Towards more sustainability? – The development of aviation emissions from Germany between 1995 and 2016

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Abstract
Aviation is considered to be one of the major contributors to climate change. While aviation's emissions currently account only for about 2.0% to 2.5% of total anthropogenic carbon dioxide emissions and about 12% of carbon dioxide emissions from transportation, its share is expected to grow further due to long-term demand growth. Aviation is currently almost fully dependent on petroleum-based fuels and technological improvements are unable to offset demand growth. We use activity data from the German air transport statistics and an emissions calculation tool based on emissions profiles generated with EUROCONTROL's Base of Aircraft Data (BADA) and commercial flight performance tool PIANO-X in order to analyze the development of carbon dioxide emissions from flights departing at German airports in a time series from 1995 to 2016. For the calculation of emissions and subsequent indicators, actual payload data is being used; hence it is possible to derive not only indicators on the development of absolute emissions, but also on specific transport-performance related developments. We find that Germany's aviation emissions have increased by more than 60% from 1995 to 2016 (16.9 Mt to 27.3 Mt CO_2). However, specific emissions per ton kilometer have declined by almost 30% in the same timeframe. We find that the improvement in specific fuel consumption in the long run is about 1.6% annually, which is less than the current "aspirational goal" of 2% per year agreed upon at ICAO for global aviation.

Keywords: aviation; emissions inventory; climate change

Classification: Aviation and the Environment, Air Transport Policy and Regulation, Air Transport Demand

1. Introduction

Air transport is considered to be the most energy intensive transport mode and to be one of the major contributors to climate change. Aviation's emissions currently account for about 2.0% to 2.5% of total anthropogenic carbon dioxide emissions and about 12% of carbon dioxide emissions from transportation (Lee et al., 2009). Multiple sources assert that aviation is the mode with highest CO_2 emissions measured by passenger kilometer. For instance, data of the European Environmental Agency (EEA, 2017) finds for Europe in 2014 that aviation emitted 244 g CO_2 per passenger kilometer, while road transport emitted on average 102 g and rail only 28 g CO_2. Unlike other modes, aviation continues to be heavily reliant on petroleum-based fuels for the time being. Although several efforts are undertaken to use synthetic fuels from renewable feedstock in aviation, it is questionable whether the amount of energy needed in aviation can be provided using alternative sources in the short run (Staples et al., 2018). Among the most promising routes to generate drop-in fuels for aviation are power-to-liquid processes, where surplus electricity from renewable sources is used. However, large-scale, affordable generation capacities are still probably years, if not decades, away.

In aviation, the switch to alternative energy sources is far more complex than in ground transport due to the amount of investments needed, development lead times and path dependencies involved. In road and rail transport alternative energy sources based on direct (with means of batteries) or indirect (with means of hydrogen-based fuel cells) electricity have a growing market share which help reducing emissions. In contrast, in aviation still conventional aircraft with conventional fuel use are under development and in production. Peeters et al. (2016) call many of the innovative technological concepts for solving the aviation emissions reduction challenge "technology myths", as their realization is far from being certain or even realistic. The authors even regard the visions of industry stakeholders even as counterproductive for the introduction of effective climate protection measures in aviation.

The relatively slow technological progress, in combination with growing aviation demand, is likely to increase carbon dioxide emissions from aviation for the foreseeable future. Particularly in the emerging economies aviation demand is expected to grow further at high growth rates. For instance, Airbus in its global market forecast expects annual growth rates in the Asia-Pacific region up to the year 2036 of 5.6 % per year (Airbus, 2017). But also in mature economies, Airbus expects the demand growth to be in the order of 2.4% (North America) to 3.4% (Europe).

Technological improvements implemented e.g. through new aircraft types, more efficient air traffic control or improved operational procedures result in an improvement of specific emissions of 1.2-1.4 % per year (Schaefer, 2012, Peeters et al. 2016). Efficiency improvements are significantly lower than the expected demand growth presented above. Hence absolute carbon dioxide emissions are expected to grow further for the time being.

