives a guideline on the lifecycle GHG emissions of goods and services as well. Another guideline worth mentioning is given by the IPCC (Intergovernmental Panel on Climate Change) that divides the sources of all human-caused GHG emissions into sectors: energy, industrial processes and product use, agriculture, forestry and other land use and waste.[14] Lastly, the GHG Protocol by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) is most commonly used as a reference for GHG accounting. This will be covered in more detail in the following chapter as it is also used by Lufthansa to account for its GHG emissions.

The basic process of accounting for the GHG emissions over the lifecycle of a product or service can be done in two ways. It is either possible to follow a bottom up approach, also known as process analysis or a top down approach, which is known as input-output analysis. Whereas the bottom up approach subdivides the sources of emissions into different categories and is more suitable for smaller

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[12] Pandey et al. (2011)

[13] Reilly et al. (2002)

[14] Pandey et al. (2011)

entities, the top down approach is more adequate for bigger systems as it utilizes the economic input-output model.[15]

Another crucial factor that must be taken into account when calculating the carbon footprint is the setting of boundaries. This means that it has to be defined which activities that can be derived from the primary activity will be included in the calculation. The boundaries should be set in a way such that the organization for which the carbon footprint is calculated is represented based on legal, financial or business control. For instance, if a company holds some amount of equity of another company, it should also include the fragment of emissions equal to the fragment of share held in its calculation of the carbon footprint.[15] However, the setting of the boundaries also depends on the nature of the business and what wants to be examined with the carbon footprint.

After having set the organizational boundaries, it also has to be determined where to set the operational boundaries, meaning that it should be decided which direct and indirect emissions are included. For instance, direct emissions result from the burning of fuels on site, indirect emissions are caused by the purchasing of external energy.

The actual collection of data on the emission of GHGs can then either be done through real time measurements or using approximations that are based on emission factors and models. Generally, the latter are the most common approaches. The emission of GHGs caused by an organization, a product or a service are calculated with the use of specific emission factors and models with their underlying data on fuel consumptions, energy and further input factors which lead to emissions. These emission factors are given for example by the GHG Protocol or the PAS 2050 standard.[16]

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[15] Pandey et al. (2011)

[16] Pandey et al. (2011)

2.2.3. GHG Protocol

The GHG Protocol which was introduced by the WRI and the WBCSD is the most commonly used international accounting tool used by businesses for the measurement and management of GHG emissions.[17] In the year 2016, 92% of the Fortune 500 companies that participate in the Carbon Disclosure Project made use of the GHG Protocol either directly or indirectly.[18] It provides standards to prepare the lifecycle inventory, which is a mechanism that is utilized to measure the carbon footprint and also to manage and mitigate it. Even though there are other protocols such as the ISO norms or the PSA 2050, they also share some commonalities.[19] The GHG Protocol defines three scopes of emissions, which are shown in figure 3 below:

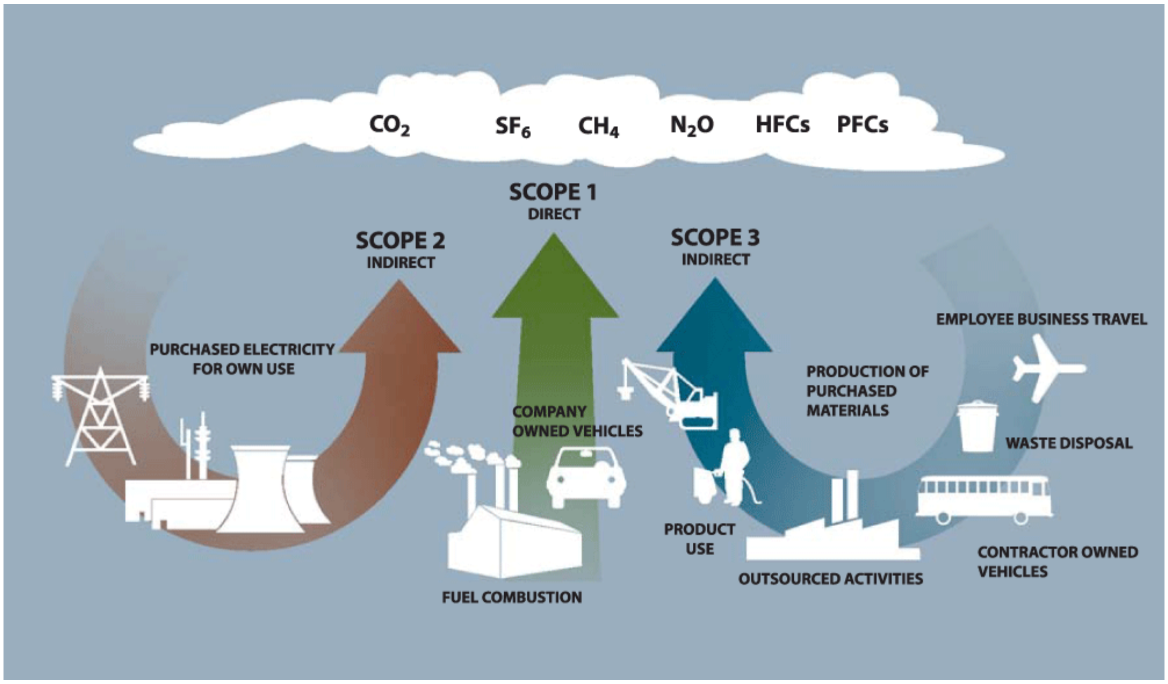

Figure 3 GHG Protocol Scopes[20]

Basically, a distinction between direct and indirect emissions can be made. Only scope 1 depicts direct emissions, whereas scope 2 and 3 include indirect emissions. The scopes can be described as follows:

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[17] Boone et al. (2012)
[18] World Resources Institute, World Business Council for Sustainable Development (2017)
[19] Boone et al. (2012)
[20] World Resources Institute (2009)

- Scope 1: All direct GHG emissions caused by resources owned and operated by a company. Supply chain operations including facilities within the company are also included.
- Scope 2: Includes all GHG emissions that result from purchased energy, for instance to heat facilities.
- Scope 3: This includes all other indirect GHG emissions that can be traced back to the company's supply chain which are not covered in scope 2. It can include things such as business travel of employees, vehicles owned by subcontractors, products purchased upstream and used by the company but also downstream supply chain activities as for instance retail, distribution and use of the product. Finally, the recapture of the waste stream caused by the product or service is also included.[21]

In most cases, companies report emissions that fall into scope 1 and 2 and often tend to neglect scope 3. Not only is it difficult to measure emissions from scope 3 as the resources causing the emissions are usually not controlled by the company, but it can also be the case that scope 3 of one company might be scope 1 of another firm. Nevertheless, much of the GHG emissions of a product or service often fall into scope 3 and can even be higher than scope 1 and scope 2 emissions. If the carbon emissions involved in the supply chain are managed correctly, it leads to a more comprehensive approach that can help firms in the supply chain to realize both, economic and ecological efficiencies.[22]

2.3. The Commercial Aviation Industry

2.3.1. Introduction and Demarcation

The history of commercial aviation dates back to the 1920s when the first passenger flights were conducted. Another milestone was reached in the 1950s when jet engines were introduced and revolutionized the aviation industry. From being a luxury means of transport, flying has now become a means of mass transportation.

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[21] Boone et al. (2012)
[22] Boone et al. (2012)

However, commercial aviation is not the only sector within the aviation industry. Basically, four sectors can be distinguished: commercial aviation, aeronautics, military aviation and general aviation. Commercial aviation comprises all aircraft that are designed to transport passengers and freight. Regarding the size of the aircraft, there is a further segmentation within commercial aviation. All aircraft with less than 100 seats are categorized to be regional and business aviation. Aircraft with capacities between 100 and 250 fall into the category of large civil aircraft (LCA) and are also referred to as single aisle or narrow body aircraft, whereas such, holding 250 to 350 seats are referred to as twin aisle or wide body aircraft. Airplanes holding more than 350 passengers are further categorized as very large aircraft.[23] For instance, single aisle aircraft are typically represented by the Airbus A320 or the Boeing 737, wide body aircraft by an Airbus A330 or a Boeing 777 and finally, very large aircraft are embodied by the Boeing 747 or the world's largest passenger aircraft, the Airbus A380.

Concerning the airlines, it can generally be distinguished between legacy carriers also called network airlines such as Lufthansa and low-cost carriers (LCCs) such as Ryanair. The business model of these two types differs significantly. On the one hand, there is the hub-and-spoke model which is used by network carriers. This system is characterized by transporting the passengers from various airports to a bigger hub where they will transfer to connecting flights bringing the passengers to their final destination. On the other hand, low cost carriers mostly use the point to point model. Normally, LCCs do not need to conduct connecting flights. This is particularly attractive on short routes. However, the LCCs are also starting to expand their networks to long haul destinations. Even numerous legacy carriers are launching LCC subsidiaries as competition is increasing. Eurowings by Lufthansa can be mentioned as an example.

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[23] Guffarth (2015)

2.3.2. Facts and Figures

The commercial aviation industry is still a relatively fast-growing industry. From 2004 to 2016, the number of transported air passengers in Germany has increased by 48% rising from 135,848,000 passengers in 2004 to 201,000,000 passengers in 2016.[24] The amounts of revenue passenger kilometers (RPK) and revenue ton kilometers (RTK) for air freight are estimated to grow at a rate of 4.8% and 4.7% respectively per annum worldwide until 2035.[25] The International Air Transport Association (IATA) even expects passenger demand to double over the next 20 years from 3.8 billion air travelers worldwide in 2016 to 7.2 billion passengers in 2035. The biggest share of this growth can be allocated to the Asia-Pacific region, constituting about half of the increase in demand. It is forecasted that China will outstrip the United States as being the world's largest aviation market by 2024 and India will transport around 50% more passengers than the UK by 2035.[26] Figure 4 shows the increase in revenue passenger kilometers from 1950 to 2012:

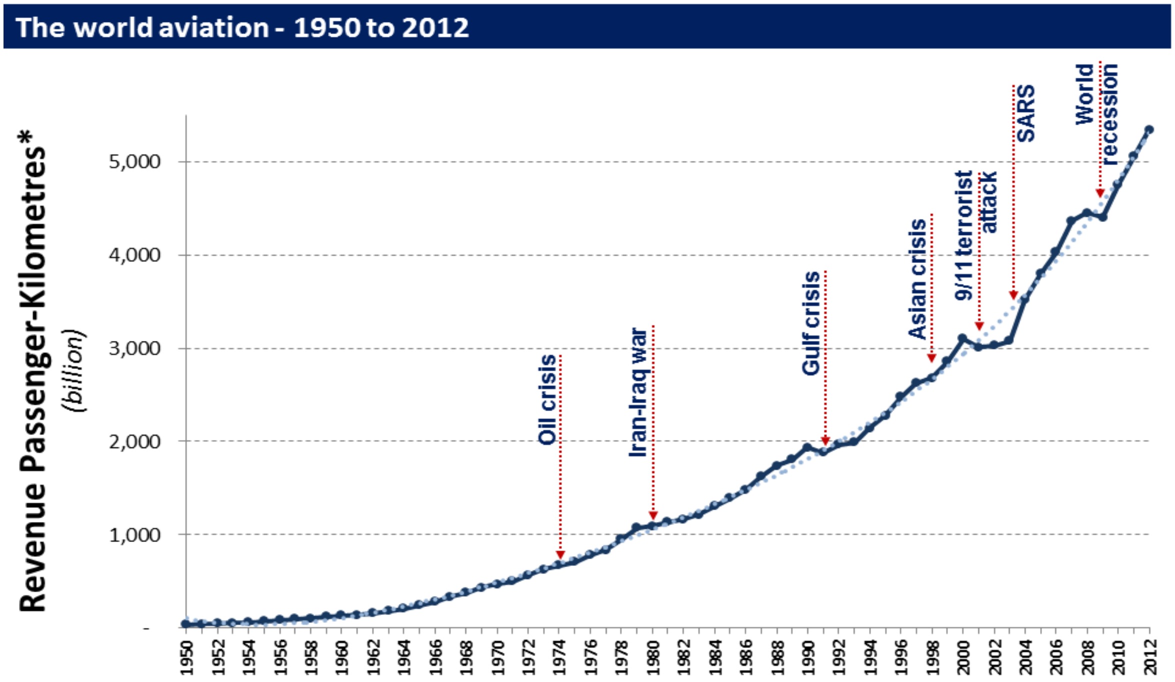

Figure 4 The world aviation - 1950 to 2012[27]

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[24] Statistisches Bundesamt (2017)

[25] Boeing (2017c)

[26] International Air Transport Association (IATA) (10/18/2016)

[27] International Civil Aviation Organization (ICAO) (2013)

It is clearly visible that the growth is exponential and according to the current forecasts will further continue. Despite several crises the demand for air travel always recovered. With a yearly revenue from passenger air traffic of 511 billion US Dollars in 2015 compared to 294 billion USD in 2004 this 74% increase also reflects the growth of the air transport industry.[28] Aircraft manufacturers are profiting from this trend as well. From 305 deliveries in 2003, Airbus more than doubled the number of deliveries to 688 in 2016.[29] A similar trend can be monitored with Boeing where deliveries raised from 281 aircraft to 748 in the same period of time.[30] A considerable driver of demand is also the availability of newer, more efficient models such as the Boeing 787 or the Airbus A350 that offer significantly decreased fuel consumption.

Each day, some 200.000 airplanes carry passengers and freight from one airport to another.[31] This is equal to an enormous 8,300 flights every hour. For instance, Lufthansa carried out around 100,000 flights in June 2017 transporting the equivalent of 11,980,000 passengers.[32]

Statistically, air transport is also still the safest means of transport. Between 2005 and 2009, only 0.3 persons were injured per 1 billion passenger kilometers. As a comparison, 2.7 persons were injured per 1 billion passenger kilometers in railway transport and 276 persons in car transport. A similar conclusion can be drawn from the number of fatalities. Nobody died during the same time per 1 billion pkm in air transport, whereas 0.04 persons died in railway transport and 2.9 people lost their life in car transport.[33] According to IATA, one person can fly without an accident for 14,000 years.

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[28] International Air Transport Association (IATA) (2017c)
[29] Airbus (2017c)
[30] Boeing (2017a)
[31] Deutsches Zentrum für Luft- und Raumfahrt (2017)
[32] Deutsche Lufthansa AG (2017c)
[33] Vorndran (2011)

2.4. Carbon Footprint in the Commercial Aviation Industry

2.4.1. Overview

Despite the fact that the efficiency of air transportation has increased significantly over the last decades, the nominal amount of emissions has still been increasing as the demand for air transportation has constantly been growing. Apart from that, it is also projected that the relative contribution of air transportation to global anthropogenic carbon emissions will increase. The key challenge that the air transportation industry and its stakeholders are facing is to reduce the carbon footprint and thus the emission of GHGs while at the same time not compromising the mobility for passengers and meeting the increasing future demand.[34] In the 37th session of the ICAO assembly in 2010 it was agreed to increase CO_2 efficiency by 1.5% each year from 2009 to 2020, to achieve carbon neutral growth from 2020 and to cut carbon emissions by 50% until 2050 based on the levels of 2005.[35] These goals are ambitious, especially when considering the fact that fuel consumption has decreased exponentially, which means that future progress in saving fuel is slowing down.[36] The industry is committed to meet these goals with various approaches with the purchasing of modern aircraft obviously being the most important measure to mitigate GHG emissions. However, this is of course just one measure that is taken; measures such as alternative fuels or operational improvements should be mentioned as well. This means that airlines cannot merely rely on the aircraft manufacturers to build more fuel efficient aircraft, they are in charge of reducing GHG emissions as well.

2.4.2. Facts and Figures

In 2014, the air transportation industry's share of the global CO_2 emissions was 2.55%.[37] At a first glance, this number might not sound that high, however, the correct framing and relation is also important. Considering the GHG emissions based

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[34] Sgouridis et al. (2011)
[35] International Civil Aviation Organization (ICAO) (2010)
[36] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2012)
[37] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b)

on grams per passenger and kilometer (g/pkm), air transportion outweighs cars, buses and railway by far. Figure 5 illustrates a comparison of the GHG emissions of different means of transport for the year 2014. With 211 g/pkm, an aircraft is emitting the highest amounts of GHGs; this is almost 49% more than cars, on average almost 4 times as much as railway and more than 6.5 times as much as coaches.[38] In addition, it also emits the highest levels of nitrogen oxides (NO_x) which are for instance responsible for acid rain.

