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Assessing the fuel burn and CO_2 impacts of the introduction of next generation aircraft: a study of a major European low-cost carrier

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Abstract

The introduction of more fuel-efficient ‘next generation’ aircraft has the potential to yield benefits for fuel burn and CO_2 emissions over current generation aircraft. This has important implications in terms of airline fuel costs and competition, but also for compliance with future environmental legislation and market based incentive schemes. In Europe, major low-cost carriers such Ryanair, easyJet, and Norwegian Air Shuttle have been active in updating their fleet, and they now operate some of the youngest fleets in the industry. Subsequently, the paper assesses the possible fuel burn and CO_2 impacts of the introduction of next generation aircraft by employing OAG data and EUROCONTROL’s ‘Small Emitters Tool’ to determine the annual fuel burn and CO_2 emissions for easyJet, a major European low-cost carrier. Estimations were then made regarding the potential impacts on fuel burn and CO_2 emissions from the introduction of the airline’s next generation of aircraft under three fleet plan scenarios. Analysis indicates that while new aircraft may allow airlines to increase the capacity in their network with only a marginal increase in overall fuel burn and CO_2 emissions, this is unlikely to lead to substantial overall reductions in total fuel burn and emissions, at least in the short term.

Key words:

Aviation, Environment, Low-cost Carriers, CO_2, Fuel Burn

1. Introduction

The environmental impacts of air travel are well known, and the role of low-cost air travel in particular has come under public and political scrutiny in recent times (Lee et al. 2009). While the growth of low-cost air travel in many regions of the world has yielded considerable economic and social benefits, this has come at the price of increased levels of emissions from aircraft and population exposure to noise. As Nilsson (2009, p126) concludes, *"from a global, environmental perspective the development of low-cost aviation is nothing less than disastrous."* Thus there remains considerable debate regarding the seemingly incompatible nature of environmental sustainability on the one hand, and the low-cost business model and growth in air travel on the other hand (see Graham and Shaw, 2008). As well as stimulating increased demand, low-cost operations have traditionally been seen as particularly environmentally damaging due to their short-haul nature. During a flight proportionally more fuel is burnt during the take-off and ascent phase than when the aircraft is at its cruising altitude (Doganis, 2002).

In Europe, low-cost carriers now operate some of the youngest fleets of aircraft in the industry[1] and have been quick to embrace new aircraft technologies, since the economics of new aircraft generations contribute to keep costs down and achieve better density economies (Tembleque-Vilalta and Suau-Sanchez, 2015; Bowen, 2010)[2]. This has potentially important implications in terms of fuel burn and emissions, as well as compliance with environmental regulation such as the EU-ETS.

The following section addresses the changing nature of the low-cost business model in more detail. This is followed by a discussion of the regulatory and policy implications in the context of increased environmental legislation and market based incentive measures. This section is in turn followed by an outline of the research methodology and choice of study airline, before the results of the analysis are presented. In light of these findings, a discussion is provided at the end of the paper along with an outline of the various management implications that arise from the analysis.

The nature of the low-cost business model: focus on reducing costs

A growing body of research attests to the changing nature of the low-cost business model, low-cost business practices, and their networks (for example, see Mason and Morrison, 2009; Klophaus et al. 2012; Dobruszkes, 2013, Daft and Albers, 2015, and Fageda et al. 2015). One important aspect of this includes the increasing focus on

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[1] This has not always been true. As highlighted by Chapman (2007), 10 to 15 years ago these LCC fleets were commonly dominated by older, less fuel efficient aircraft.

[2] Density economies are considered unequivocal in the airline industry (Caves et al., 1984). Density economies imply the decrease in the average costs from increasing traffic at the route level. This usually comes from using bigger aircraft (that are more cost efficient) at higher load factors. Density economies can also be achieved by improving aircraft technology.

reducing operating costs and, therefore, the adoption of newer, more fuel-efficient aircraft and the replacement of older, more polluting aircraft.

Table 1 shows a comparison of the average fleet age of the five largest European low-cost carriers with the five largest European full-service network carriers (in terms of scheduled passengers handled). With the exception of Turkish Airlines, it can be seen that the average fleet age of the low-cost carriers is significantly younger than their full-service network counterparts.[3] As of 2016, Ryanair, the largest low-cost carrier in Europe, operate a fleet of 328 latest generation B737-800 aircraft, with an average fleet age of 6.7 years. The airline has a further 183 of these aircraft on order up to 2020, and has options for purchasing 100 further next generation B737 MAX 200 aircraft (Ryanair, 2016). The aircraft manufacturer claims that the reduced weight of the new airframe, the improved aerodynamics and new engine design will result in an 8% fuel saving in comparison with similar narrow body aircraft (Boeing, 2016). Improved aerodynamic efficiency in particular is one area where fuel savings can be made. For example, it is estimated by the manufacturer that the new 737 MAX AT winglets, fitted at the end of the aircraft's wing to reduce drag, will reduce fuel consumption by 1.8% compared with winglets fitted to the current breed of aircraft (Boeing, 2016).