In this paper, we analyze the historical development of aviation emissions in Germany based on traffic data provided by the German Statistical Office in the timeframe 1995 to 2016. Unlike other emissions quantification studies, the basis for our analysis are actual flights (and not flight schedules), including actual payload data based on monthly and yearly averages, as reported by the official statistics. With this approach, the paper contributes to the set of literature estimating aviation fuel consumption and emissions (e.g. Wilkerson et al., 2010, Van Pham, 2010 and Schaefer, 2012)

The main questions that drive this study are the following:

- What was the general development of carbon dioxide emissions of aviation originating in Germany over the past two decades?
- Are the results for specific emissions per ton- or passenger kilometer of traffic originating in Germany comparable with the results of other studies?
- Is it possible to verify the claims of aviation industry stakeholders concerning the improvement of specific emissions?
- How do our model results compare to official statistics on fuel sales and the national emissions inventories required by the UNFCCC?

2. Input Data and Modelling Methods

The modelling approach taken by the authors contains various elements, which are described in this chapter.

In a first step, input data coming from the official air transport statistics is processed. The statistical data offers a very detailed coverage of aviation, substantially surpassing the coverage of flight schedules used in similar studies.

Air transport in Germany is subject to extensive reporting requirements as specified by the transport statistics law (Verkehrsstatistikgesetz, VerkStatG). All airports with a traffic volume of more than 150,000 work load units (WLU) in the previous year are required to report traffic to the Federal Statistical Office of Germany. One WLU is defined as one passenger or 100 kg of freight or mail. As of 2017, 24 airports in Germany are required to officially report traffic. The reporting requirements are relatively detailed, as the following data is submitted per airport pair on a monthly basis:

- Type of flight (cargo/passenger, scheduled/charter)
- Seats offered
- Number of passengers carried
- Freight and mail in kg carried
- Number of flights per aircraft type and variant