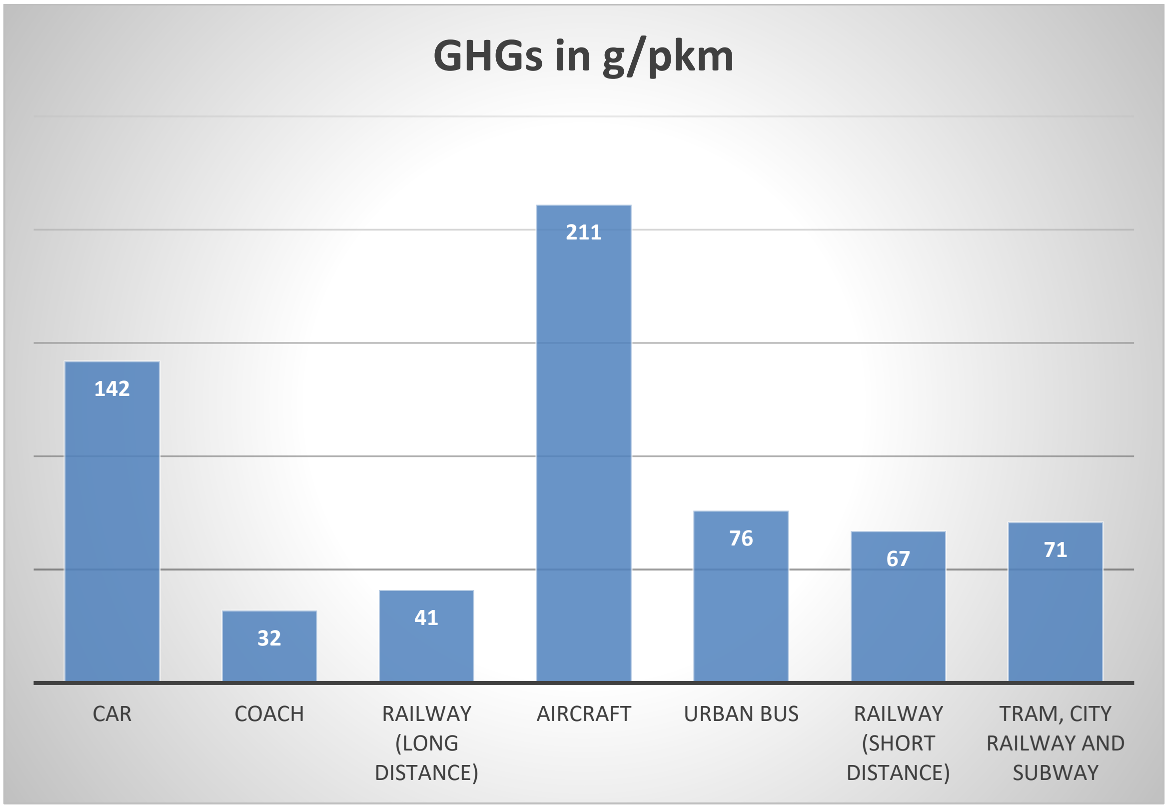

Figure 5 Comparison GHG emissions for different means of transport[39]

It is also projected, that the share of GHG emissions resulting from air transportation will further increase. From the current level of around 2.5% it might reach a share of up to 15% in 2050. In 2014, the total amount of CO_2 that was emitted in the European Union resulting from air transportation was 54.9 million tons.[40]

Looking at the fuel consumption per passenger and per 100 km, there have been significant improvements since the 1960s. Whereas around 1965 a Boeing 707, one

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[38] Umweltbundesamt (2016b)
[39] Own illustration based on Umweltbundesamt (2016b)
[40] European Commission (2017b)

of the first long haul jet engine airliners, consumed more than 8 liters of kerosene per passenger and per 100 km, the industry is now looking at less than 3 liters with modern airliners such as the Airbus A350.[41] An equivalent trend can be monitored with GHG emissions. Nevertheless, these figures presume aircrafts to be fully booked out. In fact, the German fleet of passenger aircraft reached a value of 3.64 l of kerosene per passenger and 100 km in 2016.[42] Yet, this per capita decrease in fuel consumption can not only be traced back to technological progress, but also to an increasing load factor. Between 1967 and 2011, the latter rose from 54% to 78% leading to an increase in energy efficiency.

Whereas the amount of RPK available within Germany increased by 59% between 1990 and 2015, the amount of CO_2 emissions decreased by 7%. This tendency can be observed with kerosene demand as well. Until 2015, the traffic capacity based on all departures from German airports increased by 231% since 1990, kerosene demand increased by 85%.[43]

The most common and omnipresent GHG is carbon dioxide. However, it is not the only one. The combustion of 1 kg of kerosene releases several GHGs that harm the environment and pollute the air. Table 1 shows the emission factors of kerosene in g/kg based on landing and takeoff cycles (LTO) for national and international flights. The table shows that the combustion of 1 kg kerosene produces more than 3 times as much CO_2, with CO_2 also constituting the highest share of GHG emissions, followed by H_2O (water vapor). Both of which, as well as CH_4 and N_2O, function as GHGs, whereas the global warming potential (GWP) of CH_4 and N_2O is a lot higher than the one of CO_2.

GHG	National	International
CO_2	3,150	3,150
CH_4	0.35	0.13
N_2O	0.12	0.09
NO_x	14.15	16.7
H_2O	1,237	1,237
SO_2	0.2	0.2
HC	1.06	1.1
Fine Dust	0.08	0.09
CO	10.16	15.7
NMVOC	0.7	0.9
NH_3	0.172	0.172

Table 1 Emission factors of kerosene in g/kg[44]

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[41] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2012)
[42] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b)
[43] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b)
[44] Knörr et al. (2012), Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b)

Considering that an Airbus A380 burns some 12.000 kg of kerosene per hour, this results in the emission of more than 36.000 kg of CO_2 per hour.

2.4.3. Benchmark with other Industries

To benchmark the aviation industry with other industries, it is reasonable to first stay within the transportation sector. More precisely, it is worth looking at the energy efficiency which is measured in megajoule per passenger kilometer (MJ/pkm) for passenger transportation and megajoule per ton kilometer (MJ/tkm) for freight. Kerosene has an energy density of 42.8 MJ/kg, gasoline 43.2 MJ/kg and Diesel 42,84 MJ/kg. Thus, there is no considerable difference in this regard.[45] Similarly, the amounts of CO_2 emitted by the combustion of 1 kg of kerosene are (almost) equal with 3,160 g/kg CO_2 for gasoline and 3,155 g/kg CO_2 for Diesel, making it unreasonable to compare means of transportation based on the type of fuel.[46] Based on MJ/pkm, air transportation is the second most energy inefficient means of transport, merely outstripped by cars. Air transport on average consumed 1.6 MJ/pkm in 2014, cars 2.0 MJ/pkm. The best energy efficiency in the same year was achieved by long-distance trains with 0.5 MJ/pkm and coaches with 0.4 MJ/pkm. Overall, there has been a slight increase regarding energy efficiency in the air transportation industry as the value of energy consumption was at 2.0 MJ/pkm in 1995, yet, this trend can be monitored for other transportation sectors as well.[47] Concerning freight, there is even a much bigger difference in energy efficiency. Looking at 2014 data, train, truck and inland water transportation with 0.3 MJ/tkm, 1.4 MJ/tkm and 0.4 MJ/tkm, respectively, are tremendously more energy efficient than air freight transportation with 10.6 MJ/tkm. Nevertheless, this is an almost 30% increase in energy efficiency compared to 1995.[48]

Considering the transportation industry in Germany as a whole, it can be said that in 2013, air transport accounted for 9.6% of the CO_2 emissions compared to 58.3%

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[45] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b), Bild der Wissenschaft (2007), own translation into MJ, for calculation see annex 1

[46] DEKRA Automobil GmbH (2017), own translation into g/kg, for calculation see annex 2

[47] Umweltbundesamt (2017)

[48] Umweltbundesamt (2017)

caused by individual motor car traffic, 30.1% caused by transportation of goods and 0.4% by railway and public transport. Whereas the CO_2 emissions from other transportation sectors such as road traffic are projected to decrease, those of air traffic are projected to increase. On a global scale, transportation accounts for 23% of CO_2 emissions.[49]

Looking at absolute terms, it can be said that Volkswagen, which also accounts for its GHG emissions using the GHG protocol, in 2016 emitted close to 338,000,000 tons of CO_2 including scope 1, scope 2 and scope 3 emissions, Lufthansa emitted around 38,000,000 tons of CO_2. Whereas for Lufthansa, approximately 76% of its emissions fall into scope 1, direct emissions, for Volkswagen only around 1.3% fall into the same category. Looking at scope 3, this changes with Lufthansa having close to 23% scope 3 emissions and Volkswagen having 97% of CO_2 emissions in this category.[50] The reason for this difference lies in the nature of the business both companies are in. Clearly, Lufthansa produces most of its emissions by the burning of fuel of their aircraft, whereas there are only few downstream emissions of their activities. The use of the product for instance, is in this case their business activity itself, falling into scope 1 emissions. For Lufthansa, scope 3 emissions are mostly caused by their kerosene supply chain. For Volkswagen, the case is of course different. The reason for VW having almost all its emissions in scope 3 is also due to the supply chain and purchased goods and services they use, although mostly it obviously results from the use of their products, thus, downstream activities.

Lastly, another interesting comparison of absolute numbers can be drawn with the coal industry. The CO_2 emissions caused by Germany's most climate-damaging coal-fired power plant in 2013 are almost equal to the amount of CO_2 emitted by Lufthansa in 2016 with 33.28 million tons versus 38.3 million tons.[51]

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[49] International Energy Agency (2017)

[50] Volkswagen AG (2017), Deutsche Lufthansa AG (2017e)

[51] Statista (2017b), Deutsche Lufthansa AG (2017e)

2.4.4. Inclusion of the Aviation Industry in the EU-ETS

After the EU emission trading system (EU-ETS) had been decided in 2003, it was introduced in 2005. In addition to the 28 EU member states, Norway, Iceland and also Liechtenstein have committed to participate in the EU-ETS. The scheme includes approximately 12,000 facilities that are operating in the energy industry and in energy intensive industries. The combined emissions of these facilities account for almost 50% of all CO_2 emissions of the EU and 8% of the worldwide emissions. The EU-ETS works according to the cap and trade principle, with the cap determining the maximum amount of emissions within a trading period. The emissions permits will then either be allocated at no charge or have to be purchased by auction, also the permits are freely tradable. In the course of time, the cap is lowered to decrease overall emissions. Companies may also obtain restricted amounts of international vouchers from projects that mitigate emissions. At the end of each year, companies must hold sufficient CO_2 permits to cover their emissions, otherwise, they will be fined. If a company has permits left over, for instance due to a reduction of its CO_2 emissions, it may either keep them for the future or sell them to other companies. Whereas in the beginning, EU member states could decide on the caps themselves and more CO_2 permits were allocated free of charge, since 2013 there is a uniform cap for the entire EU and less permits are allocated without charge. Based on 2005, the goal is to reduce the emissions that are encompassed by the EU-ETS by 21% until 2020.[52]

Since the beginning of 2012, air traffic has also been included in the EU-ETS. Virtually all flights that depart or arrive within the EEA should be covered by the ETS, including airlines that are not headquartered within the EEA. The scheme requires allowances for all flights performed by fixed wing aircraft with a maximum take-off weight of 5,700kg or above. Flights that are performed under visual flight rules (VFR) and rescue flights are exempt from the rule. The amount of allowances in the first year should equal 97% of historic emissions caused by aviation. Historic emissions are calculated based on the average emissions of 2004 – 2006 caused by the operators affected by the scheme. In the beginning, most of the allowances were

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[52] Umweltbundesamt (2016a)

allocated free of charge, 85% in 2012 and the remainder is auctioned by the EU member states, whereas revenues should be used to mitigate climate change.[53] The benchmark for the initial allocation of allowances is calculated based on historic emissions per revenue ton kilometer.[54]

The inclusion of the air transportation industry in the EU-ETS has been heavily criticized by European airlines as well as non-EU countries. On the one hand, EU airlines such as Lufthansa fear the adverse distortion of competition, on the other hand, non-EU countries have raised concerns about the conformity of the inclusion of non-EU airlines with international law.[55] Due to this pressure and to support ICAO's efforts to establish a global market based measure for climate protection the ETS was restricted to flights departing and arriving within the EEA. Furthermore, the EU stated that, once an agreement by the ICAO has been reached, the inclusion of aviation in the EU-ETS will be reviewed. Despite the fact that ICAO ratified an agreement on the reduction of emissions caused by air transportation in October 2016, which will come into effect in 2021, many EU representatives intend to retain emission trading for the air transport industry, as they consider the ICAO agreement not to be as effective as the EU-ETS. This view is also advanced by numerous experts. According to the ICAO agreement, emissions may further rise until 2020 and shall then be kept at the 2020 level, intending carbon neutral growth. However, the EU-ETS also intends to lower the absolute amount of emissions. If the EU Commission considers international efforts to be insufficient, it might as well extend the ETS again to its original extent including flights to and from non-EU countries again.

Studies have shown, that even if non-EU carriers were included in the EU-ETS, competition would still be distorted. European airlines that compete with non-European airlines on long haul routes given the same origin and destination pair, have their short haul feeder network in the EU making it subject to the EU-ETS whereas airlines from third countries have their short haul feeder network outside of the EU.[56]

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[53] Schaefer et al. (2010)

[54] Vespermann, Wald (2011)

[55] Scheelhaase et al. (2010)

[56] Scheelhaase et al. (2010)

Regarding ecological effects it can be said that the aviation sector might induce the reduction of emissions in other sectors, as the industry is buying considerable amounts of allowances from other sectors. It is questionable whether this makes sense as it merely leads to a displacement of emissions. Besides, the effects of the ETS will only be visible in the long run and will most likely not lead to substantial decrease of emissions in the air transport industry.[57]

> *This chapter has shown that so far, there is no uniform definition of the carbon footprint and its measurement still varies. Apart from this, it has been illustrated that the commercial aviation is steadily and relatively strongly growing. As a result, the emissions of the industry are expected to further increase as well. With the EU-ETS, a first measure to mitigate the emissions has been presented.*

3. Lufthansa

> *This chapter will introduce measures undertaken by the aviation industry to mitigate the carbon footprint using the example of Lufthansa. In the first part, some information about the Lufthansa Group will be given, including its carbon footprint and a benchmark with competitors. This will be followed by an introduction of the measures which will then be evaluated.*

3.1. Company Presentation

In terms of the number of transported passengers, Lufthansa is currently the second biggest airline in Europe behind Ryanair. In 2016, the airline transported 110 million passengers, followed by the British IAG Group (British Airways, Iberia, Vueling and Aer Lingus) with 101 million passengers and Air France KLM with 90.3 million

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[57] Vespermann, Wald (2011)

passengers.[58] The airline had initially been founded in 1926 and was re-founded after World War 2 in 1953 as “Aktiengesellschaft für Luftverkehrsbedarf” (Luftag). In 1954 it bought the name, trademark and the colors of the previous Lufthansa and has ever since called itself “Deutsche Lufthansa AG”. On April 1st, 1955, scheduled air services started. The privatization of Lufthansa took place in 1997.[59] The group includes 550 subsidiaries and investments companies nowadays with Swiss, Austrian Airlines, Eurowings and Brussels Airlines being 100% subsidiaries of Lufthansa. Swiss, Austrian Airlines and Lufthansa are considered the premium brands within the group that act as network carriers, Eurowings serves as a point to point low-cost platform, which will be supported by the incorporation of Brussels Airlines. Air freight transportation is operated by Lufthansa Cargo, Lufthansa Technik works as a maintenance, repair, and overhaul (MRO) service provider and LSG Group mainly focuses on catering and other inflight services. This allows for a differentiation of five strategic business areas: passenger transportation, logistics, MRO, catering and others. Under others, areas such as IT services and flight training are summarized.[60] Lufthansa is also a member of Star Alliance, a network of numerous airlines worldwide such as United Airlines, Thai Airways International or Air Canada. In addition, Lufthansa is conducting joint ventures with Air Canada and United Airlines, All Nippon Airways, Singapore Airlines and Air China.[61] The corporate strategy of Lufthansa states that the group wants to be first choice in the area of aviation for customers, employees, shareholders and partners. It breaks down the group into three pillars: premium hub airlines, Eurowings Group and aviation services.[62]

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[58] Statista (2017a)
[59] Deutsche Lufthansa AG (2017d)
[60] Deutsche Lufthansa AG (2017m)
[61] Deutsche Lufthansa AG (2017j)
[62] Deutsche Lufthansa AG (2017n)

3.2. Key Figures of Lufthansa

The numbers shown in table 2 are based in 2016 except for the number of destinations which is based on the 2017 summer schedule.