Similarly, Europe's second largest low-cost carrier, easyJet, operates a relatively young fleet of Airbus A319 and A320 aircraft with an average age of 6.2 years. The airline has 130 new A320neo (new engine option) aircraft on order and 56 'normal'

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[3] Note that the younger average fleet age of Turkish Airlines is linked to the transformations and significant network growth undertaken by the airline. See, for example, Dursun et al., 2014.

A320 aircraft (also called A320ceo, or ‘current engine option’). These are due for delivery between 2017 and 2022 (easyJet, 2015). The aircraft manufacturer claims that the new aircraft will be 13% to 15% more fuel-efficient than the previous generation of aircraft (Airbus, 2016).

Table 1. Average fleet age comparison between major European low-cost carriers and full-service network carriers

	Airline	**Scheduled passengers 2014 (thousands)***	**Fleet size****	**Average fleet age (years)****
Low-cost carriers	Ryanair	86,370	328	5.5
	easyJet	62,309	241	6.2
	Air Berlin	29,911	132	7.6
	Norwegian Air Shuttle ^	24,260	64	3.6
	Vueling ^	20,703	102	6.7
Full-service network carriers	Lufthansa	59,850	264	11.2
	Turkish Airlines	53,384	267	6.6
	Air France	45,406	225	11.7
	British Airways	41,164	266	12.7
	KLM	27,740	115	11.1

*Source: IATA, 2015

** correct as of February 2016, source: company websites

^ Air Berlin, Norwegian Air Shuttle and Vueling are often considered as representing a ‘hybrid’ business model as opposed to a ‘pure’ low-cost one. However, they are included here as they exhibit greater similarity to low-cost carriers in a number of key business areas (see Klophaus et al. 2012 and Fageda et al. 2015).

The improved range and fuel efficiency of some new narrow body aircraft, such as the B787 Dreamliner, are also making long haul operations economically feasible for low-cost carriers (De Poret et al., 2015). Traditionally, low-cost operators have found it difficult to sustain profitable long-haul operations as the key aspects of their low-cost model, i.e. a 'no-frills' service, single class seating, no cargo, and high aircraft utilization, were generally ill suited to long-haul services (Francis et al. 2007, Morrell, 2009). Currently, both Air Berlin and Norwegian Air Shuttle serve long-haul transatlantic routes between Europe and North America using new Airbus A330-200 and Boeing 787 Dreamliner aircraft, respectively.

Environmental and regulatory implications

In addition to opening up new low-cost markets, the introduction of next generation aircraft may have important implications in terms of emissions and fuel burn. In 2015 the International Council on Clean Transportation published a report detailing the fuel efficiency of the top 20 airlines operating non-stop transatlantic passenger services between the US, Canada and Europe (ICCT, 2015). Using data relating to each carrier's top transatlantic city pair (in terms available seat kilometres), fuel efficiency was calculated for each carrier in terms of passenger kilometres per litre of fuel burn. The two airlines with the highest fuel efficiency were found to be Norwegian Air Shuttle (40 pax km/l) and AirBerlin (35 pax km/l). In contrast, the least fuel-efficient airlines were found to be Lufthansa (28 pax-km/l), SAS (28 pax-km/l) and British Airways (27 pax-km/l). While high fuel efficiency for Norwegian Air Shuttle was largely attributed to its young fleet, in the case of Air Berlin the high seat density and low levels of premium business class seating were also major contributing factors. Environmental efficiency advantages should also be felt for low-cost carriers operating short and medium haul routes.

This may have important implications for airlines not just in terms of fuel cost savings, but also in terms of future compliance with environmental regulation or market-based measures. For example, the International Civil Aviation Organisation (ICAO) already enforces stringent certification standards for aircraft in relation to noise before aircraft are allowed to operate. In February 2016, ICAO's Committee on Environmental Protection (CAEP) also established for the first time a standard for aircraft CO_2 emissions (ICAO, 2016). Under the recommendations, the CO_2 emissions standard would apply to new aircraft designs as of 2020, as well as deliveries of current in-production aircraft models by 2023. CAEP has also recommended that production aircraft that do not meet the new standards should be phased out by 2028.