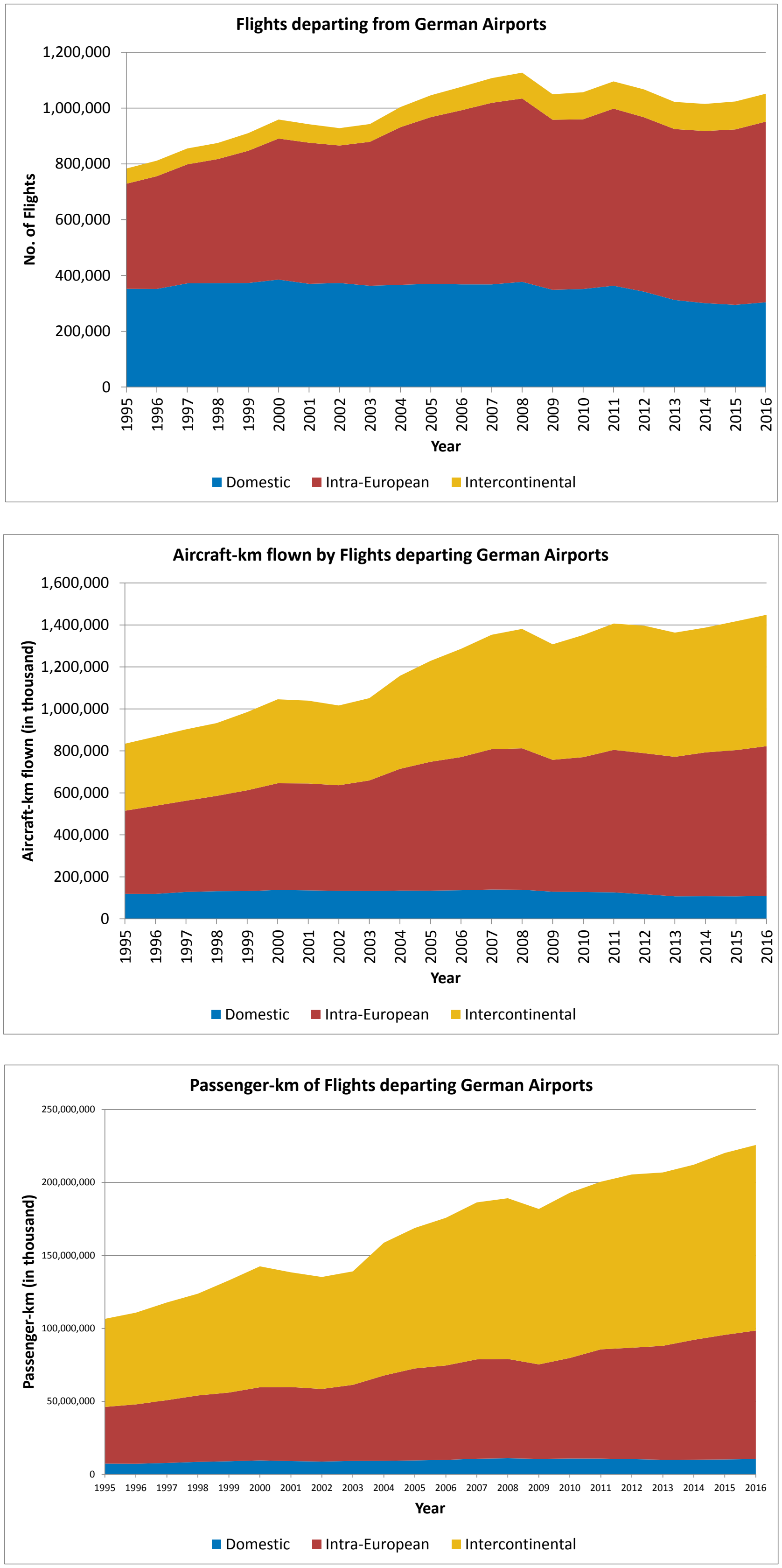

Figure 1: Flights, Aircraft-km and Passenger-km 1995-2016

For the modelling of emissions, this level of detail of flight activity is superior to flight schedules, as all flights that have actually been performed are covered, including charter, cargo and business aviation. These sectors of aviation are otherwise difficult to cover. Moreover, the monthly averages of passenger, freight and mail payload allow a detailed calculation of emissions and allow also the calculation of indicators combining transport and emissions data, such as emissions per ton-kilometer transported.

For our model, flight data from 1995 to 2016 is prepared so that for each year, each airport pair and each aircraft type/variant the number of flights, seats offered and passengers/cargo carried are listed in a database. The summarized results for all departing flights are shown in the following figure.

The number of flights departing from German airports has exceeded one million for the first time in 2004 and peaked in 2008. Since then, it has more or less remained on the same level, with only a slight growth trend since 2014. The number of aircraft kilometers flown has constantly grown, reaching a peak in 2016. The same applies to passenger kilometers. From this data it can be shown that average aircraft size has increased from 167 seats in 1995 to 194 seats in 2016. Also, passengers travel over longer distances: In 1995, the average distance flown per passenger was 1,906 km. This value has increased to 2,009 km in 2016. Over the 22 years of data analyzed for this paper, the database contains 22.7 million flights with a total distance of 26.1 billion aircraft kilometers flown.

In a second step, the flight activity data is combined with an emissions calculation tool based on emissions profiles generated with EUROCONTROL's Base of Aircraft Data (BADA) and commercial flight performance tool PIANO-X. For 109 different aircraft types, emissions profiles have been generated, representing a set of standardized combinations of payloads and mission distances. Distances and payloads of actual flight missions falling in between the standardized combinations of distances and payload are interpolated in order to derive emissions. All emissions profiles contain data on fuel consumption, which is linearly correlated with CO_2 emissions[1] and NO_x emissions (Schaefer et al. 2013). For the purpose of this study, the authors have analyzed the output concerning carbon dioxide only, as CO_2 is a major contributor to aviation-induced climate change.

The distribution (emission inventory) of emissions around the globe (with an additional time coordinate) is stored in a MySQL database using software named 4D-Race (4-Dimensional Distribution of Aircraft Emissions), which has been developed at the DLR Institute of Air Transport and Airport Research. To facilitate specific investigations, emission inventories can be determined for certain regions, periods, aircraft or engine types. 4D-Race also allows the temporal and spatial resolution of an emission inventory to easily be adapted. In the technical implementation of 4D-Race, a modular and expandable design was of particular importance to

[1] Jet fuel has very narrow specifications concerning energy and carbon content. Hence a uniform emissions factor can be applied for fuel globally. An emissions factor of 3.15 kg CO_2 per kg fuel is applied by EEA, 2017.

ensure that it would be possible to respond to future requirements for climate modelling, new aircraft designs or flight procedures.