Revenue and result	
Revenues	Million € 31,660
EBIT	Million € 2,275
Net income	Million € 1,776
Balance sheet and cash flows	
Total assets	Million € 34,697
Equity ratio	% 20.6
Net indebtedness	Million € 2,701
Cash flow from operating activities	Million € 3,246
Capital expenditure (gross)	Million € 2,236
Profitability and share	
EBIT margin	% 7.2
Share price at year-end	€ 12.27
Earnings per share	€ 3.81
Traffic figures	
Passengers	Thousands 109,670
Available seat kilometers (ASK)	Millions 286,555
Revenue seat kilometers (RSK)	Millions 226,633
Passenger load factor	% 79.1%
Available cargo ton kilometers (ATK)	Millions 15,117
Revenue cargo ton kilometers (RTK)	Millions 10,071
Cargo load factor	% 66.6
Number of flights	1,021,919
Number of destinations	308
In number of countries	103
Fleet and employees	
Number of aircraft	617
Open orders	205
Average number of employees	124,306

Table 2 Lufthansa key figures[63]

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[63] Deutsche Lufthansa AG (2017k), Deutsche Lufthansa AG (2017f), Deutsche Lufthansa AG (2/23/2017)

3.3. Carbon Footprint of Lufthansa

3.3.1. Key Figures

In accordance with the increase of global emissions caused by the air transportation industry, Lufthansa's carbon dioxide emissions have increased as well. In 2016, the total CO_2 emissions caused by Lufthansa Group, this means scope 1, scope 2 and scope 3 emissions according to the GHG protocol, amounted to 38,300,213 tons. Due to the nature of the business Lufthansa is performing, most of the emissions are obviously categorized as scope 1. Figure 6 shows the distribution of emissions between the scopes for Lufthansa:

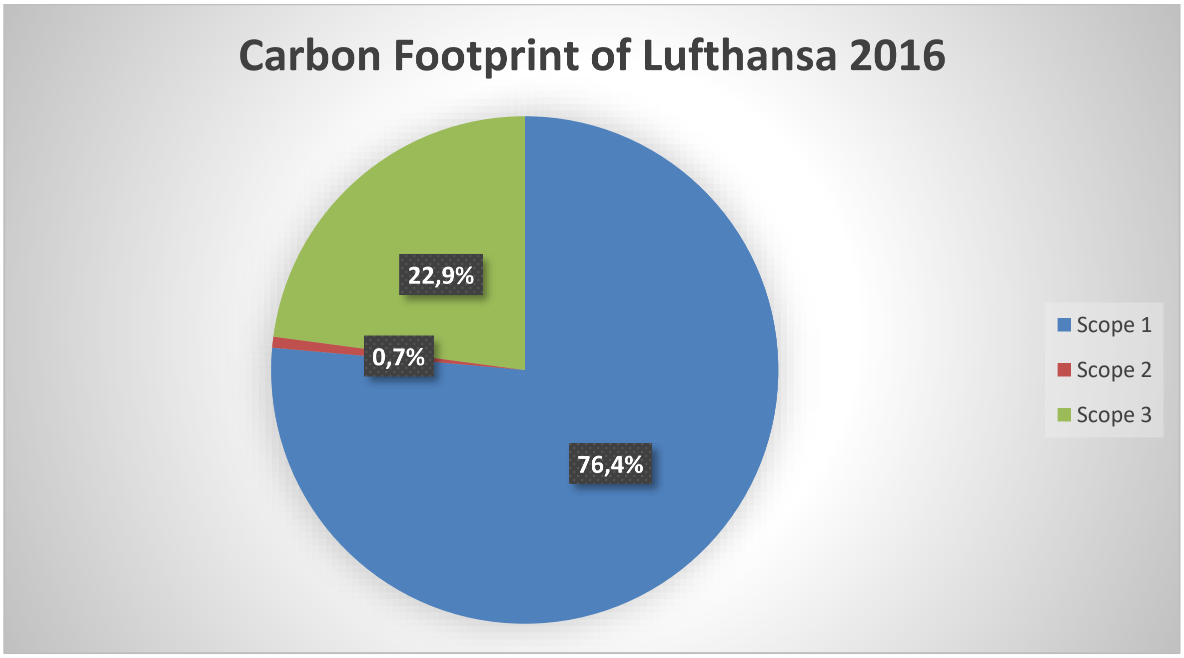

Figure 6 Carbon footprint of Lufthansa 2016[64]

In absolute numbers, scope 1 emissions amounted to 29,250,821 tons of CO_2, scope 2 emissions accounted for 275,161 tons of CO_2 and scope 3 emissions for 8,774,231 tons of CO_2. Looking in more detail at scope 1 it can be said that approximately 97.5% of the emissions were caused by flight operations (the combustion of 9,055,550 tons of kerosene) and the remaining 2.5% were caused for instance by ground-based traffic such as maintenance vehicles or own power plants, resulting in flights itself causing some 74.5% of the carbon footprint. Scope 3 emissions can

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[64] Own illustration based on Deutsche Lufthansa AG (2017e)

mainly be traced back to Lufthansa's kerosene supply chain as well as emissions from manufacturing the aircraft in the fleet. Scope 2 emissions are mainly caused by purchased energy for ground operations such as catering and maintenance.[65] As a result, most potential to reduce the carbon footprint lies in scope 1. During the last decade, the amount of CO_2 caused by the combustion of kerosene rose from 21,890,614 tons in 2006 to 28,524,981 tons in 2016, which is an increase of approximately 30%. During the same time, the amount of ASK increased by the equivalent of 46%. This means that the efficiency of Lufthansa has increased, which is represented by the specific fuel burn and emissions as well. In 2006, the former for Lufthansa Passage, measured in liters per 100 passenger kilometers (l/100 pkm), was equal to 4.38 l/100 pkm, while in 2016, the value was at 3.85 l/100 pkm. Accordingly, the specific amount of CO_2 emitted, measured in kilograms per 100 passenger kilometers (kg/100 pkm) improved from 11.05 kg/100 pkm in 2006 to 9.71 kg/100 pkm in 2016. Concerning air freight transportation, the specific fuel consumption, measured in grams per ton kilometer (g/tkm), amounted to 182 g/tkm in 2006 to 224 g/tkm (28 l/100 tkm) in 2016 and thus increased. However, the freight load factor during this decade also decreased. Within Lufthansa Group, Swiss scored the lowest specific CO_2 emissions (8.67 kg/100 pkm), followed by Lufthansa (see above), Austrian Airlines (10.17 kg/100 pkm) and Eurowings (11.24 kg/100 pkm).[66] Due to more LTO cycles, more CO_2 is produced in the short haul sector. In general, it should be considered that improvements of specific values such as fuel consumption in l/100 pkm are obviously influenced by the load factor. Despite an increase of such a value, overall emissions do not change.

With 1,021,919 flights executed in 2016, each flight on average caused the emission of close to 28 tons of CO_2, an average German citizen causes the production of approximately 11 tons of CO_2 per year. This amount was slightly higher in 2006 with each flight causing around 31.5 tons of CO_2.

Apart from CO_2, Lufthansa caused the emission of 139,008 tons of NOx and 19,320 tons of carbon monoxide (CO) in 2016.

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[65] Deutsche Lufthansa AG (2017e)

[66] Deutsche Lufthansa AG (2017e), Deutsche Lufthansa AG (2007)

3.3.2. Benchmark with Competitors

A reasonable tool to benchmark airlines according to their climate friendliness is given by the atmosfair Airline Index. It covers 92% of international air traffic including some 32,000,000 flights. Airlines are categorized according to efficiency classes reaching from A to G with A being the highest efficiency class. To classify airlines, they are given efficiency points (EP) between 0 and 100, with 100 being the best possible score. According to the index, Lufthansa is classified as a class D efficiency airline. Among 125 other airlines, Lufthansa ranked 77th with 62.6 EP, causing Lufthansa to perform weaker than average, with the latter being 65.15 EP. The highest score and hence rank one was achieved by China West Air, a Chinese regional carrier with 83.1 EP categorized as efficiency class B airline. No airline has managed to achieve efficiency class A. Lufthansa's biggest German competitor, Air Berlin, reached rank 16 in the index, scoring 75 EP and achieving efficiency class C. Two more high scoring German airlines are also worth mentioning: TUIfly and Condor, which both are charter carriers. TUIfly ranked second, attaining 82.7 EP and being allocated to efficiency class B. Condor ranked seventh in the atmosfair Airline Index, accomplishing a score of 78.7 EP, also falling into efficiency class B. Other relevant competitors to benchmark Lufthansa with are for instance Emirates, being a strongly and quickly expanding premium network carrier from the middle east, Air France, constituting a European premium network carrier, and Delta Air Lines, being the second biggest airline in the world according to the number of transported passengers. Emirates performed considerably better in the index than Lufthansa. The airline ranked 30th with a score of 70.1 EP, falling into efficiency class C. Air France as a European competitor also outscored Lufthansa, achieving rank 49 in energy class C with 66.3 EP. With 65.5 EP on rank 54 in efficiency class C, Delta Airlines also lies ahead of Lufthansa. The reasoning for the ranking of Lufthansa can be traced back to several things.[67] First, except for Emirates, both, Air France and Delta Airlines have a higher load factor than Lufthansa. In 2016, Air France achieved a load factor of 85.4% and Delta Airlines 84.6%, whereas Lufthansa reached 79.1%.[68] The load factor influences the efficiency considerably: if planes are more

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[67] Atmosfair (2016)

[68] Air France-KLM (2017b), Delta Air Lines, Inc. (1/4/2017), Deutsche Lufthansa AG (2017i)

booked out, they obviously fly more efficiently. However, this can be taken further. Usually, the same types of aircraft hold different numbers of seats from airline to airline. Whereas an Airbus A330-300 of Lufthansa holds 216 – 255 passengers, the same type of aircraft holds 293 passengers at Delta Airlines. In the case of Air France, an Airbus A340-300 (identical fuselage with A330-300) holds 275 passengers. As a result, a fully booked out Airbus A330-300 of Delta Airlines would fly more efficiently than a fully booked out Airbus A330-300 of Lufthansa. Another influencing factor is the modernity of the fleet. Emirates for instance has one of the youngest aircraft fleets in the world which positively influences its efficiency. In addition, Emirates also mainly operates long haul routes which generally produces less CO_2 emissions due to a lower number of LTO cycles.

It is also reasonable to directly compare emissions between the airlines. The specific emissions of Air France are slightly lower than those of Lufthansa with 8.5 kg/100 pkm CO_2 versus 9.71 kg/100 pkm. This is reflected by the specific fuel consumption accordingly, with Lufthansa burning 3,85 l/100 pkm kerosene and Air France 3,4 l/100 pkm. The specific CO_2 emissions of Delta Air Lines are slightly higher with 11,26 kg/100 pkm and a kerosene consumption of 4,47 l/100 pkm accordingly. However, with approximately 60% of the seat miles offered domestically, the share of short and medium haul routes and thus the number of LTO cycles is considerably higher in the case of Delta Air Lines compared to 40% short and medium haul routes offered by Lufthansa and some 20% by Air France. [69] As Delta Airlines also reports according to the GHG protocol including all three scopes, its carbon footprint can be easily compared to the one of Lufthansa. In 2015, the total CO_2 emissions of Delta amounted to 37,685,493 tons, in the same year, Lufthansa emitted 36,950,436 tons of CO_2. The distribution of the emissions between the scopes is also relatively similar to the one of Lufthansa. For Delta in 2015, roughly 88% of the emissions were scope 1, less than 1% scope 2 and approximately 11% scope 3 (Lufthansa 2015: scope 1 77.4%, scope 2 0.9%, scope 3 21.7%), whereas scope 1 could almost entirely be traced back to the emissions of the aircraft engines as depicted by Figures 7 and

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[69] Air France-KLM (2017a), Delta Air Lines, Inc. (1/4/2017), Deutsche Lufthansa AG (2017e), own translation from gallons per available seat mile to l/100 pkm and kg/100 pkm, see annex 3 for further details

8.[70] It is shown that the carbon footprints of the two companies are relatively similar, even regarding the total emissions.

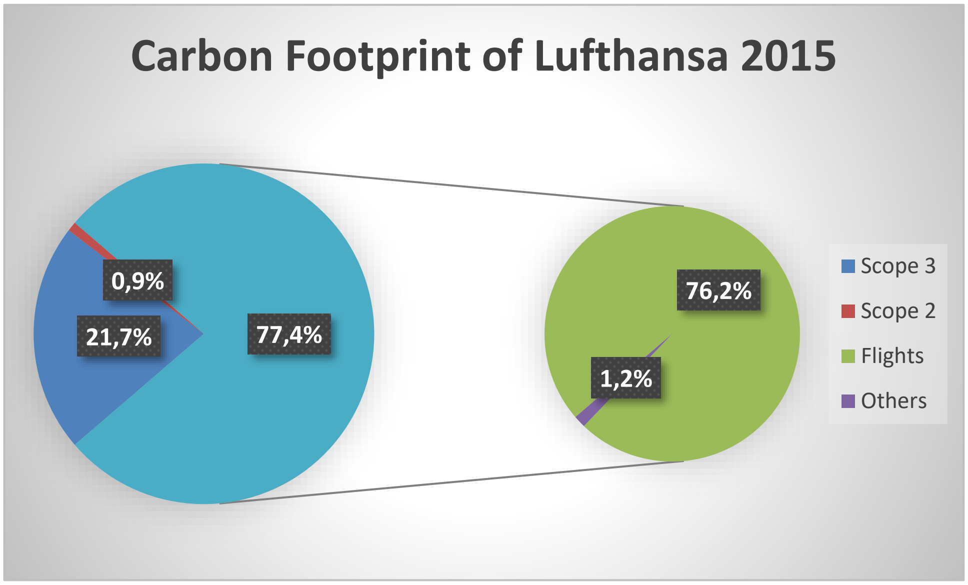

Figure 7 Carbon footprint of Lufthansa 2015[71]

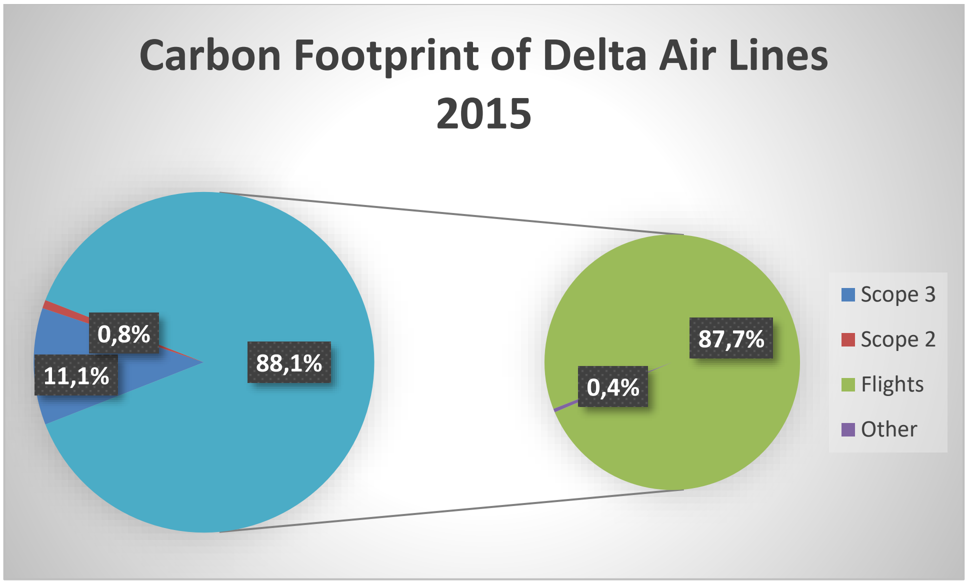

Figure 8 Carbon footprint of Delta Air Lines 2015[72]

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[70] Delta Air Lines, Inc. (2016), Deutsche Lufthansa AG (2016b)
[71] Own illustration based on Deutsche Lufthansa AG (2016b)
[72] Own Illustration based on Delta Air Lines, Inc. (2016)

3.4. Lufthansa’s measures to reduce the Carbon Footprint

3.4.1. Subdivision of Measures

Lufthansa subdivides its efforts to mitigate the carbon footprint into four pillars: technological progress, infrastructure improvement, operative measures and economic measures. This is a common approach in the industry which was defined by IATA. The intention of pillar one, technological progress, is to optimize aircraft, engines and systems to the most possible extent to make them as ecofriendly as possible. In the short term, this may be implemented my modifying existing fleets, yet, in the medium term it is essential to replace the current fleets by more modern aircraft. For instance, the Airbus A320 neo which promises 15% less fuel consumption than current models this size or the Airbus A350 promising 25% less fuel consumption than current equivalent models can be mentioned. Airlines can directly influence this pillar with their buying behavior.