While aviation is unusual in that the fuel used for international air travel is exempt from taxation, and only a small number of countries impose taxes on fuel for domestic use, various frameworks are in place for incentivizing emissions reductions for airlines. Most notably, in 2012 it was decided by the European Parliament that aviation would join the European Union Emissions Trading Scheme (EU-ETS) as part of the second phase of the programme (European Commission, 2013). Under the scheme, airlines would be free to buy and sell carbon 'permits' between operators depending on whether they were operating an emissions surplus or shortfall. While there remains a delay for full ratification of the EU-ETS for flights outside of the EU, the commencement of the full EU-ETS in the future remains a distinct possibility[4]. In this case airlines with lower emissions profiles will likely be at a significant advantage to their competitors.

The paper seeks to build on existing literature concerning aviation and the environment and the changing nature of the low-cost business model by quantifying the annual fuel burn and CO_2 emissions of easyJet, a major European low-cost carrier, and following this assessing the potential fuel and CO_2 impacts of the introduction of their new 'next generation' aircraft. The following section describes the method employed and the choice of study airline.

Method and Study Airline

It was decided at an early stage that analysis should focus on a single carrier rather than attempt to compare the experiences of a number of different carriers, given that there is often significant variation between them in terms of their specific network configuration, fleet size and cabin configuration. Subsequently, easyJet were selected as the airline on which to base the study. In terms of annual passengers carried, easyJet are the second largest low-cost carrier in Europe, and the 8th largest carrier worldwide (IATA, 2015). In 2015 the airline carried over 60 million passengers, and operated 735 routes between 136 airports across Europe and North Africa (IATA 2015; easyJet, 2015). As of February 2016, the airline operated a fleet of

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[4] Besides the EU-ETS, some European governments have proactively imposed taxes on aviation emissions. For example, since May 2016, the Government of Catalonia enforces a tax on NOx emissions for commercial aviation (Act 12/2014).

148 Airbus A319 and 93 Airbus A320 aircraft. The airline has 130 new A320neo aircraft currently on order plus 56 'normal' A320 aircraft which are scheduled for delivery from 2017 onwards.

A two-stage process was then conducted to calculate the airline's fuel burn and CO_2 emissions profile. This was done so as to act as the 'baseline' from which the estimations of future fuel burn and emissions could be made, although this stage of the analysis also provided valuable insights in its own right. Initially, data relating to easyJet's flight schedule for 2015 was collated using online OAG (Official Airline Guide) data (OAG, 2016). Extracted information included the date of operation for each flight, the flight number, the origin and destination airport (designated by its three letter IATA code), the sector length (which was subsequently converted from kilometres to nautical miles for the modelling stage), sector time, and the type of aircraft used for each flight. It was also possible to calculate the value of Available Seat Kilometres (ASK) to indicate the airlines total capacity across their network. This was calculated by multiplying the number of available seats by the total distance (km) for each individual sector and then aggregating this across the entire network.

This information was subsequently collated into a spreadsheet, and used to calculate the fuel burn and emissions generated from each flight using the 'Small Emitters Tool', a freely available Microsoft Excel based online model provided by EUROCONTROL, the European Non-Governmental Organisation responsible for the Safety of Air Navigation. The tool estimates total CO_2 emissions (kg) and fuel burn (kg) for a given flight based on the type of aircraft used and the distance flown.

The level of fuel burn is estimated using official ICAO statistics for all aircraft weighing over 57,000 kg. This figure is then converted to CO_2 emissions (kg) by applying a conversion factor of 3.15 for jet and turboprop aircraft, and 3.10 for piston aircraft.

It should be noted here that the sole focus on CO_2 emissions in the analysis does not in any way ignore the significant contribution of other harmful pollutants such as nitrous oxides, aerosols or water vapour (Lee et al. 2009). However, at present the Small Emitters Tool only calculates CO_2 emission outputs and not the full range of other pollutants. As noted by Lee et al. (2009), among others, CO_2 typically represents the largest share of net radiative forcing from aircraft emissions and, unlike some other pollutants, has a broadly similar impact regardless of the location or altitude at which it is emitted. For this reason, CO_2 was considered a suitable focus for the analysis, while acknowledging that it does not alone fully account for the environmental impacts of aircraft.

An example of the model outputs is shown in Figure 1, with a number of different aircraft types shown for illustrative purposes. Official ICAO aircraft type designators were used to define the type of aircraft used. For example, a ‘B732’ (see row 3) designates a Boeing 737-200 aircraft. The Airbus A319 and A320 (i.e. the aircraft used in the analysis) are designated as ‘A319’ and ‘A320’, respectively[5].