3. Results

We find that Germany's CO_2 emissions from aviation have increased by more than 60% from 16.9 Mt in 1995 to 27.3 Mt in 2016 (Figure 2). The development varies in the different geographical areas: CO_2 emissions from domestic flights have declined by 1.6% (1.83 Mt to 1.8 Mt, CAGR -0.08%), emissions of flights to European destinations have increased by 68.1% (5.32 Mt to 8.95 Mt, CAGR 2.50%) and emissions of intercontinental flights have increased by 69.4% (9.76 Mt to 16.54 Mt, CAGR 2.51%).

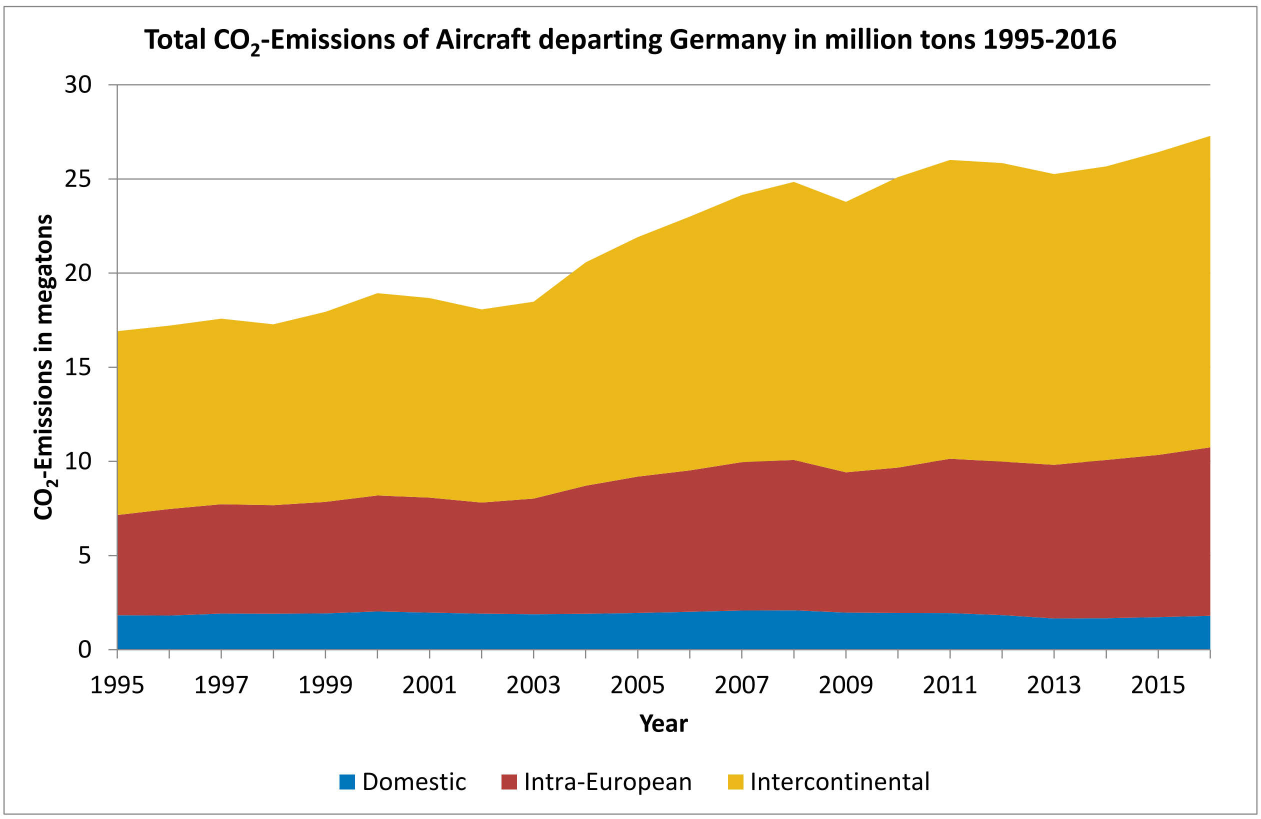

Figure 2: Development of absolute carbon dioxide emissions, 1995-2016.