Pillar two, the improvement of infrastructure, includes the enhancement of infrastructure of airports and especially the improvement of air space management and usage. It is estimated that improvements in these areas could lead to a reduction of CO_2 emissions by 12%. The Single European Sky (SES) is an important example in this regard. It would allow airlines to optimize their routings from origin to destination without having to consider small sections of state borders. However, this measure can hardly be influenced by the airlines but mainly by policy makers.

Operative measures, pillar three, mainly involves eco efficient operating procedures such as efficient ground operations or the use of efficiently sized aircraft. Estimations predict that up to 6% of fuel might be saved by implementing pillar three.

Pillar four should serve as a supplement for pillars one to three. It should provide a global market based measure that should make airlines pay for their emissions similar to the European ETS. Yet, IATA opposes itself to regional solutions such as the EU-ETS as the air transportation industry is highly globalized and regional measures would lead to market distortions. ICAO has ratified CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) in 2016, an agreement on an international scale to offset and reduce emissions from aviation to guarantee carbon neutral growth from 2020. However, this agreement will only be binding from

2027, during the pilot phase and the first phase from 2020, participation of states will be voluntary. [73]

3.4.2. Technological Progress

3.4.2.1. Fleet Renewal

The most efficient way of reducing the emissions from air transportation is to invest in new and modern aircraft powered by efficient engines. Lufthansa is currently undergoing the largest fleet renewal program in its history. In 2016, the airline has received 47 new aircraft, eight of which were long haul airliners. At year end of 2016, still 205 aircraft, 143 short and medium haul and 62 long haul aircraft, were on order amounting to a total list price of more than 35 billion €. Concretely, this includes 34 Boeing 777-9X, 4 Boeing 777-300ER, 24 Airbus A350-900, 7 aircraft from the Airbus A320 ceo (current engine option) family, 111 aircraft from the Airbus A320 neo (new engine option) family and 25 Bombardier C Series. These aircraft are planned to be integrated into the fleet and distributed among the group airlines until 2025. In 2017, the airline expects the receiving of 38 new aircraft. This measure will considerably decrease the average age of the fleet which was 11.3 years at year end 2016.[74] As the biggest share of cost for the airline is kerosene, the reduction of fuel consumption and thus emissions also leads to lower costs for Lufthansa.

Airbus A320neo

The Airbus A320neo family was introduced by Airbus in 2010. It is a further development of the successful Airbus A320 family that was launched in 1987. The jet is a narrow body aircraft that is mostly used for short and medium haul routes. Lufthansa was the first airline to integrate the new model into its fleet in December 2016. Due to aerodynamic improvements of the wings and mostly due to newly developed engines, the aircraft will consume 15% less fuel than its predecessor.[75] The engines have a considerably higher bypass ratio than those of the Airbus A320ceo making it more efficient. Apart from technological improvements, the

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[73] Deutsche Lufthansa AG (2017e)
[74] Deutsche Lufthansa AG (2017h)
[75] Deutsche Lufthansa AG (2016c)

A320neo also features a redesigned cabin enabling more seats which also drives efficiency. Lufthansa will use the new aircraft to replace older aircraft from the A320 family and Boeing 737-300 -400 and -500 in its fleet. The replacement of older Boeing 737 aircraft will even lead to efficiency gains that will exceed 15%. Whereas a Boeing 737-300 consumes on average 3.33 liters of kerosene per 100 seat kilometers (l/100 skm), assuming a capacity of 137 seats, the new Airbus model Lufthansa has been introducing only consumes 2.18 l/100 skm.[76] As a result, an increase of efficiency comparing Boeing 737 and Airbus A320neo of some 35% can be achieved. This can be applied to the emissions accordingly. A fuel burn of 2.56 l/100 skm for the Airbus A320ceo transfers into the emission of CO_2 amounting to 6.47 kg/100 skm, for a Boeing 737-300 it transfers from 3.33 l/100 skm into 8.38 kg CO_2 /100 skm and for the Airbus A320neo this means the emission of 5.48 kg CO_2 /100 skm. In different dimensions, it can be said that statistically, assuming a daily flight from Frankfurt to Munich and back, Lufthansa will Save 386 tons of CO_2 per year for this route when using an A320neo versus an A320ceo. In total, Lufthansa intends to save some 3600 tons of CO_2 per year by the use of the new airliner model.[77]

Airbus A350

The Airbus A350 is another recently introduced airliner by Airbus that first flew in 2013 and entered commercial service in 2014 with Qatar Airways. Currently, there are two options available that differ in fuselage length, the A350-900, as ordered by Lufthansa, and the bigger A350-1000. In the configuration of Lufthansa, the airliner holds 293 seats and is thus a wide body aircraft. The normal range of the aircraft amounts to some 15.000 km.[78] Lufthansa has ordered 25 and signed another 30 options for this type, three of which have already been delivered and operate from the airline's hub in Munich where the first 15 aircraft of this type will be stationed. The airliner is an entirely new development and currently said to be the most modern and advanced commercial passenger aircraft. It is built from 53% composite carbon

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[76] Park, O'Kelly (2014), Budd, Suau-Sanchez (2016), own translation from kg/S-NM into l/100 skm and kg/100 skm, for further details see annex 4

[77] Deutsche Lufthansa AG (2016d)

[78] Airbus (2017d)

fiber materials, making it lightweight and efficient. A significant amount of efficiency is also contributed by the Rolls Royce Trent XWB engines that power the aircraft.[79] Lufthansa will use the A350 to replace older types of the A340 and Boeing 747. Both of the latter are four-engine aircraft, whereas the A350 is a twin-engine aircraft, making it considerably more efficient. On average, the Airbus A350 promises 25% less fuel burn than current models such as the A340, B777 or B747.[80] For its configuration and capacity utilization, Lufthansa expects a fuel consumption of 2.9 l/100 pkm resulting in CO_2 emission of 7.31 kg/100 pkm.[81] However, reliable fuel consumption data are yet to be collected, as the aircraft has not been in service for so long.

Boeing 777-9X

Boeing launched the 777X program in November 2013 during the Dubai Air Show. As in the case of the A320neo, Lufthansa will also be the launch customer for this aircraft. Boeing estimates that the maiden flight will take place around February 2019 and deliveries to commence in 2020. The wide body, long haul aircraft comes in two variants, the 777-8X and the 777-9X and will be a further development of the current 777. Lufthansa ordered 34 of the latter which will become the longest and also the biggest twin-engine passenger aircraft in the world. Regarding capacity, the -8X will hold between 350 and 375 seats and the -9X will hold between 400 and 425 seats.[82] Apart from competing with the A350 (-8X), the model even competes with Boeing's own B747-8i jetliner which has not seen any orders for a considerable amount of time. The 777X will also be powered by the biggest commercial jet engines ever built. Boeing promises that the engines will burn 10% less fuel than those of its predecessor 777-300ER and even 5% less than those of the A350-1000.[83] Due to the size of the aircraft, it will have foldable wings which will ease ground handling and will insure that airlines can still use the same ground infrastructure as with the previous model. Lufthansa will use the model to replace Boeing 747-400s and older A340s, both of which are four-engine aircraft of similar sizes. The aircraft will also

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[79] Airbus (2017a)
[80] Airbus (2017a)
[81] Deutsche Lufthansa AG (2016a)
[82] Boeing (2017d)
[83] Steinke

contribute to Lufthansa's efforts to reduce fuel consumption and thus carbon dioxide emissions. However, the actual savings in fuel consumption and CO_2 can only be determined once the aircraft has entered service. The list price of a 777-9X amounts to approximately 400,000,000 USD.

Boeing 777-300ER

The Boeing 777 family was already introduced in 1994. The -300ER (Extended Range) model which was a slightly overhauled model of the original 777, was put into commercial service in 2004. Amongst others, the wings were reworked with an increase in wing span, resulting in better operational efficiency. The almost 74 m long aircraft features a range of 13,650 km and a typical three-class capacity of 365 seats.[84] The Lufthansa Group began introducing the airliner, of which it has received eight so far, to its fleet within Swiss, which will also receive the remaining aircraft still on order. Swiss' 777 features a capacity of 340 seats in three classes. Swiss will use the triple seven to replace old Airbus A340-300 and thereby achieve less emissions and fuel consumption while increasing capacity. Swiss estimates specific fuel consumption and CO_2 emissions to decrease by up to 23% compared to the A340-300.[85] However, improvements of some 10% are more likely. Based on current numbers, an Airbus A340-300 has a specific fuel consumption of 3.77 l/100 skm. Transferred to the cabin layout of Swiss, this amounts to 4.35 l/100 skm. For the Boeing 777-300ER these values are 4.04 l/100 skm and 3.96 l/100 skm, given the Swiss configuration accordingly. This amounts to CO_2 emissions of 10.95 kg/100 skm for Swiss' A340 and 9.97 kg/100 skm for the triple seven.[86] Based on data of Lufthansa and Swiss, the reasoning for an efficiency improvement of up to 23% as stated by Swiss could not be clarified. The improvement in efficiency is largely based on the fact that the A340 operates with four engines at a lower capacity as compared to the 777. Hence, considerable reductions in emissions and fuel consumption are possible despite the 777-300ER not being the most modern available airliner. Swiss has opted for the -300ER for several reasons. First, despite further efficiency gains,

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[84] Boeing (2017b)

[85] Swiss (2017)

[86] Park, O'Kelly (2014), own translation from kg/S-NM into l/100 skm and kg/100 skm, see annex 5 for further details

the 777X would not have been available early enough for the Lufthansa Group member with an inauguration in 2020. Second, the new model is also considerably bigger than the current one, which would have resulted in overcapacities for Swiss and hence would have led to a decrease in efficiency in turn. Finally, due to Boeing launching a successor of the current model, the prices of the current model became more favorable.

Bombardier CSeries

Another aircraft type that has been integrated into the Swiss fleet and for which the Lufthansa Group is launch customer, is the Canadian Bombardier CSeries. The single aisle aircraft that has entered service in 2016 comes in two different versions, the CS100 and CS300. It was especially designed for smaller markets. Swiss has ordered ten CS100 and 20 CS300, eight of the former and two of the latter have already been received. The aircraft will replace the inefficient four-engine Avro Jet that operates in Swiss' European network. It is expected that the fuel efficiency with the Bombardier will increase by 20% compared to the Avro, hence, CO_2 emissions are expected to decrease accordingly.[87] Bombardier has developed the airliner completely newly. Like the A320neo, it is powered by Pratt & Whitney geared turbofan engines with a high bypass ratio, that were mainly modified in size to fit the CSeries.

Airbus A320ceo

With its maiden flight in 1987, the current model of the A320 family was introduced 30 years ago. At the time, it was the first airliner that made use of the Fly-by-wire technology, meaning there was no more mechanic connection between the flight controls in the cockpit and the actuators on the wings, elevator and rudder. Along with Boeing's 737, it has become one of the most successful short and medium haul airliners with the family comprising of A318, A319, A320 and A321. Around half of Lufthansa Group's fleet currently consists of members of the Airbus A320 family.[88] Airbus has overhauled the current model with slight improvements from time to time, making current models more efficient than former models. For instance, the current

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[87] Deutsche Lufthansa AG (2017h)
[88] Deutsche Lufthansa AG (2017h)

model of the A320ceo features the same winglets as the A320neo resulting in an improvement in efficiency and hence the reduction of emissions. Some improvements such as the winglets can also be retrofitted to the current models, which Lufthansa has done as well. The remaining seven orders of A320ceos as of December 31st, 2016 had been ordered before the A320neo and will replace older A320 aircraft and thus only lead to a slight reduction of carbon emissions.

Figure 9 summarizes the specific CO_2 emissions of selected aircraft in the fleet of the Lufthansa Group. The fuel consumption is represented by the size of the globes. Hence, bigger globes are located further towards the top of diagram due to higher fuel consumption leading to higher emissions.

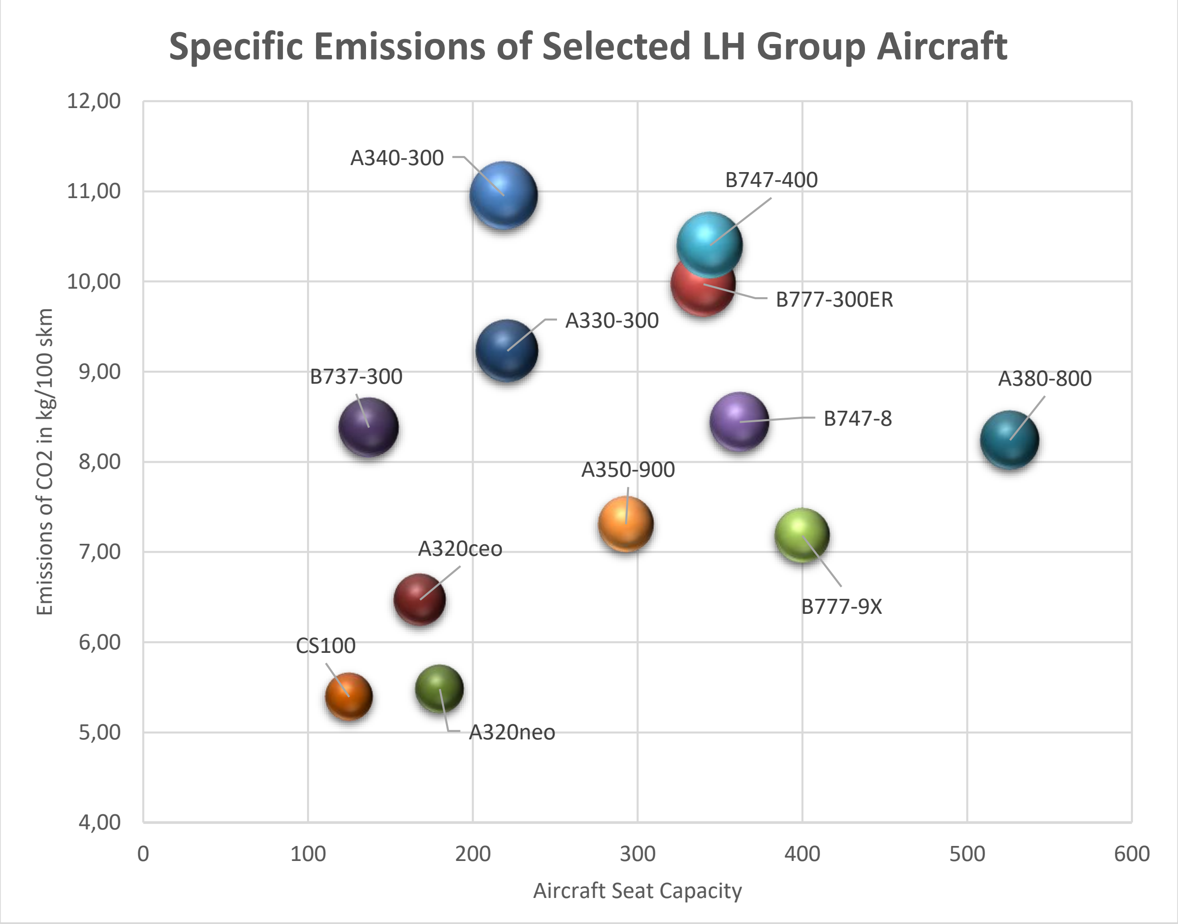

Figure 9 Specific emissions of selected Lufthansa Group aircraft[89]

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[89] Own illustration based on Park, O'Kelly (2014), Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b), Leeham Co EU (2014), Deutsche Lufthansa AG (2017e), Deutsche Lufthansa AG (2017g), see annex 6 for further details.