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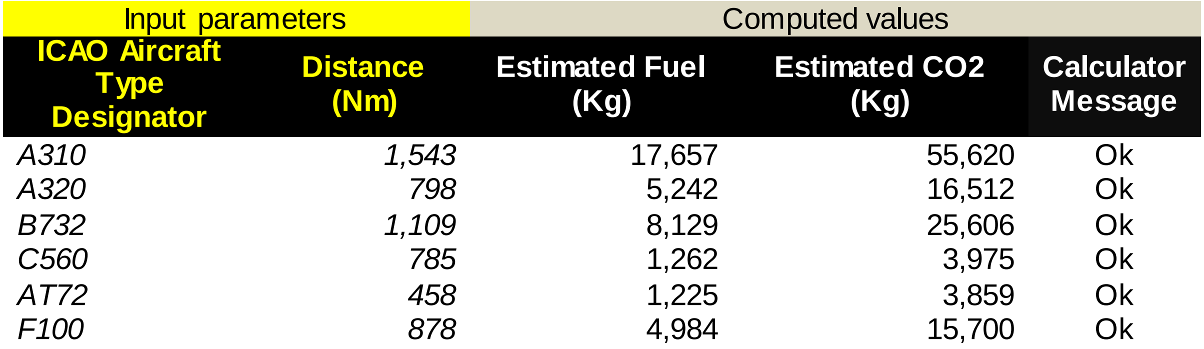
[5] The airline plans to adopt a 186 seat configuration for their A320neo aircraft once they are in service, and intend to progressively convert their existing A320 fleet from the current 180 seat configuration to 186 seats from 2016 (easyJet 2015). However, as the parameters for the Small Emitters Tool are



Input parameters		Computed values		
ICAO Aircraft Type Designator	Distance (Nm)	Estimated Fuel (Kg)	Estimated CO2 (Kg)	Calculator Message
A310	*1,543*	17,657	55,620	Ok
A320	*798*	5,242	16,512	Ok
B732	*1,109*	8,129	25,606	Ok
C560	*785*	1,262	3,975	Ok
AT72	*458*	1,225	3,859	Ok
F100	*878*	4,984	15,700	Ok

Figure 1. Example model input parameters and outputs from 'Small Emitters Tool'

Source: EUROCONTROL, 2016

By applying the information regarding sector length and aircraft type into the model, it was possible to calculate the annual fuel burn and CO_2 emissions profile of the airline. However, it should be noted that the model does not take into account variables such as load factors, total aircraft payload, or seat configuration, nor does it allow for disaggregation of emissions and fuel burn for different stages of the flight.

It is also important to note that sector distances, as used here, refer to the great circle distance (GCD) between the origin and destination airport in question, as recorded by OAG (OAG, 2016). This reflects the shortest distance between two points on a sphere, or in this case the shortest distance between two airports on the face of the earth. However, in reality this does not account for the 'true' distance of

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pre-set at 180 seats for the A320, and it is not clear at what rate the current A320 aircraft will be converted, for the purpose of the analysis a 180 seat configuration for both aircraft is assumed, whilst fully acknowledging this limitation.

any particular flight, given that a number of factors such as weather conditions or 'stacking' may cause an aircraft to deviate from the GCD and thus fly further and burn more fuel.

To try and reconcile this issue, an additional distance can be applied retrospectively to account for the likely deviation of each flight from the GCD. For example, EUROCONTROL recommend adding an additional 95km (or 51.3 nautical miles) to each flight (EUROCONTROL, 2016). However, this in itself can incur sources of error given that it cannot account for variations in weather conditions (which may have a strong regional and temporal dimension) or the airport in question (busier, congested airports are generally more likely to require aircraft to stack). Inevitably it also disproportionally impacts shorter sectors, which typically form the basis of LCC networks. For this reason, calculations in the analysis are based on the GCD distance only, although it is acknowledged that in reality the 'true' distance flown, and by association the fuel and CO_2 emissions, will likely be higher.

In the second stage of the analysis, the fuel burn and emissions profile were applied to three future fleet plan scenarios up to 2019. This was done to assess the likely fuel and CO_2 implications of the introduction of the airlines new A320neo aircraft. This involved making a number of assumptions based on the airlines published fleet plan and findings from the first stage of the analysis. The process for how this was conducted is explained in more detail in the following section.

3. Results

Results of the analysis are presented in two stages. Initially, the current fuel burn and CO_2 emissions profile are presented. This is followed by estimations of future fuel burn and CO_2 emissions profile up to 2019.