A key indicator for the assessment of the environmental efficiency of transport is specific emissions per revenue ton kilometer. As our analysis includes both passenger and cargo transport and in many cases in commercial aviation both passengers and cargo are transported, we show the indicator based on revenue ton kilometers, whereas a passenger is converted into 100kg, analogously to the WLU calculation in German transport statistics.

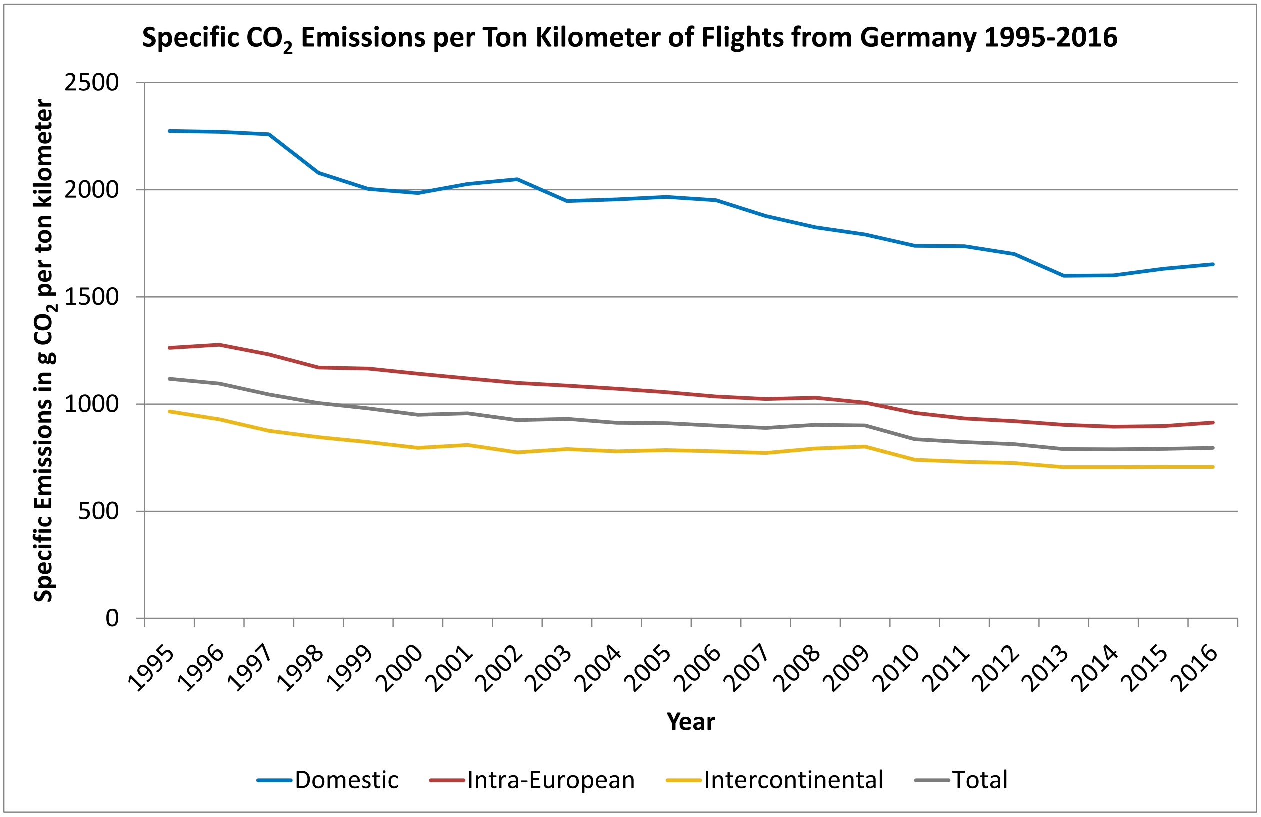

Figure 3: Development of specific carbon dioxide emissions, 1995-2016.