3.4.2.2 Evaluation of the Measure Fleet Renewal

The figure shows that the new aircraft models that Lufthansa ordered and already started to integrate in its fleet by replacing older models will lead to considerable improvements in fuel efficiency and thus lower CO_2 emissions. The five new types (excluding A320ceo) promise fuel efficiency increases of 20% on average. However, it should be considered that numbers in this regard are typically relative. This means that instead of looking at the absolute amounts of emissions caused by an aircraft, it is more reasonable to look at specific numbers such as per seat emissions. The reason for this is that airlines usually have different cabin layouts for the same type of aircraft leading to different capacities. Oftentimes, these layouts even vary within an airline. The business model of an airline has considerable influence on the capacity of an airliner. Low cost carriers typically only have one class on board of their aircraft (economy) which allows them to significantly increase the number of seats on an aircraft. Whereas Lufthansa typically fits 168 passengers in an A320, easyJet's A320s can hold 186 people. Lufthansa's wholly owned low-cost subsidiary Eurowings can board 174 passengers on the A320.[90] As Lufthansa positions itself as a premium network carrier, it of course has to offer superior passenger comfort and also premium booking classes leading to lower capacities which means that based on specific number such as emissions per passenger and 100 kilometers, Lufthansa and also other premium airlines will always be worse off than low cost carriers. In the Transatlantic Airline Fuel Efficiency Ranking, 2014, Lufthansa only ranked third last in terms of efficiency, burning 44% more fuel than the most efficient airline in the ranking, Norwegian Air Shuttle. The study includes the top 20 airlines between the US and Canada, representing 91% of total ASK on transatlantic routes. As measured by the study, per one liter of fuel, Lufthansa only achieved a distance of 28 passenger kilometers, whereas Norwegian Air Shuttle, a rapidly expanding low cost carrier, achieved 40 passenger kilometers per liter of fuel (pax-km/l fuel). The German competitor Air Berlin ranked second with 35 pax-km/l fuel. The industry average shown in the study is 32 pax-km/l fuel. Transferred into l/100 pkm, this amounts to 3.57 l/100 pkm for Lufthansa, 2.86 l/100 pkm for Air Berlin and 2.5 l/100

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[90] Eiselin (2015), Deutsche Lufthansa AG (2017a), Deutsche Lufthansa AG (2017b)

km for Norwegian Air Shuttle. The least fuel efficient of the 20 airlines in the ranking is British Airways with 27 pax-km/l fuel, respectively 3.7 l/100 pkm. Other legacy carriers such as Air France and KLM achieved 33 pax-km/l fuel, respectively 3.03 l/100 pkm. The study states that the reason for Lufthansa scoring comparatively bad can be traced back to the utilization of inefficient aircraft such as the Boeing 747-400 or the Airbus A340 as well as the A380, which, on the route from Frankfurt to New York JFK only achieved a load factor of 78%. Besides, the airline was also found to have the third lowest seat density by using extensive premium seating. Seat density was also the reason for Air Berlin ranking second, apart from using relatively efficient twin engine Airbus A330 aircraft. The study also identifies key drivers of airline fuel efficiency.[91] This is shown in figure 10:

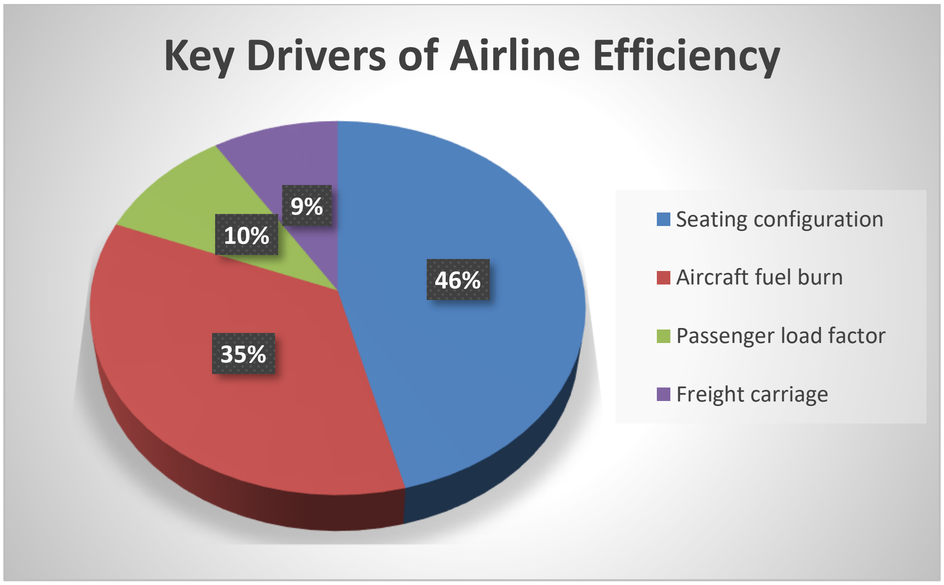

Figure 10 Key Drivers of Airline Fuel Efficiency[92]

As illustrated, the seating configuration has the highest influence on an airlines' fuel efficiency. It is closely followed by the fuel consumption of the aircraft and with considerably less influence by the passenger load factor and freight carriage. Hence, the acquisition of new and modern aircraft is a considerable driver in the effort of increasing fuel efficiency. The two main drivers as illustrated in the figure are, amongst others, also typically a formula of success for low cost airlines. The fleets

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[91] Kwan, Rutherford (2015)
[92] Own illustration based on Kwan, Rutherford (2015)

of the latter are mostly very young with fuel efficient aircraft and high seat densities. Apart from what has been mentioned, air transportation is a fast-growing industry. Despite purchasing modern airliners, the absolute emissions and hence the carbon footprint might still increase if an airline is growing. However, it should not be forgotten that despite overall growth of an airline and different specific emissions, the carbon footprint of a single flight can still be reduced when operating a modern aircraft instead of an older one. Based on 1991, the overall offered transportation capacity of Lufthansa has increased by 355%, whereas the overall demand of kerosene for the airline has only risen by 189%. Hence, an increase in efficiency of 166% could be achieved.[93]

This shows that the absolute emissions, and hence the carbon footprint of the Lufthansa Group, can only decrease if the gains in efficiency outweigh the growth of the airline.

3.4.2.3. Alternative Fuels

Another crucial measure to reduce the GHG emissions in the aviation industry is the exploration of alternative fuels. This refers especially to drop-in bio fuels. As the net carbon footprint of bio kerosene is considerably lower than the one of petrol based kerosene, its usage would allow to sustainably cut CO_2 emissions in the airline industry. Hence, it would also allow to better cope with the increasing worldwide demand of mobility.

Basically, there are four drivers and influences that can be identified regarding the development of alternative jet fuels, namely economic sustainability, environmental sustainability, energy supply diversity and the competition for energy resources.

Given the scarcity of crude oil and the increasing demand, the prices for oil have steadily been increasing despite economic recessions.[94] Economic sustainability and thus the cost of kerosene is also a crucial factor for the Lufthansa Group. In 2016, 15.4% of the Group’s operating expenses were caused by the purchasing of kerosene. To put this figure in a relation: personnel expenses accounted for 23.2%

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[93] Deutsche Lufthansa AG (2017e)

[94] Hileman, Stratton (2014)

of the expenses. Kerosene was thus one of the biggest cost factors for the aviation group.[95] In 2008, when kerosene prices were peaking the share of cost from kerosene was even higher. For many airlines, the cost of kerosene became the biggest cost driver, superseding personnel cost.[96] The cost of kerosene for Lufthansa in the same year constituted some 21% of total operating cost, while personnel expenses amounted to approximately 22%.[97] As long as jet fuel is relying on the production from petroleum, the oil price will continue to determine the market price of it.

Another factor that relates to economic aspects regarding bio kerosene is the cost of changing infrastructure. This means that from a current standpoint, switching cost from regular kerosene to bio kerosene or blends should be kept as low as possible. This can only be achieved with the previously mentioned drop-in bio fuels. These fuels are characterized as being able to substitute regular petroleum based kerosene without any modifications to current aircraft and engine technologies as well as the infrastructure needed for the jet fuel. According to Boeing, the global aircraft fleet in 2012 consisted of 20,310 commercial aircraft with all of them being designed to use regular kerosene.[98] Given the high acquisition prices for an aircraft, for instance roughly 108 million euros for an A320neo or 311 million euros for an A350-900 and apart from that, relatively long useful lives of typically around 20 years, it is clear that changes to technology and infrastructure are not feasible.[99] Besides, with the size of the worldwide commercial airliner fleet, it would also take some time to replace the current technology.

Energy diversity as a driving factor for bio jet fuels refers to energy independence. Many countries have to import oil in order to meet their demand which is greatly driven by transportation. Bio fuels would add another source of energy resulting in more energy independence.

Another driver for the development of bio jet fuels is given by competition for alternative fuels. The feedstocks that could be utilized to produce bio jet fuels could

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[95] Deutsche Lufthansa AG (2017h)
[96] Hileman, Stratton (2014)
[97] Deutsche Lufthansa AG (2009)
[98] Hileman, Stratton (2014)
[99] Aerotelegraph (2017), International Air Transport Association (IATA), KPMG (2016)

as well be used to produce bio fuels for ground transportation, to create heat and to generate electricity. Ground transportation is also a considerably bigger consumer of fuel that has more experience with alternative fuels such as ethanol, biodiesel or natural gas. Hence, the competition for bio fuels is driven. Apart from this, the requirements for jet fuel are significantly higher than those of ground transportation fuels as jet fuels have to withstand more influences such as pressure or temperature due to the high operating altitudes of commercial aircraft.

The last factor that of course drives and influences the development of alternative jet fuels is environmental sustainability. The use of biofuel can decrease the emissions incurred during the life cycle of the fuel. However, this does not result from different emissions from the combustion of bio fuels but more from the nature and the production of biofuels itself. Whereas the CO_2 that is caused by the combustion of conventional fuels has accumulated in the ground for millions of years, the biomass that serves as a basis for bio fuels is created by the photosynthesis of water and CO_2. The plants that are needed to produce the biomass absorb CO_2 from the atmosphere, which results in net zero CO_2 emissions from the combustion of the bio kerosene.[100]

Before examining the various sources of bio jet fuels, it should first be looked at the standards that the fuels must meet. In the US, these standards are defined by the standardization organization ASTM, more specifically the applied standards are ASTM D1655 and D7655, according to which jet fuel needs to have several characteristics. First, the fuel needs to exhibit a high energy density, i.e. high amounts of energy per unit volume, which is necessary to conduct long range flights. Second, the specific energy should also be high, hence high energy per unit mass as weight reductions lead to better fuel efficiency. Third, the jet fuel needs to have a high boiling point. This means that the production of vapor that can be ignited should be high for safe usage to be guaranteed. Fourth, due to the high cruising altitudes and the low temperatures at the latter, jet fuel should also be characterized by a low freezing point. Fifth, as the temperatures in the engines are very high, a good thermal stability of the fuel is also crucial. Chemical disintegration should be avoided for fuel

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[100] Hileman, Stratton (2014)

lines not to be blocked. Sixth, in order for the fuel pumps to properly work, lubricity is important as well. Finally, it should also be guaranteed that the fuel exhibits appropriate content of aromatic compound, which is necessary to achieve the desired swelling of seals in the fuel system that prevents leakages.[101]

Given the above criteria, different sources and types of alternative kerosene can be examined. First of all, there are two different types of biofuels that have to be distinguished, namely primary and secondary biofuels. Primary biofuels are not produced using chemical processes, they can be directly used to generate electricity or heat. Examples of which are wood or organic waste oils. Secondary biofuels are produced using chemical processes, for instance vegetable oils, biodiesel, ethanol, methanol or biogas. The secondary can then be further subdivided into first, second and third generation biofuels. Figure 11 illustrates the different types and the subdivision of different biofuels.

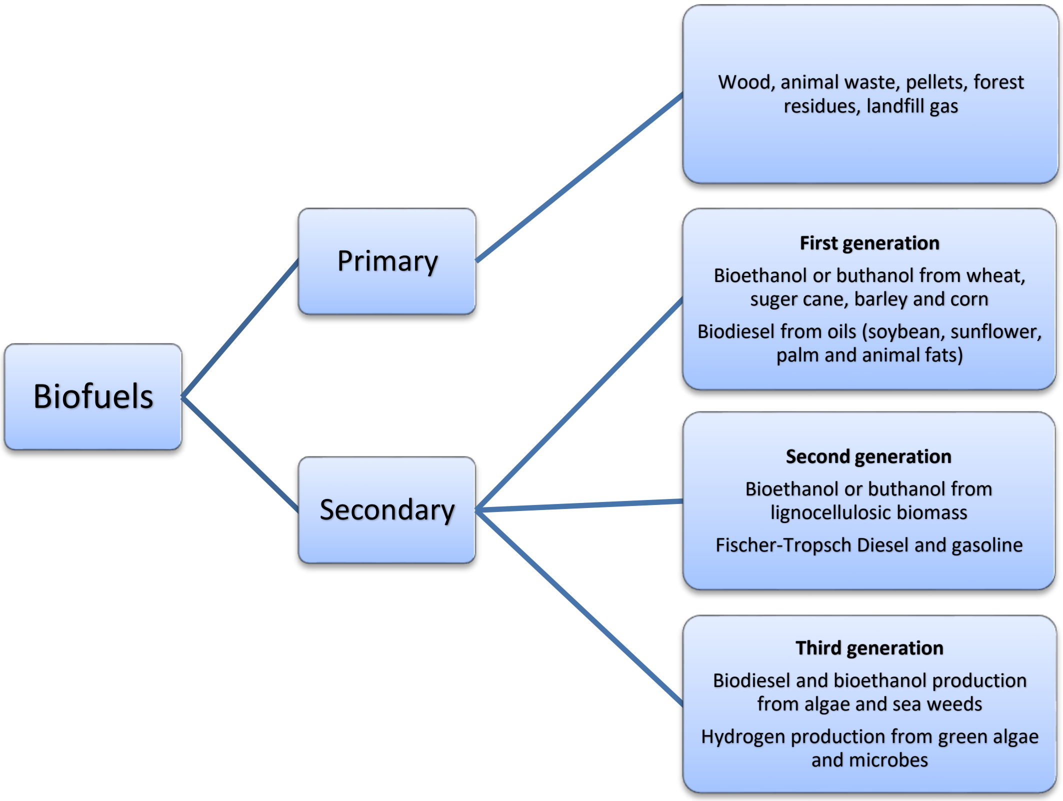

Figure 11 Types of biofuels[102]

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[101] Hileman, Stratton (2014)

[102] Own illustration based on Yilmaz, Atmanli (2017)

Second and third generation biofuels are the most popular ones these days. The research that is done focuses on biofuels that are made from inedible sources to avoid negative effects on the food chain. Plants that are in the focus are jatropha, camelina, algae but also different wastes, all of which have shown considerable potential for the transportation industry.

The jatropha plant is a poisonous energy crop that on the one hand contains high amounts of oil (30 – 40% per grain), which is needed to produce fuel, and on the other hand is a very resistant plant. It can withstand drought and pest and also grows with rough soils and bad climatic conditions. Besides, once it has started growing, the plant is able to yield up to 40 years.

Like jatropha, camelina also is a non-edible energy crop, containing between 38 and 43% oil. It can grow on infertile soil and is cultivated based on a rotation with wheat and cereals.

Algae is probably one of the most desirable sources for bio fuels. This has several reasons. First of all, the land use of algae is very low. As a result, it does not compromise the cultivation of edible plants for the sake of fuel production. Even though the plants mentioned above do not directly affect the food chain, they do so indirectly by requiring land to be cultivated, which otherwise could have been used to cultivate edible plants. Second, the algae grows faster than energy crops and it also contains higher amounts of oil, to be more specific, 60% based on weight. This results in 30 times more yields per acre compared to other energy crops. Third, algae grow by using sunlight, CO_2 and (waste) water. Hence, it possesses a high potential to absorb CO_2 and could also benefit waste water treatment. Research that is currently done shows that jet fuel produced from algae could potentially decrease the life cycle GHG emissions by 76%.

Finally, various wastes such as plant based or animal based wastes could serve as a reliable source for alternative fuels as well. This could support waste management. As the production methods have improved, all of these sources could be used to produce fuels such as biodiesel, bio alcohols or synthetic fuels. The conversion process can be achieved thermochemically or biochemically. [103] Yet, as the demand

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[103] Yilmaz, Atmanli (2017)

in the aviation industry is high, the environmental sustainability and economic feasibility should be kept in mind. Economic feasibility can be a challenge when promoting biofuels, especially when oil prices are low. The production of these fuels will have to be commercialized more, on the one hand to offer sufficient quantities equivalent to petroleum based jet fuel and on the other hand to offer them at reasonable prices that can compete with regular jet fuel.