Current fuel burn and CO_2 emissions profile

Descriptive statistics summarising easyJet's 2015 operations are provided in Table 2. As shown, the airline operated a total of 466,226 flights in 2015, with a fleet of 241 aircraft. The average sector length was slightly less than 600 nautical miles (roughly the equivalent of flying from London to Barcelona), with a corresponding average sector time of just over 2 hours. There was significant variation between the routes flown, with the longest recorded sector being the route to/from Manchester in the UK, and Sharm-el-Sheikh in Egypt (2216.5 nm, 6:10 minutes sector time). In contrast, the shortest sector was 77.2 nm to/from the Isle of Man and Liverpool, UK. In terms of total network capacity this equated to nearly 83 billion ASK, resulting in 1.86 billion kg of fuel burnt at an average of nearly 4,000kg of fuel per flight. In terms of CO_2 emissions, this equated to 5.87 billion kg of CO_2 over the course of 2015, at an average of 12,596.3 kg per flight or 21.3kg per nautical mile flown . Across the network 70.8g of CO_2 were emitted per ASK.

Table 2. Descriptive statistics, easyJet flight operations 2015.

Variable	Value
Flights	466,226
Fleet size	241
Total sector distance (nm)	268.846,754.3
Average sector time (hours)	2:02
Average sector distance (nm)	591.3
Longest sector distance (nm)	2216.5, Sharm-el-Sheikh – Manchester
Shortest sector distance (nm)	77.2, Isle of Mann - Liverpool
ASK (total)	82,857,451,364
Total Fuel Burn (kg)	1,863,503,656
Average Fuel Burn per flight (kg)	3,998.8
Total CO_2 emissions (kg)	5,870,050,742
Average CO_2 per flight (kg)	12,596.3
CO_2 per nautical mile flown (kg per nm)	21.3
CO_2 per ASK (grams per ASK)	70.8

It is also important to examine variations between the different aircraft within the fleet. Table 3 provides a breakdown of how the different aircraft in the fleet varied in terms of their operational characteristics, fuel burn and CO_2 emissions.

Table 3. Operational, fuel burn and CO_2 statistics by aircraft type, easyJet 2015

Aircraft type	**Seats per flight**	**Flights (% total)**	**Average sector time (hours)**	**Average sector distance (nm)**	**Total ASK (mil) (% of total)**	**Average fuel burn per flight (kg) (% total)**	**Average CO_2 per flight (kg) (% total)**	**CO_2/nm (kg)**
A319	156	303,412 (65.1%)	1:53	525.4	44,090.8 (53.2%)	3,577.7 (58.3%)	11,269.8 (58.3%)	21.4
A320	180	162,448 (34.8%)	2:19	712.8	38,602.3 (46.6%)	4,772.2 (41.6%)	15,032.4 (41.6%)	21.1
B757-200	202	369 (0.1%)	3:20	1193.7	164.3 (0.2%)	6,880.6 (0.1%)	21,674.2 (0.1%)	18.2

As shown, the Airbus A319 aircraft (156 seat configuration) accounted for the majority of the airline's flight operations in 2015 (65.1%). In comparison, the slightly larger A320 aircraft (180 seat configuration) represented 34.8% of flight operations. The A319s were generally employed on shorter sectors (525.4 nm) than the larger A320s (712.8 nm). This was reflected in the fuel burn and emissions calculations accordingly, with a higher average fuel burn and levels of CO_2 per flight for the A320 fleet (4,772.2kg and 15,032.4g CO_2) than the A319 fleet (3,577.7kg and 11,269.8kg CO_2). In terms of contribution to overall capacity, the A319 fleet accounted for 53.2% of total ASK (44,090.8 million ASK), while the A320 fleet accounted for 46.6% of total ASK (38,602.3 million ASK). Regarding the relative contribution of each aircraft type to the total fuel burn and CO_2 emissions profile, it can be seen that the contribution of the A319s (58.3%) was proportionally less than the A320s (41.6%). This is likely a reflection of the shorter average sector time of the A319 aircraft.

The data also revealed a small number of flights (369) operated by larger Boeing 757-200 aircraft (202 seats). These aircraft are not owned by the airline, but were leased on a short term basis during the months of July, August and September to serve the routes to/from London Gatwick, Alicante and Tenerife (as reflected by the relatively long average sector time for this aircraft of 3:20). While notable in that the average fuel burn (6880.6 kg) and CO_2 emissions (21,674.2 kg) for these flights were considerably higher than other operations, their overall contribution to fuel burn (0.1%), emissions (0.1%), and ASK (0.2%) was minimal.

The airline is in the process of growing and renewing its fleet of aircraft, with 130 new Airbus A320neo aircraft on order, and 56 'normal' A320 aircraft (also called A320ceo, or 'current engine option'). The impacts of these changes in term of annual fuel burn and CO_2 emissions of these new aircraft are examined in the following section.