Specific emissions per ton kilometer have declined across the board by almost 30% between 1995 and 2016 (Figure 3). In terms of specific emissions, domestic air transport shows the worst performance with 1653g CO_2 per ton kilometer in 2016. Specific emissions of passengers and cargo transported within Europe amounts to 914g CO_2 per ton kilometer in 2016, while on intercontinental flights, specific emissions are at 706g CO_2 per ton kilometer. The relatively high values for domestic flights can be explained by lower load factors and that the energy-intensive take-off and climb phase is distributed over a shorter flight distance. Moreover, domestically, cargo is rarely transported in larger quantities by air, further worsening this indicator.

An insight into the decoupling of air transport performance from CO_2 emissions is shown in the following figure, where all relevant values are indexed to a value of 100 in the year 1995. While transport performance measured in ton kilometers has more than doubled, CO_2 emissions have increased a little more than 50%. Specific CO_2 emissions have been reduced by almost 30%.

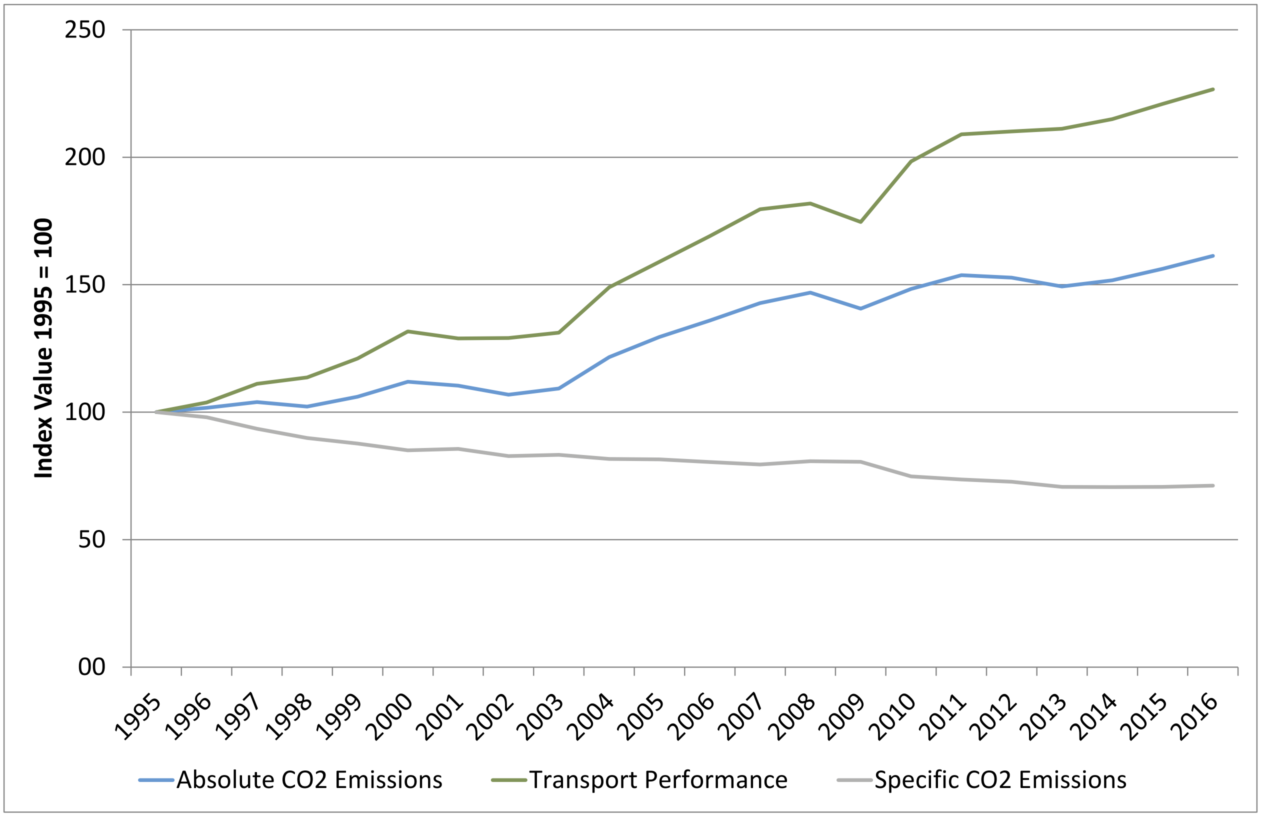

Figure 3: Development of indicators indexed to 100 for 1995

4. Discussion

The modelling results presented herein are comparable to the results presented in other studies. Germany has reported in its official submission under the United Nations Framework Convention on Climate Change (UNFCCC) by the Federal Environmental Agency (Umweltbundesamt, UBA) in its national inventory report 2017 a total of slightly less than 25 Mt CO_2 from international bunker fuels consumed on flights departing German airports in 2016 (Umweltbundesamt, 2017). Our own model results in 24.7 Mt CO_2. The share of aviation fuel consumption on international flights is reported by the Federal Environmental Agency to be 91.8%. Our model results in slightly higher figures at 93.4%. The difference can be explained as the UBA, or their contractors, respectively, have undertaken some effort to include further flights not contained in official air transport statistics, e.g. from general aviation flying at small airfields (IFEU, 2016), which do not appear in the official air transport statistics. Hence, we can verify the accuracy of the modelling conducted by the UBA.

However, we cannot confirm the relatively high value for emissions from aviation per passenger kilometer reported by the European Environmental Agency with 244g CO_2 per passenger kilometer for intra-European traffic. When we convert our ton-kilometer figure to passenger kilometers using the typically applied weight for a passenger including baggage of 100kg, we end up at only 98.7g CO_2 per passenger kilometer in 2016 for a combination of domestic and intra-European air transport. If intercontinental traffic is included, the value declines to 79.5g CO_2 per passenger kilometer. The German Aviation Association (Bundesverband der Luftverkehrswirtschaft, BDL), claims in its annual climate protection report (BDL, 2017) for