Aircraft manufacturers as well as airlines have been researching on this topic for quite a while. Test flights with biofuels began in 2008, to date, more than 1,500 passenger flights powered by sustainable biofuel have taken place. Virgin Atlantic was the first airline to conduct a passenger test flight with bio fuel in 2008, flying with a Boeing 747 from London Heathrow to Amsterdam.[104] Lufthansa followed in 2011, however, not by conducting a single test flight but as the first airline testing bio jet fuel in its regular operations for six months. The research was conducted under the project BurnFAIR. Its goal was to find out whether bio kerosene could be an adequate means to meet the Lufthansa Group's CO_2 goals. The research was fostered by the German department of economy and energy, as the research also benefitted the industry in general. Even though security risks regarding bio fuels had been excluded, no long-term tests under real conditions had ever been conducted. Impacts on technical wear of the engines and operational suitability in general were yet to be examined. This served as motivation for Lufthansa to launch the BurnFAIR project and test bio kerosene in day to day operations on the route between Hamburg and Frankfurt with an Airbus A321. During the test phase, one engine of the aircraft was exclusively run with bio kerosene. The kerosene was sustainably produced by a Finnish company and shipped to Hamburg where the Airbus was fueled. The fuel for the return flight from Hamburg to Frankfurt was also already loaded in Hamburg. In total, 1,188 flights with the bio kerosene were conducted. With 50% bio kerosene, the maximum allowed admixture was utilized. During the flights, the engine running on bio kerosene was continuously monitored.[105] In order to assess the impact on the engines and the fuel system of the aircraft, all parts that were in contact with fuel, were thoroughly examined. In the entire fuel system and

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[104] Bio-based news (2008)

[105] Zschocke et al. (2014)

engines there were no indications that bio kerosene implicates negative effects. Instead, in some parts, wear could even be reduced. Due to a higher energy density of bio kerosene, the fuel consumption in tons was 1% less compared to the engine running on regular kerosene. During the test phase, Lufthansa also monitored parameters such as noise, which also proved to be unaffected by the use of bio kerosene. Most importantly, the emissions as compared to regular kerosene have proven not to be negatively affected with the use of bio kerosene.

In addition to the technical characteristics of bio kerosene, the BurnFAIR study also included research on ways to produce it. The research included the entire production chain, reaching from the preparation of biomass through the transportation to the airport. This implied cost calculations, life cycle assessments, expert interviews and more. Two production processes were examined, on the one hand, the HEFA (Hydroprocessed Esters and Fatty Acids) process, which was also used to produce the bio kerosene for Lufthansa, and on the other hand the Fischer – Tropsch (FT) process.[106] In the HEFA process oils and fats, for instance from jatropha or algae, are initially hydrated and afterwards refined.[107] The Fischer – Tropsch synthesis is a chemical process which can transfer carbonic materials into fuel.[108] Both of these processes are currently authorized methods for the production of bio kerosene.

The basis for the analysis of the HEFA process was determined to be jatropha. The reason for Lufthansa choosing the plant was its inedibility and its drought resistance. The assessment of the jatropha plant also incorporated the examination of three different possible cultivation locations and different harvesting procedures.

For the Fischer – Tropsch process, Lufthansa assumed the utilization of wood from plantations as a feedstock. As cultivation locations, Germany and Brazil were analyzed.

Lufthansa found that both, jatropha and wood could theoretically meet the world demand for kerosene, yet, wood proved to have higher potential.

The result of the BurnFAIR research showed that technically there are no objections to the utilization of bio kerosene. However, it could also be revealed that under

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[106] Zschocke et al. (2014)
[107] Avaition Initiative for Renewable Energy in Germany e.V. (2017b)
[108] Weber (2008)

current circumstances, neither the bio kerosene production from jatropha using the HEFA process, nor the production from wood using the FT process could economically compete with regular kerosene. The study also suggests that the potential to decrease GHG emissions is not yet sufficient. Although this is largely based on characteristics of the biofuel and not on the emissions from burning it. Nevertheless, the study concludes that the current issues regarding bio kerosene could be solved relatively shortly.[109]

Apart from the study, Lufthansa has also experimented with other alternative fuels. In 2014, Lufthansa was the first airline to fuel an aircraft on a passenger flight with a 10% admixture of Farnesan, bio fuel based on sugar.[110] The results showed improvements of the emission characteristics.[111]

In 2016, Lufthansa fueled some 5,000 flights of the group with kerosene that contained 5% bio kerosene on the airport of Oslo in Norway. Air BP Aviation, the Norwegian airport operator Avinor and SkyNRG, a biofuel specialist, supplied roughly 1.25 million liters of bio kerosene to the airport that was used in day to day operations.[112]

Finally, along with 33 other members, the Lufthansa Group is also a member of Aviation Initiative for Renewable Energy in Germany e.V. (AIREG). The goal of the association is to force the production and the utilization of alternative jet fuels, that ought to constitute 10% of the demanded kerosene in Germany by 2020.[113]

3.4.2.4. Evaluation of the Measure Alternative Fuels

Bio jet fuels could have a great potential to reduce the carbon footprint in the aviation industry. This is especially true when using plant based fuels, as the feedstock would absorb CO_2 from the atmosphere and would thus not emit more CO_2 than it absorbed. Nevertheless, there are still challenges that have to be overcome. Most importantly, the biofuel production must not compromise food production. Therefore,

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[109] Zschocke et al. (2014)
[110] Avaition Initiative for Renewable Energy in Germany e.V. (2017a)
[111] Deutsche Lufthansa AG (2017l)
[112] Deutsche Lufthansa AG (2017l)
[113] Avaition Initiative for Renewable Energy in Germany e.V. (2017c)

algae could be a suitable feedstock for bio kerosene. Due to its land use, wood potentially compromises food production more than algae. Besides, it is also possible that wood plantations, such as for instance in Brazil might cause further cutting of the rainforest. Water consumption is another critical point that should be kept in mind when considering wood as a potential feedstock for bio kerosene. In this regard, jatropha or camelina would serve as a better solution, as they do not require much irrigation. However, algae would present an even better solution, as it even grows in waste water. The latter should also be considered by Lufthansa as a potential feedstock.

Apart from the sustainability issues, improvements still have to be done on the production side. Increasing the production volumes would make bio kerosene economically more competitive. Furthermore, it must be guaranteed, that the demand can be fully covered.

From the current standpoint, it is hard to quantify, how much exactly bio fuels in aviation could contribute to a reduction of the carbon footprint. At the moment, there are still too many uncertainties concerning feedstock, production and the emissions related with the production of bio kerosene. However, research suggests that it is well worth pursuing the examination of bio fuels in aviation, as other alternative powering in the aviation industry cannot be as easily implemented as in ground transportation. Whereas battery driven cars are becoming increasingly popular and the ranges of which are increasing, the technology is still far from becoming suitable for day to day use in aviation. It is even questionable whether battery powered long and ultra-long range aircraft will be realistic in the medium term. Apart from range, batteries are still relatively heavy, which is problematic as weight in aviation is an extremely crucial issue. Research is also being conducted in the field of hydrogen powering. This would imply engine powering by using a fuel cell that produces electric power. With water vapor being the only emission of the fuel cell process, this might seem reasonable in the first place, yet there are also still numerous issues regarding the production of hydrogen.

3.4.3. Infrastructure Improvement

3.4.3.1. Single European Sky (SES)

Airspace and traffic management is a big challenge, especially in the EU. The task of air traffic management (ATM) is to navigate aircraft at airports, around them and between airports. In the EU, air navigation service is still enormously fragmented. The root problem is that countries have sovereignty over their airspace, as a result, air navigation service is handled individually by each country leading to numerous air navigation service providers that each have their own systems and way of operating. The coordination of these different providers is of course a challenge, hence, combined with the fact that aircraft usually have to pass several airspaces along their route, this leads to inefficiencies.[114] Due to similar sizes of the airspaces, it makes sense to compare the air navigation services of the EU and the US. Table 3 illustrates this comparison based on 2010 data:

	EU	US	Difference
Area of the airspace (million km²)	11.5	10.4	-10%
Number of air navigation service providers	38	1	
Number of air traffic controllers	16,700	14,600	-13%
Total staff in air navigation services	57,000	32,500	-38%
Controlled flights in million	9.5	15.9	+67%
Flight hours controlled	13.8	23.4	+70%
Relative density (flight hours/km²)	1.2	2.2	+80%
Number of centers en route	63	20	-68%

Table 3 EU and US air navigation services comparison[115]

The table shows that the airspaces of the US and the EU are relatively similar concerning size. However, the first major difference is the tremendous difference in the number of air navigation service providers. Whereas there are 38 providers in the EU there is only one in the US, namely, the Federal Aviation Administration (FAA). Despite, there being 67% more flights controlled in the US airspace and despite a higher flight density, the number of air traffic controllers in the US as well as the number of total employees is lower the air navigation services sector is lower

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[114] Button, Neiva (2013)
[115] Button, Neiva (2013)

in the US. In addition, the number of centers that statistically are along a route between which flights have to be handed over is tremendously lower in the US than in the EU. While liberalization of aviation has already made considerable progress on the part of airlines and partly also airports through privatization, air traffic control is a more difficult topic to reform. A standardization of air space management would be highly desirable or otherwise at least a common platform enabling the smooth passing through of flights. The high degree of fragmentation, where airspaces typically map the actual state border and the lack of coordination between the different systems is also believed to cause high costs. In 2011, it was estimated that due to this inefficiency as much as € 4 billion delay costs were incurred. For this reason, the European Commission has set up the SES initiative with the intention to obtain an airspace which is one single entity.[116]

As the implementation of the SES is an enormous effort it has been agreed to gradually transition towards this goal with the help of functional airspace blocks (FABs). The FABs intend to combine several local air navigation service providers to bigger units intending to treat flights as if there actually was just one provider. In total, nine FABs were determined, two of which are already established.[117] Figure X shows the FABs of which UK – Ireland and Denmark – Sweden have already been established. It is clearly visible, that the FABs would already serve as a good basis for unifying the European airspace as it would already defragment it considerably. Nevertheless, the fact that so far only two of the FABs were established also shows how challenging the reformation of air traffic management is.

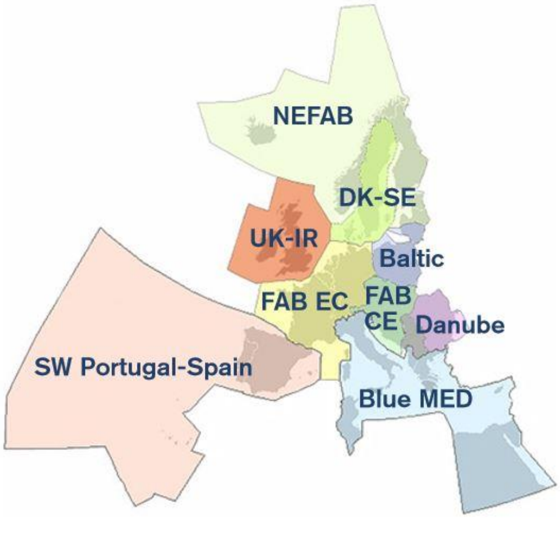

Figure 12 FABs[118]

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[116] Previous section Button, Neiva (2013)
[117] International Air Transport Association (IATA) (2017a)
[118] International Air Transport Association (IATA) (2017a)

Historically, the SES initiative was based on a white paper authored by the European Commission in 1996. The paper expressed concerns that the current air traffic management system might pose a risk to the growth of air transportation in Europe due to lacking capacities. Hence, the EU launched two SES packages, one in 2004 the second one in 2009. Based on 2005, the SES aims to enable the EU airspace to handle three times more traffic, to improve safety tenfold, to reduce the environmental impact of air traffic by 10% and to cut air traffic management unit cost by 50%. All of which is intended to be achieved by 2020.[119]

The first package was based on four pillars, namely, performance, technology, safety and capacity. For the technology pillar the European Commission initiated a Single European Sky ATM Research (SESAR) master plan.[120] Experts form the Lufthansa Group airlines as well as from Lufthansa Systems, an IT service provider subsidiary of the aviation group also participate in the research.[121] The safety pillar was assigned to the European Aviation Safety Agency (EASA). A performance review of the EU's Performance Review Commission (PRC) recommended in its report in 2006 among others to accelerate the implementation of the FABs and the corresponding technology. Consequently, the European Commission launched a second SES package in 2009. In this package five pillars for the SES initiative were defined: technology with its main part SESAR, legislation, setting deadlines for the implementation of the FABs and the assignment of Eurocontrol as network manager, safety, still maintained by EASA, an airport pillar and a human factor pillar.[122]

Implementing the SES will result in several different benefits, economically, environmentally as well as passenger related. Capacity-wise, the SES would be able to handle 20 million flights per year and would hence not restrict growth of air traffic. On the efficiency side, it is estimated that current inefficiency costs of the ATM system could be reduced by € 3 billion per annum, for flight efficiency it could potentially lead to € 6 billion savings yearly and also reduce flight time on average by 10 minutes. Economically, the SES is estimated to deliver € 419 billion of additional GDP to Europe between 2013 and 2030. Finally, and most importantly,

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[119] International Air Transport Association (IATA) (2017a)
[120] Baumgartner, Finger (2014)
[121] Deutsche Lufthansa AG (2017e)
[122] Baumgartner, Finger (2014) and International Air Transport Association (IATA) (2017a)

the SES could save the emission of 18 million tons of CO_2 each year, which is a reduction by 10%.[123] Looking at figure 13, it becomes clear why SES could save millions of tons of CO_2:

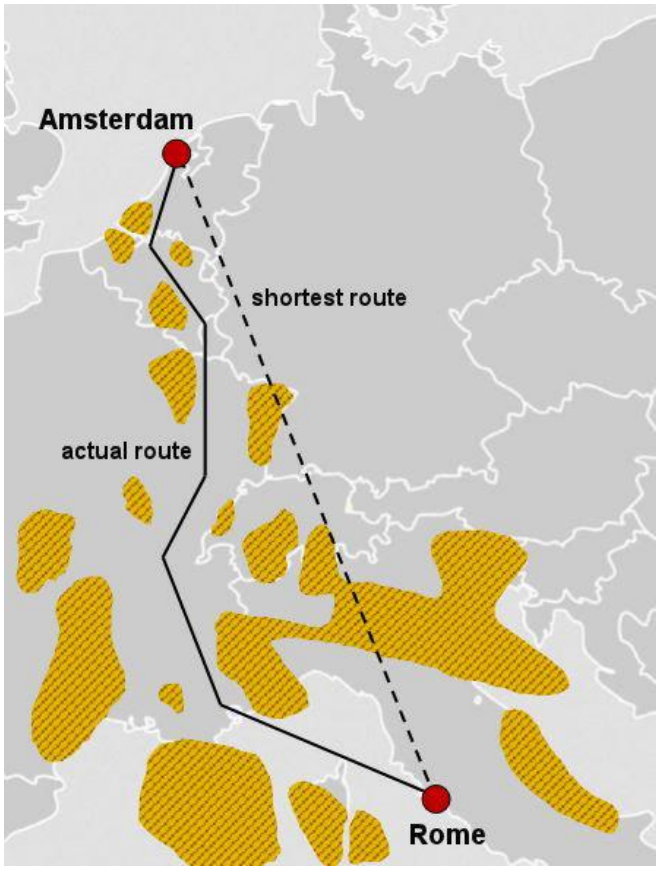

Figure 13 Route example SES[124]

The figure illustrates a possible route between Rome and Amsterdam, whereas the flight data such as emissions and fuel consumption are based on a Boeing 737-800. While the shortest route would be 1,450 km long, the actual route in this example is 1,750 km long, resulting in a difference of some 300 km or 17%. Accordingly, the flight time could be reduced by 23 minutes from 2:19 to 1:56. More importantly, the kerosene consumption could be decreased by 1,400 kg from 6,600 kg to 5,200 kg and hence, the CO_2 emissions would amount to 16,380 kg instead of 20,800 kg. This constitutes a reduction of 21%.[125] Even though this example assumes ideal

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[123] International Air Transport Association (IATA) (2017a)
[124] Bundesverband der Deutschen Fluggesellschaften (BDF) (2017), own translation into English
[125] Bundesverband der Deutschen Fluggesellschaften (BDF) (2017)

conditions as it determines the ideal route to be a straight route between the two cities, which, due the common navigation in air traffic between waypoints would not occur, it still illustrates the current fragmentation and inefficiencies in the European airspace. The aircraft has to be handed over between air navigation service providers each with their own way of operating resulting in an inefficient routing. Despite the fact that even under the SES a straight-line route would not be realistic, the potential is still existent.