Estimating future fuel burn and CO_2 emissions profile

Having established the current fuel burn and CO_2 emissions profile, information from the airline's annual reports were used to determine the airline's future fleet plan. This was done so as to form the basis upon which the future fuel burn and CO_2 emissions calculations could be made. In particular, it was necessary to determine how many (and when) the A320neo aircraft would be in operation, given that these aircraft are estimated to be 13-15% more fuel efficient per flight than the current generation of the aircraft.

Initially, it was necessary to determine the future size of the fleet. In their annual report, the airline outline three possible scenarios for their future fleet between 2015 and 2019 (see Table 4). These scenarios range from a growth of 241 to 316 aircraft (Maximum Fleet), to a decline of 241 to 204 aircraft by 2019 (Minimum Fleet). The 'Base Case' represents the projected 'most likely' scenario based on the current economic and market conditions, showing a growth of 241 aircraft in 2015 to 304 aircraft in 2019. As can be seen, the only difference between the 'Maximum Fleet' and 'Base Case' are the 12 additional aircraft (316 versus 304) delivered in 2019 under the 'Maximum Fleet' scenario. As the airline claim that the 'Base Case' is their most likely growth scenario, it was chosen as the one on which to base analysis in this paper.

Table 4. easyJet fleet plan scenarios, 2015-2019

Year	2015 (current)	2016	2017	2018	2019
Base Case (aircraft)	241	259	281	296	304
Minimum Fleet (aircraft)	241	250	261	226	204
Maximum Fleet (aircraft)	241	259	281	296	316

Source: easyJet annual report, 2015

Having established the fleet size, it was then necessary to determine the possible fleet composition over the same period. While a schedule for the delivery of new aircraft and the retirement of existing aircraft was not available, it was possible to make an informed estimation of the potential fleet based on past trends and the number of aircraft currently on order. For example, between 2011 and 2015 the number of A319s in the easyJet fleet was reduced by 19 aircraft, from 167 to 148. During the same period, the number of A320 aircraft in the fleet grew from 54 to 93 aircraft. As of November 2015, the airline had confirmed orders for 130 new Airbus A320neo aircraft ('new engine option') and 56 A320 aircraft (also called A320ceo, 'current engine option'). There were no orders for any new A319 aircraft. The delivery of the A320neo aircraft is scheduled to commence from 2017.

Based on this information, and using the fleet 'Base Case' for the total number of aircraft as a starting point (see Table 4), three separate fleet plan scenarios were developed by the authors. These were designed to describe a 'low', 'moderate', and 'high' uptake scenario regarding the introduction of the new Airbus A320neo aircraft up to 2019. These fleet plan scenarios are outlined in Table 5.

Table 5. Fleet plan scenarios

Year		**2015 (current)**	**2016**	**2017**	**2018**	**2019**
Total Aircraft (Base Case)	All	241	259	281	296	304
Scenario 1	A319	148	148	143	138	133
'Low'	A320	93	111	133	148	156
	A320neo	0	0	5	10	15
Scenario 2	A319	148	143	141	138	130
'Moderate'	A320	93	116	130	138	144
	A320neo	0	0	10	20	30
Scenario 3	A319	148	143	133	123	107
'High'	A320	93	116	128	133	137
	A320neo	0	0	20	40	60

Under the ‘Low’ scenario, it was assumed that from 2015-2019 a total of 15 new Airbus A320neo enter service. This would be accompanied by more rapid uptake of the traditional A320 aircraft (rising from 93 to 156) over the same period, and modest retirements of the A319 (falling from 148 to 133). Under the ‘Moderate’ scenario, a total of 30 new A320neo aircraft are delivered by 2019, with moderate growth of the A320 fleet (93 to 144), and a moderate decline of the A319s (148 to 130). In the ‘High’ scenario, a total of 60 new A320neo aircraft are delivered by 2019, accompanied by more modest growth of the A320 fleet (93 to 137) but a rapid decline of the A319 fleet (148 to 107). The leasing of the Boeing 757-200 aircraft, which featured in the 2015 data, was not included in either of the scenarios.

Estimations were then made regarding the number of future flight operations for the three scenarios. For each scenario it was assumed that the increase in fleet size up to 2019 would yield proportional increases in the total number of flight operations. In 2015 each aircraft in the fleet undertook 1,934.5 flights over the course of the year (i.e. 466,226 operations/241 aircraft). For the purpose of the analysis it was therefore assumed that all additional aircraft in the fleet would show the same level of utilization. It was also assumed that the average sector distance for each aircraft type would remain the same over the same time period, and that the new A320neo aircraft would be employed in the same way as the existing A320 aircraft. In other words, it was assumed that the airline’s route network would remain the same up to 2019. While in reality this will fluctuate year to year to some extent, by the same token it was considered unlikely that the airline would make any drastic changes to its network (for example, by commencing long-haul transatlantic operations), at least in the relatively near future.