its (German) member airlines a value of 91.7g CO_2 per passenger kilometer. This value seems to be plausible, when energy-efficient foreign long-haul airlines are excluded from our value of 79.5g CO_2 per passenger kilometer for total traffic departing from German airports. In any case, the exact calculation of emissions attributable to passenger transport is difficult to achieve, as many flights, particularly on the long-haul, transport both passengers and cargo at the same time. Moreover, when looking at payload expressed as weight, flights transporting cargo only are at an advantage. The payload of dedicated cargo flights can be much higher than with a passenger flight as a payload of cargo can be packed much more densely than a payload of passengers – although one might have a different subjective impression as a low-cost passenger nowadays.

Our study finds that the improvement in specific fuel consumption in the long run is about 1.6% annually, which is somewhat less than the current “aspirational goal” of 2% per year agreed upon at ICAO.[2] This shows that the goal is highly ambitious, but not totally unrealistic to be reached. Starting from the middle of the 2010s, new aircraft types like the Boeing 737 Max, Airbus A320neo, Boeing 787 and Airbus A350 are being introduced into the fleet, which feature an improvement in specific CO_2 emissions per revenue ton kilometer in the order of 15% over their predecessors. A wider introduction into the fleet of these types should main the trend of continuous emissions reduction for the time being.

5. Conclusions

In this paper, a model for emissions calculation based on actual flight statistics including information on payload is presented, which features a high level of accuracy in air transport emissions modelling. Several indicators have been calculated, showing the long-term environmental performance of flights from German airports.

It could be shown that a decoupling of aviation transport performance and CO_2 emissions has taken place for at least the last two decades. Specific emissions have declined, but total emissions have increased substantially. Hence, if aviation stakeholders would like to contribute in a meaningful way to sustainability and the attenuation of climate change, other measures need to support the replacement of aircraft and more efficient air traffic management. Given the persistently high demand growth, economic measures like the EU emission trading scheme or

[2] Other studies, such as Schaefer, 2012 find reductions in specific emissions on a global level to be at 1.86% (2000-2010) and 0.93% (2010-2020) or

ICAO's CORSIA seem to be effective to at least offset the carbon dioxide emissions of aviation through reductions in other sectors. In the long run, fuels from alternative low carbon or carbon neutral sources may contribute to the ultimate aim of a reduction of absolute carbon dioxide emissions in aviation required to reach a truly sustainable air transport system.

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