The demonstration project FREE Solutions (Free Route Environmental & Efficiency Solutions) in which Lufthansa is also involved aims to relate the development of SESAR with its implementation.[126] Several air navigation service providers and airlines work together in the project to show the concept of free routes and other operational measures for the benefits of the SESAR measures to be proven under real life circumstances. Between 2014 and 2016, more than 1,000 flights were implemented under the project.[127] So far, Lufthansa could conduct 68 flights in accordance with the FREE Solutions project and permanently shorten several routs such as Frankfurt – Nice, Frankfurt – Barcelona or Munich – Paris amongst others, which according to Lufthansa resulted in fuel and hence, CO_2 emission savings equivalent of 200 flights between Frankfurt and Zurich per year.[128]

Other SESAR Related Projects

Apart from the SES initiative, the Lufthansa Group also engages in other infrastructure related projects. Group member Swiss is involved in iStream, a project which helps to optimize the approaches of aircraft. In association with the airport of Zurich and swiss air traffic control skyguide, the approach system of Zurich airport for one year, starting in 2015. The focus was on approaches between six and seven o'clock in the morning as this is the most frequented time during the day where usually many holding patterns had to be performed by the aircraft and inefficient vectoring was instructed in order to sequence the air traffic for landing. This of course harbors the risk for significant inefficiencies as the approaches become longer and hence more fuel is consumed. With better timing management coordinated between

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[126] SESAR Joint Undertaking (2016), Deutsche Lufthansa AG (2016b)
[127] SESAR Joint Undertaking (2016)
[128] Deutsche Lufthansa AG (2017e)

the dispatch, the pilots and air traffic control, these inefficiencies could be reduced significantly. Skyguide could coordinate the approaches more in advance and sequence the aircraft earlier leading to optimized approaches. In fact, the project led to a 96% reduction of holding patterns and a reduction in the length of the approach route by roughly 30%. As a result, in October 2016 this approach procedure became mandatory for all approaches during the morning peak time.[129] As the project proved to be successful, it is planned to extend this approach procedure to Paris Charles-de-Gaulle airport, Paris Orly airport and London Heathrow.[130]

Another project in which Lufthansa is involved is Augmented Approaches to Land (AAL). Apart from noise reductions, the project also aims to reduce the impact on environment that airspace users have on the environment. Basically, this shall be achieved by a more precise adherence of approach routes with the help of innovative technologies. Amongst others, these technologies include for instance synthetic vision guidance systems, ground based augmentation systems or satellite based augmentation systems.[131] An example of a vision guidance systems is a head up display unit (HUD) which directly displays relevant information in the field of vision of the pilot. Lufthansa has equipped aircraft of its Boeing 747-8, Airbus A380 and A320 fleet to experiment with the new technologies.[132]

3.4.3.2. Evaluation of Infrastructure Improvement

It has been shown that air traffic and air space management is a challenging component in the aviation industry. Even though the exact impact on the reduction of the CO_2 emissions of Lufthansa and air traffic in general is hard to asses, it is still obvious that engaging in ATM Research in order to improve routes and approaches, in this case SESAR, is worthwhile as the reductions that can be achieved are far from being negligible. However, in the case of the SES, the power of an airline is limited as the implementation of a unified European airspace also requires political action due to the member state’s sovereignty over their airspaces. Hence, it is more

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[129] Skyguide (2016) and Deutsche Lufthansa AG (2017e)
[130] Deutsche Lufthansa AG (2017e)
[131] European Commission (2017a), Deutsche Lufthansa AG (2017e)
[132] Deutsche Lufthansa AG (2017e)

difficult do bring the different stakeholders together. This becomes obvious when considering the fact that so far, only two out of nine planned FABs on the way to unify Europe's airspace have been implemented, even though they all had been required to be implemented by December 2012. An acceleration of this process would be highly desirable as the inefficiencies of the current system on the one hand create unnecessary cost and, above all, cause air

transportation to harm the environment more than necessary. Hence, all stakeholders could benefit from an accelerated implementation of the SES and it would ease to meet the CO_2 goals the aviation industry has set itself.

Apart from the SES, it can also be recommended, to incorporate projects that have proven to be successful, such as iStream, quickly to as many airports as possible. As the system is neither airport nor airline specific, this can be achieved relatively easily.

3.4.4. Operative Measures

3.4.4.1. Measures Undertaken by Lufthansa

Operative measures to reduce the carbon dioxide emissions comprise a number of different fields where actions can be taken. This includes the utilization of adequately sized aircraft in relation with high load factors, new flight procedures and optimized routes and speeds, projects to reduce weight, the development and use of intelligent software and efficient ground processes.[133]

One of the biggest issues in aviation is weight. The reduction by 1kg of weight in aviation results in the saving of 4t kerosene and hence, 12,600kg of CO_2 each year. This is the equivalent of a flight from Munich to Berlin. In this regard, fuel is an important influencing factor, more specifically, the correct planning of fuel needed for the trip. On long haul flights, fuel adds the most weight to the aircraft. An Airbus A380 for instance can almost carry more than 250 tons of kerosene.[134] The

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[133] Deutsche Lufthansa AG (2017e)

[134] Airbus (2017b)

entrainment of large amounts of fuel also leads to long haul flights becoming more inefficient as their length increases. Figure 14 illustrates the relationship between the length of the flight and the amount of fuel burned:

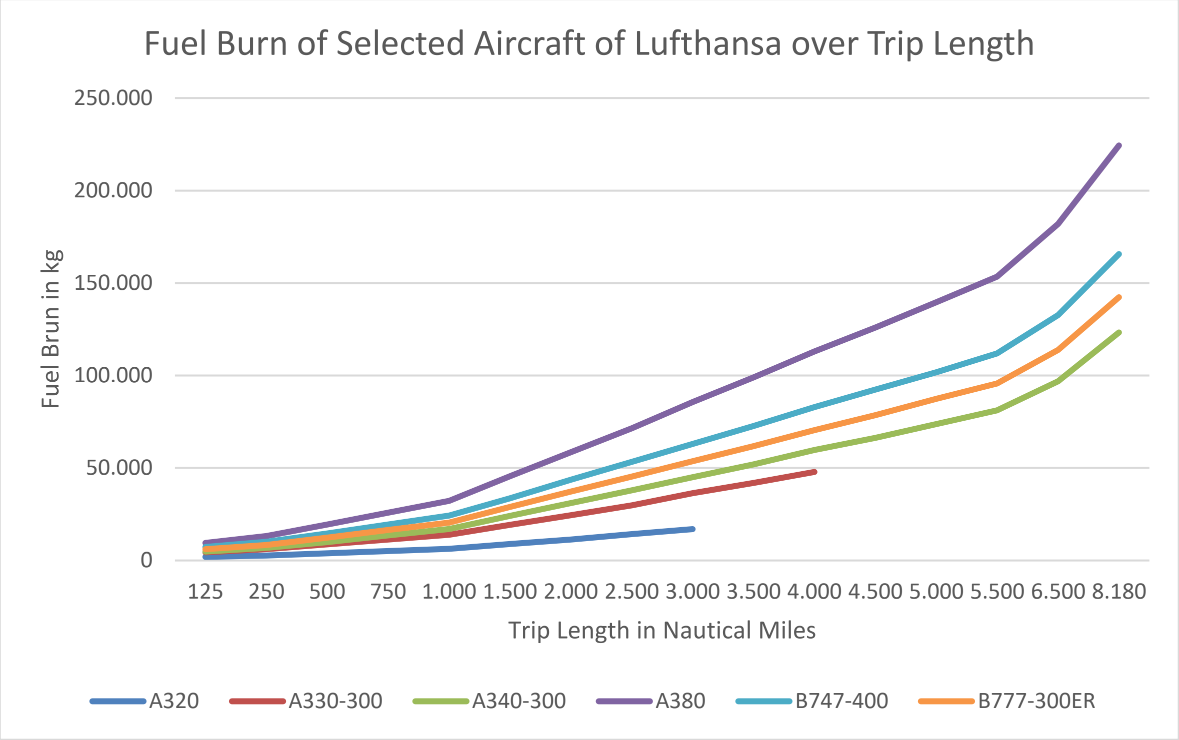

Figure 14 Fuel burn of selected Lufthansa aircraft over trip length[135]

For all aircraft, the slope changes around 1,000 NM of distance, at around 5,550 NM and at 6,500 NM. At these points, the slope of the graphs increases, which means that the relationship between trip length and fuel consumption is not liner but exponential. The reason for this is quite obvious: the longer the trip becomes, the more fuel has to be carried, hence more weight is added which results in higher fuel consumption and less efficiency. For the amount of CO_2 emissions this would look exactly the same, yet the units would be different. This also shows that weight plays a crucial role for airlines. The amount of fuel in kg that is required for a trip is typically calculated by the dispatch, as is the route, however, the final decision is taken by the captain, who takes into account other factors such as safety, weather and traffic, which adds additional fuel to the minimum amount. In 2015 and 2016, Lufthansa implemented improvements concerning the calculation of required fuel. These

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[135] Own illustration based on European Environment Agency (2013)

improvements are expected to result in the saving of CO_2 emissions in excess of 28,000 tons per annum. Further weight reductions could be achieved by the replacement some 30,000 older service trolleys between 2011 and 2016, whereas the new models weigh 35% less than the old models. Lufthansa estimates this measure to save more than 30,000 tons of CO_2 each year. Another weight related project refers to all documents that are necessary to conduct a flight. These include for instance checklists for the pilots, air navigation charts or logbooks amongst others. Instead of paper based documents, this data is now delivered electronically with so called “Electronic Flight Bags” (EFBs). It is expected that this measure will decrease the CO_2 emissions by more than 9,500 tons per annum.[136]

Apart from weight related projects in this category of CO_2 mitigation measures, research is also done in other fields. As an example, shark skin coating can be mentioned. In this case, concepts that can originally be found in the nature are transferred to modern technology. More specifically, there are some types of sharks that have a special micro structure in their skin which reduces frictional resistance. As less friction means less fuel consumption, Lufthansa Technik conducted research in association with Airbus and the Fraunhofer Institute for Production Engineering and Applied Materials Research on special coatings that apply this structure to the skin of aircraft. First of all, the durability of the of the skin had to be tested, for which Lufthansa equipped two Airbus A340 with eight small patches of the coating. As the coating had proven to be durable, Lufthansa launched a continuative project called FAMOS which then aimed to develop large scale application methods to enable implementation of shark skin coating in aircraft production. In December 2016, the first fully shark skin equipped Lufthansa aircraft took off to Montreal launching a two-year test phase. Shark skin coating is expected to lower the fuel consumption by 1.5% and hence, emissions accordingly.[137]

Other operational measures that can be mentioned are for instance a process developed by Lufthansa to clean engines (Cyclean) and the use of hybrid tractors to move the aircraft on the ground. Cyclean was developed by Lufthansa Technik and

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[136] Deutsche Lufthansa AG (2017e)

[137] Deutsche Lufthansa AG (2017e), Deutsche Lufthansa AG (2015)

enables airlines to save 0.5% fuel merely by washing the engines.

As the taxiing from the gate position to the takeoff runway and vice versa after landing also consumes considerable amounts of kerosene, especially on bigger airports, ground movements of aircraft are also meaningful to conduct research on. In association with Israel Aerospace industries, Lufthansa LEOS, a Lufthansa Group member that focuses on ground support equipment, developed a diesel-electric hybrid tractor that can be controlled from the cockpit and can move aircraft from the gate to the takeoff position without the engines of the aircraft running.[138] The amounts of fuel and hence emissions that can be saved are to be neglected: the fuel consumption rate of an Airbus A320 during taxi operations amounts to roughly 15.4kg per minute.[139] Given a taxi time to the runway of 15 minutes which can easily be reached on an airport like Frankfurt, this amounts to roughly 230kg of kerosene and almost 727kg of CO_2. This is just for half a flight (as after landing the aircraft has to taxi as well) and a small aircraft. Bigger aircraft such as the A340 or A380 consume considerably more fuel for taxiing. Considering a simplified model for the A320 with three flights per day, which is realistic for short haul aircraft, and an estimated total taxi time of 20 minutes per flight, this results in a taxi fuel consumption of 337,260kg per year which turns into more than 1,000 tons of CO_2. It should be kept in mind that this only refers to one aircraft. Even though this is a simplified model and the tractor obviously consumes some fuel as well (though considerably less than the aircraft engines), it points out that there is considerable potential for the reduction of emissions concerning ground movements.

Research in this regard is also done regarding the integration of an electric engine into the main gear that would be powered by the auxiliary power unit (APU). This would also allow the aircraft to taxi without the main engines running.[140]

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[138] Deutsche Lufthansa AG (2015)
[139] Ryerson et al. (2017)
[140] Deutsche Lufthansa AG (2014)

3.4.4.2. Evaluation of Operative Measures

The operational measures taken to reduce the emissions of Lufthansa are various. Research is conducted in many different fields. However, the various efforts to reduce the emissions add up to considerable amounts, this has best been shown by the possible savings in taxi fuel. Hybrid and possibly fully electric ground movement can also be easily extended to all ground based traffic such as catering trucks. This of course also requires cooperation with the airports as they are also responsible for much ground traffic.

Another key factor is weight. On the one hand, this can be influenced by the airlines for instance by implementing paperless cockpits or utilizing lightweight services trolleys. Yet, on the other hand, weight can largely be influenced by aircraft manufacturers. This relates to pillar one, technological measures, more specifically the purchasing of modern aircraft.

Despite the fact that reductions of 1.5% by the use of shark skin coating or 0.5% by engine washing might seem marginal at the first glance, these two measures together still save some 181,000 tons of CO_2 each year, based on 2016.[141]

However, it should also be said that the progress in some fields is still relatively slow even though they could technically be implemented already. This especially refers to the ground movements of aircraft. Technically, it would be viable to integrate an electric engine into the landing gear that is driven by the APU of an aircraft which consumes significantly less fuel than its main engines, however this is still not implemented in the current state of technology.

3.4.5. Economic Measures

3.4.5.1. ETS and Offsetting Schemes

Economic measures mainly act as a supporting pillar for technological progress, infrastructure improvement and operative measures. More specifically economic measures describe a market based system to offset carbon dioxide emissions such as the EU-ETS which has been covered under 2.4.4. However, Lufthansa would prefer a global measure as it views the EU-ETS as distortion of competition as only

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[141] Deutsche Lufthansa AG (2017e)

inner European flights are covered. In October 2016, ICAO agreed on a global Carbon Offsetting and Reduction Scheme (CORSIA).[142] Similar to the EU-ETS, airlines will also have to purchase CO_2 certificates to offset their carbon dioxide emissions. The scheme will come into effect 2020 and should support IATA's goals of carbon neutral growth from 2020 and an absolute reduction of net Aviation CO_2 emissions of 50% by 2050 based on 2005.[143] To achieve this, all growth-related emissions will be offset through especially designed climate protection projects that are monitored by the United Nations. Figure X illustrates the role of CORSIA as marked based measure to achieve the industry's goals:

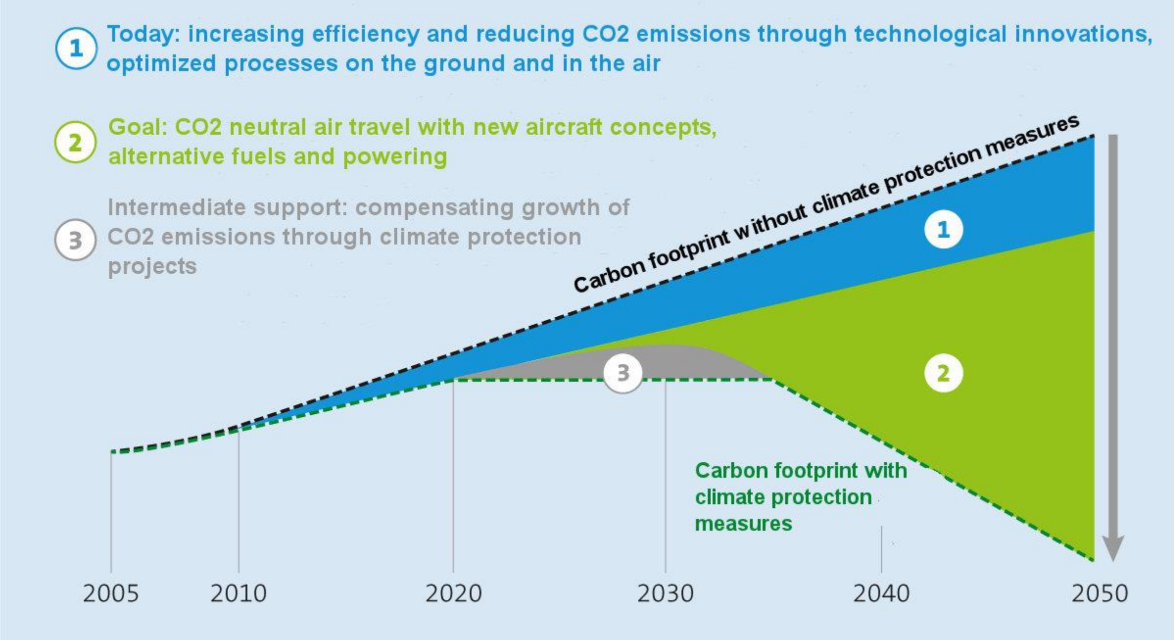

Figure 15 Aviation industry's climate protection goals[144]

The CORSIA scheme is depicted by the grey area in the illustration. EU-ETS can also be allocated to this area. It can be said that the marked based measures such as CORSIA and EU-ETS should merely serve as an intermediate support to achieve the industry's climate goals until new aircraft technologies including powering and fuels are ready.