Based on these assumptions the future fuel burn and CO_2 emissions profile were calculated for each of the 'Low', 'Moderate' and 'High' scenarios. To do this, the projected number of flight operations was multiplied by the average fuel burn and CO_2 emissions per flight for each type of aircraft, as established earlier in the analysis (see Table 4). For the new A320neo aircraft it was assumed that the average fuel burn per flight was 13% lower than for the existing A320s and the new A320ceo aircraft on order, as claimed by the aircraft's manufacturer. It was not possible to use the 'Small Emitter Tool' to directly calculate fuel burn and emissions for the A320neo, as with the 'normal' A320 and A319, as at the time the new A320neo aircraft type was not supported by the model. The results of the analysis are shown in Table 6.

As can be seen, the projected fuel burn and CO_2 emissions are similar across the three scenarios. In 2016, estimations of annual fuel burn range from 2.049 billion kg ('Low' Scenario) to 2.06 billion kg ('Moderate' and 'High' Scenarios), with corresponding estimations for levels of CO_2 emissions (6.45 to 6.49 billion kg CO_2). In both cases, fuel burn and CO_2 emissions are 0.55% higher for the 'Moderate' and 'High' scenarios. After the introduction of the A320neo aircraft in 2017 greater variation is observed in the data, albeit still with a certain degree of similarity between the different scenarios. In 2017 the 'High' scenario shows the highest levels of fuel burn (2.26 billion kg) and CO_2 emissions

		2016 259 aircraft			**2017** 281 aircraft			**2018** 296 aircraft			**2019** 304 aircraft			**Total**	
	Aircraft type	Flights	Fuel Burn (million kg)	CO$_2$ emissions (million kg)	Flights	Fuel Burn (million kg)	CO$_2$ emissions (million kg)	Flights	Fuel Burn (million kg)	CO$_2$ emissions (million kg)	Flights	Fuel Burn (million kg)	CO$_2$ emissions (million kg)	Fuel Burn (million kg)	CO$_2$ emissions (million kg
Scenario 1 'Low'	A319	286098	1023.6	3224.3	276695	989.9	3118.3	266842	954.7	3007.2	257587	921.6	2902.9	3889.8	12252.9
	A320	214949	1025.8	3231.2	257126	1227.1	3865.2	286312	1366.3	4304.0	301695	1439.7	4535.2	5058.9	15935.5
	A320neo	0	0	0	9785	40.6	128.0	19469	80.8	254.6	28817	119.6	376.9	241.0	759.15
	Total	501047	2049.4	6455.5	543606	2257.6	7111.5	572623	2401.9	7565.8	588099	2481.0	7815.0	9189.8	28947.8
Scenario 2 'Moderate'	A319	276578	989.5	3117.0	272890	976.3	3075.4	266842	954.7	3007.2	251706	900.5	2836.7	3821.0	12036.2
	A320	224469	1071.2	3374.3	251690	1201.1	3783.5	266842	1273.4	4011.3	278759	1330.3	4190.4	4876.0	15359.4
	A320neo	0	0	0	19570	81.3	255.9	38938	161.7	509.2	58222	241.7	761.4	484.7	1526.8
	Total	501047	2060.7	6491.3	543606	2258.7	7114.9	572623	2389.8	7527.8	588099	2472.6	7788.5	9181.7	28922.5
Scenario 3 'High'	A319	276578	989.5	3117.0	257126	919.9	2897.7	238211	852.2	2684.6	207011	740.6	2333.0	3502.2	11031.9
	A320	224469	1071.2	3374.3	247884	1183.0	3726.3	257108	1227.0	3865.0	265233	1265.7	3987.1	4746.9	14952.7
	A320neo	0	0	0	38596	160.2	504.8	77304	320.9	1011.0	115855	481.0	1515.2	962.1	3030.6
	Total	501047	2060.7	6491.3	543606	2263.1	7128.8	572623	2400.2	7560.5	588099	2487.4	7835.2	9211.4	29015.8

Table 6. Projected Fuel Burn and CO emissions under 'Low', 'Moderate' and 'High' scenarios, 2016-2019

(7.13 billion kg CO_2). This is likely a function of the rapid replacement of the less fuel intensive A319 with the larger A320neo aircraft at this time. In other words, while the A320neo may prove to be more fuel-efficient than the existing A320 fleet, it is still comparatively more fuel intensive than the smaller A319s that it was replacing. In 2018, fuel burn and CO_2 emissions are highest in the 'Low' scenario (0.07% greater than in the 'Moderate' scenario; 2.40 billion kg and 7.56 billion kg CO_2). This is likely a result of the relative predominance of the older A320s in the fleet mix in comparison with the 'Moderate' and 'High' scenario at this time.