CORSIA will be implemented in three phases, whereas phase three should then

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[142] Deutsche Lufthansa AG (2017e)

[143] International Air Transport Association (IATA) (2017b)

[144] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017b), own translation into English

cover 90% of international air traffic. In the pilot phase from 2021 – 2023 as well as in the first phase from 2024 – 2026, participation is voluntary and members can quit the agreement at any time. In the second phase, which reaches from 2027 – 2035, all countries, that had a share in global revenue ton kilometers (RTK) of more than 0.5% in 2018 are obliged to participate, however, in total 90% of global RTK have to be covered, meaning that it is possible that also countries with a lower share than 0.5% might have to participate.

Airlines that emit less than 10,000 tons of CO_2 per annum, aircraft with a maximum takeoff weight of less than 5.7 tons as well as humanitarian, medical or firefighting flights are exempt from CORSIA.[145]

So far, 71 states have voluntarily committed to participate in the CORSIA scheme, representing almost 88% of global RTKs.[146]

From 2022, CORSIA will be checked every three years in order to assess its effectivity and its impact on sustainable development of the air transportation industry. Current estimates predict that by 2035 between 443 and 596 tons of CO_2 will be offset by the scheme.[147]

European airlines hope that CORSIA will replace the EU-ETS, eliminating additional costs that they are facing compared to non-European airlines. Even though the European Commission announced to review the system again, it is not clear yet, whether it will disenthrall the air transportation industry from the EU-ETS again as many EU representatives view CORSIA as too lax.

3.4.5.2 Evaluation of Economic Measures

In the aviation industry, CORSIA is seen as an important and historic achievement as it makes it the first industry with an own climate agreement. However, there is also criticism about the scheme. First of all, in all phases, only those routes that are between two participating countries will be covered. For instance, a flight that departs in Germany bound for Tanzania will not be covered by CORSIA, as Tanzania is not participating in the scheme. Apart from this, CORISA will only cover international

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[145] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017a)

[146] International Civil Aviation Organization (ICAO) (2017)

[147] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017a)

flights, whereas domestic flights are neglected which constitute 35% of the total traffic. It is estimated, that if CORSIA was implemented today, only 39% of the total passenger capacity would be covered, this goes for the CO_2 emissions accordingly. The US for instance, is the biggest domestic aviation market, representing 14% of the global passenger capacity, yet unlike in the EU, it is improbable that the US will also introduce an ETS that will cover domestic aviation emissions such as the EU-ETS.[148] Hence, due to these criticisms it is likely that the European Commission will retain the current ETS for domestic flights.

In addition, the approach of calculating the amount that has to be offset is also questionable as it does not treat all airlines equally, at least until 2030. There are two different ways to calculate the required offsets, sectoral and individual. With the sectoral approach, the emissions of the respective airline based on 2020 are multiplied by the global growth rate of air traffic. With the individual approach, the emissions of the airline from 2020 are multiplied with their own growth rate. This means that between 2020 and 2030, where the sectoral approach is applied, an airline that grows at a rate which is less than the global growth rate will be discriminated, whereas airlines growing at higher rates than the global growth rate will have an advantage. This will also be the case for Lufthansa and many German and European airlines as their growth lies below the global growth which is mainly driven by Asia. From 2030 – 2032 the share of individual compensation will then be raised to at least 20% and at least 70% between 2033 and 2035.[149]

> *This chapter has shown, that in terms of emissions and efficiency, there is still room for Lufthansa to improve. It has also been illustrated, that the measures taken to mitigate are various and besides, usually are not airline specific. Furthermore, the progress in some fields is still relatively slow.*

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[148] Evans, Schröter (2017)

[149] Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) (2017a)

4. Conclusion

One thing that is important to keep in mind when thinking about the reduction of emissions in the aviation industry is that for an airline reducing its emissions is not only about being more environment friendly but generally also about reducing cost. Most of the emissions of an airline are obviously caused by the combustion of kerosene, which for Lufthansa and practically all other airlines is one of the biggest cost drivers. Hence, there is also an economic incentive to reduce the carbon footprint, making the mitigation of emissions somewhat self-motivational. As in the medium and long-term oil prices are like to further steadily increase, the cost saving factor becomes even more important. The economic driver was for instance proven by British Airways last year as it announced that it would keep older 747s longer than initially planned due to lower oil prices which made it economically more reasonable again to keep the older more inefficient aircraft.

Furthermore, it is important to mention that the long-term reduction of emissions also brings various challenges for the aviation industry. On the one hand, there is the pressure to reduce the emissions on the other hand, air transportation is a relatively strongly growing sector and is project to further grow at considerable rates. To reduce the carbon footprint, it is not enough to merely increase efficiency as these gains are likely to be outweighed by the overall growth of the industry, leading to the absolute amounts of emissions to further increase. To make matters worse, the technological progress is also slowing down, significant efficiency increases as they could be observed during the last some 25 – 30 years cannot be achieved as quickly anymore. Even comparably easy technological improvements such as electric engines that could be integrated into the main gear to reduce fuel consumption resulting from taxi operations are only emerging slowly. The current generation of technology is also limited. If all tricks could be implemented, such as aerodynamic improvements, engine improvements and better interaction of components, a maximum of another 40% efficiency improvements could be achieved. Further improvements can only be achieved with entirely new aircraft concepts and powering. However, new concepts such as electric powering which is nowadays becoming more common in individual ground transportation, is much more difficult to implement in aviation. First of all, the range is still a big issue, this is also still criticized regarding electric cars. For aircraft, this is even more critical. Current batteries would have to be ten times more powerful to be feasible for aviation use. Apart from this, the batteries are also still relatively heavy, as previously shown, weight is a serious topic in aviation. Research is also conducted in the field of hydrogen and fuel cell powering, small models with this type of powering have already taken off. Yet, hydrogen production is still an issue and the life cycle emissions would currently not be more advantageous than those of regular kerosene. Biofuels such as kerosene from algae or other non-edible plants are closer to maturity and day to day use. Especially the fact that their net life cycle emissions could be zero as the feedstock absorbs CO_2 from the atmosphere makes them good potential alternative until newer technological concepts are ready.

Another reasonable intermediate solution is represented by emissions trading and offsetting schemes such as the EU-ETS and CORSIA. In the medium term, they will help to reduce the emissions of the aviation industry by offsetting them. Nevertheless, even though CORSIA is the first global agreement of the industry, it still is not sufficiently far-reaching and especially in the initial phases too lax, as participation is voluntary. Hence, despite some additional economic burdens, from an environmental point of view it would make sense to maintain EU-ETS.

The current trend towards low cost flying also leads to increasing emissions of the industry as it fosters demand and hence growth. This especially refers to short haul routes. The possibility of flying from Stuttgart to Berlin for € 20 might lead people to choose a flight instead of the train which, as shown, would be much more environmentally friendly. On long haul routes, there are obviously no alternatives, yet, demand is still driven. In addition, the low-cost trends increases cost pressure on airlines which might lead them to refrain from investing in research for new technologies. However, it is important that airlines also act themselves instead of leaving research merely to aircraft manufacturers to develop more efficient aircraft.

It can also be noted that most of the measures shown reduce scope 1 emissions. This goes for fleet renewal, infrastructure improvement, more specifically the SES and also the operative measures as they aim to reduce the kerosene consumption. As most of the emissions of Lufthansa and in the air transportation industry result from the combustion of kerosene, this seems reasonable. Alternative fuels, especially bio kerosene from plants would reduce scope 3 emissions due to lower life cycle emissions compared to petroleum based kerosene. As seen, most of Lufthansa’s scope 3 emissions are caused by the kerosene supply chain and could hence be reduced using bio kerosene.

For many measures, the exact effectivity concerning the reduction of the emissions and thus, the reduction of the carbon footprint has yet to be proven. The potential of some of the measures is based on estimates, such as the SES but also the purchasing of new aircraft.

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Annex

The following assumptions are valid for all calculations:

Kerosene density:	0.8 g/cm³ (grams/cm³)
1 NM (Nautical mile) =	1.852 km
CO_2 per 1 kg kerosene:	3.15 kg

1. Energy density of gasoline and diesel according to Bild der Wissenschaft (2007)
   Gasoline: 12.0 kWh (Kilowatt-hour)
   Diesel: 11.9 kWh
   1 kWh = 3.6 MJ (Mega joule)

   $$12.0 \times 3.6 = 43.2$$

   $$11.9 \times 3.6 = 42.84$$

2. CO_2 emissions of gasoline and diesel according to DEKRA Automobil GmbH (2017)
   Gasoline: 2.37 kg/l (kilograms/liter)
   Diesel: 2.65 kg/l

   Calculation for gasoline:

   Density of gasoline: 0.75 g/cm³ (grams/cm³)

   $$0.75\ kg = 2{,}370\ g$$

   $$\frac{2{,}370\ g}{0.75\ kg} = 3.16\ \frac{g}{kg}$$

   Calculation for diesel:

   Density of diesel: 0.84 g/cm³

$$0.84\ kg = 2{,}650\ g$$

$$\frac{2{,}650\ g}{0.84\ kg} = 3{,}155\ \frac{g}{kg}$$

3. Calculation l/100 pkm (liter/100 passenger kilometers)

   Efficiency as given by Delta Air Lines, Inc. (2016):
   16.07 gal/1000 asm (gallons/100 available seat mile)

   1 gal = 3.785 l

   1 mile = 1.609 km

   Load factor of Delta Air lines: 84.6%

$$16.07\ gal = 1{,}000\ miles$$

$$16.07\ gal = 1{,}609\ km$$

$$60.82\ l = 1{,}609\ km$$

$$0.03779\ l = 1\ km$$

$$3.78\ l = 1\ km$$

   As this is the efficiency per seat mile (load factor 100%), a translation into passenger kilometer is necessary.

$$\frac{3.78\ l}{84.6\%} \approx 4.47\ l$$

   Hence, the fuel efficiency of Delta Air Lines equals to 4.47 l/100 pkm

   The specific emissions can be calculated by calculated as follows:

$$4.47\ l \times 0.8\ \frac{kg}{l} = 3.576\ \text{kg}$$

$$3.576\ kg \times 3.15\ kg \approx 11.26\ \text{kg}$$

4. **Boeing 737-300:**

Fuel burn rate as given by Park (2014): 0.0493 kg/S-NM (seat nautical mile)

$$0.0493\ kg = 1\ NM$$
$$0.0493\ kg = 1.852\ km$$
$$0.0266\ kg = 1\ km$$
$$2.66\ kg = 100\ km$$
$$\frac{2.66\ kg}{0.8} \approx 3.33\ l$$

Emissions:

$$2.66\ kg \times 3.15 \approx 8.38\ kg$$

Airbus A320ceo:

Fuel burn rate as given by Park (2014): 0.0403 kg/S-NM

$$0.0403\ kg = 1\ NM$$
$$0.0403\ kg = 1.852\ km$$
$$0.0217\ kg = 1\ km$$
$$2.17\ kg = 100\ km$$
$$\frac{2.17\ kg}{0.8} \approx 2.71\ l$$

This assumes a configuration of 159 seats. Lufthansa's A320 can seat 168 passengers. The adjustment for this looks as follows:

$$2.71\ l \times 159 = 430.89\ l$$
$$\frac{430.89\ l}{168} \approx 2.56\ l$$

Emissions:

$$2.17\ kg \times 3.15 \approx 6.84\ kg$$
$$6.84\ kg \times 159 \approx 1{,}087.56\ kg$$
$$\frac{1{,}087.56\ kg}{168} \approx 6.47\ kg$$

Airbus A320neo:

Assuming an efficiency increase of 15% as expected:

$$2.56\ l \times 0.85 = 2.18\ l$$

Emissions:

$$2.18\ l \times 0.8 = 1.74\ kg$$
$$1.74\ kg \times 3.15 \approx 5.48\ kg$$

5. **Airbus A340-300:**

Fuel burn rate as given by Park (2014): 0.0558 kg/S-NM (seat nautical mile)

$$0.0558\ kg = 1\ NM$$
$$0.0558\ kg = 1.852\ km$$
$$0.030\ kg = 1\ km$$
$$3.01\ kg = 100\ km$$
$$\frac{3.01\ kg}{0.8} \approx 3.77\ l$$

This assumes a capacity of 253 seats. Lufthansa’s model can accommodate 219 seats. The adjustment looks as follows:

$$3.77\ l \times 253 = 953.81\ l$$
$$\frac{953.81\ l}{219} \approx 4.35\ l$$

Emissions:

$$3.01\ kg \times 3.15 \approx 9.48\ kg$$
$$9.48\ kg \times 253 \approx 2{,}398.82\ kg$$
$$\frac{2{,}398.82\ kg}{219} \approx 10.95\ kg$$

Boeing 777-300ER:

Fuel burn rate as given by Park (2014): 0.0599 kg/S-NM (seat nautical mile)

$$0.0599\ kg = 1\ NM$$
$$0.0599\ kg = 1.852\ km$$
$$0.0323\ kg = 1\ km$$
$$3.23\ kg = 100\ km$$
$$\frac{3.23\ kg}{0.8} \approx 4.04\ l$$

This assumes a configuration of 333 seats. Swiss's models seat 340 passengers. The adjustment for this looks as follows:

$$4.04\ l \times 333 = 1{,}345.32\ l$$
$$\frac{1{,}345.32\ l}{340} \approx 3.96\ l$$

Emissions:

$$3.23\ kg \times 3.15 \approx 10.17\ kg$$
$$10.17\ kg \times 333 \approx 3{,}388.11\ kg$$
$$\frac{3{,}388.11\ kg}{340} \approx 9.97\ kg$$

6. For aircraft types A340-300, B777-300ER, B737-300, A320ceo and A320neo, see above.

A380-800, B747-8 and B777-9X based on Leeham Co EU (2014)

A350-900 based on Deutsche Lufthansa AG (2016)

CS100 based on Bundesverband der Deutschen Luftverkehrswirtschaft (2017)

Boeing 747-400:

Fuel burn rate as given by Park (2014): 0.0563 kg/S-NM (seat nautical mile)

$$0.0563\ kg = 1\ NM$$

$$0.0563\ kg = 1.852\ km$$

$$0.0303\ kg = 1\ km$$

$$3.03\ kg = 100\ km$$

$$\frac{3.03\ kg}{0.8} \approx 3.80\ l$$

This assumes a configuration of 375 seats. Lufthansa's models seat 344 passengers. The adjustment for this looks as follows:

$$3.80\ l \times 375 = 1{,}425\ l$$

$$\frac{1{,}425\ l}{344} \approx 4.14\ l$$

Emissions:

$$3.03\ kg \times 3.15 \approx 9.54\ kg$$

$$9.54\ kg \times 375 \approx 3{,}579.18\ kg$$

$$\frac{3{,}579.18\ kg}{344} \approx 10.40\ kg$$

Airbus A330-300:

Fuel burn rate as given by Park (2014): 0.0423 kg/S-NM (seat nautical mile)

$$0.0423\ kg = 1\ NM$$

$$0.0423\ kg = 1.852\ km$$

$$0.0228\ kg = 1\ km$$

$$2.28\ kg = 100\ km$$

$$\frac{2.28\ kg}{0.8} \approx 2.86\ l$$

This assumes a configuration of 284 seats. Lufthansa's models seat 221 passengers. The adjustment for this looks as follows:

$$2.86\ l \times 284 = 812.24\ l$$

$$\frac{812.24\ l}{221} \approx 3.67\ l$$

Emissions:

$$2.28\ kg \times 3.15 \approx 7.18\ kg$$

$$7.18\ kg \times 284 \approx 2{,}039.12\ kg$$

$$\frac{2{,}039.12\ kg}{221} \approx 9.23\ kg$$