In 2019, the 'High' scenario in shown to yield the highest levels of fuel burn (2.49 billion kg) and CO_2 emissions (7.84 billion kg CO_2). In comparison, overall fuel burn under the 'Moderate' scenario is 14,800,000kg (or 0.59%) lower and CO_2 emissions are 46,700,000kg (0.59%) lower for the same year. Overall, up to 2019 the 'Moderate' scenario is shown to yield the lowest level of fuel burn (9.18 billion kg) and CO_2 emissions (28.92 billion kg CO2) of the three scenarios, albeit only marginally. In comparison, the 'High' scenario shows the highest levels of fuel burn (9.21 billion kg) and CO_2 emissions (29. 02 billion CO_2) of the three scenarios.

Following this, the projected ASK and CO_2 per ASK were calculated for each of the three scenarios over the same time period. For the purpose of this part of the analysis it was assumed that each of the three aircraft types would exhibit the same average sector distance for all future operations as they did in 2015 (see findings in Table 3). Using the predicted number of flights for each aircraft type (see Table 6), it was then possible to arrive at an aggregate total distance flown by each aircraft type and the network overall. This figure was then converted from nautical miles to km and used to calculate projected ASK using the seating configuration for each aircraft (see Table 3). In turn this figure was then divided by the amount of CO_2 emitted for each aircraft type for each of the three scenarios up to 2019 in order to establish CO_2 emissions per ASK (shown in grams). The outcomes of this are presented in Figures 2 and 3.

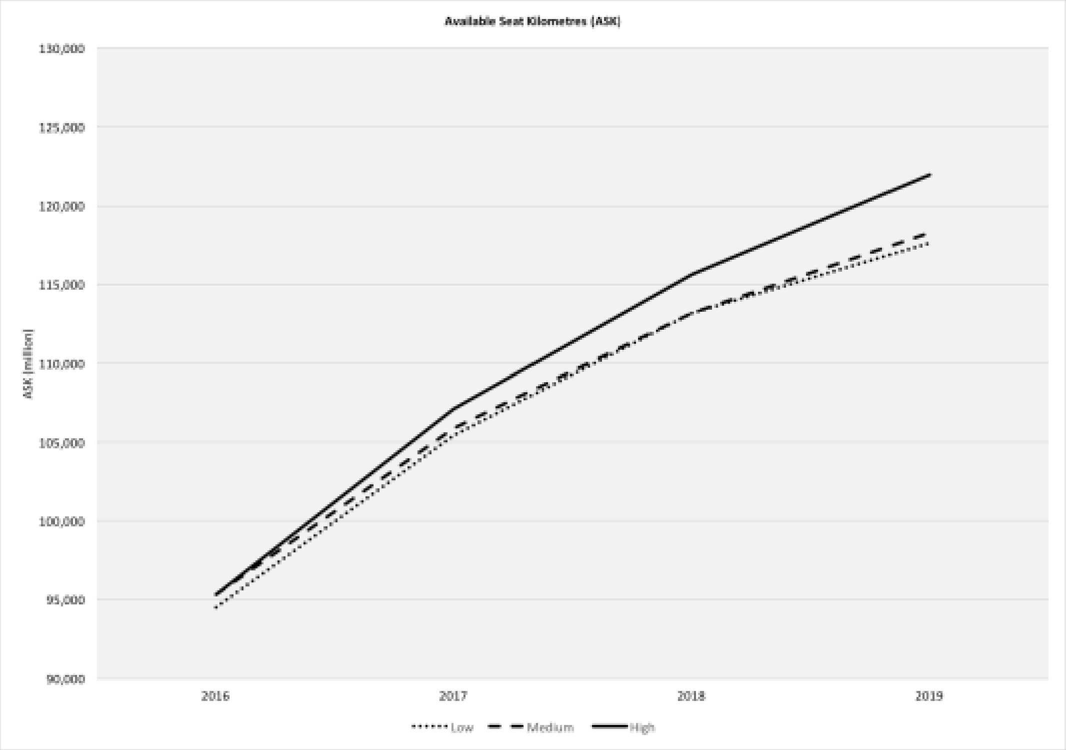

Figure 2. Projected total ASK for Low, Moderate and High Scenarios, 2016-2019

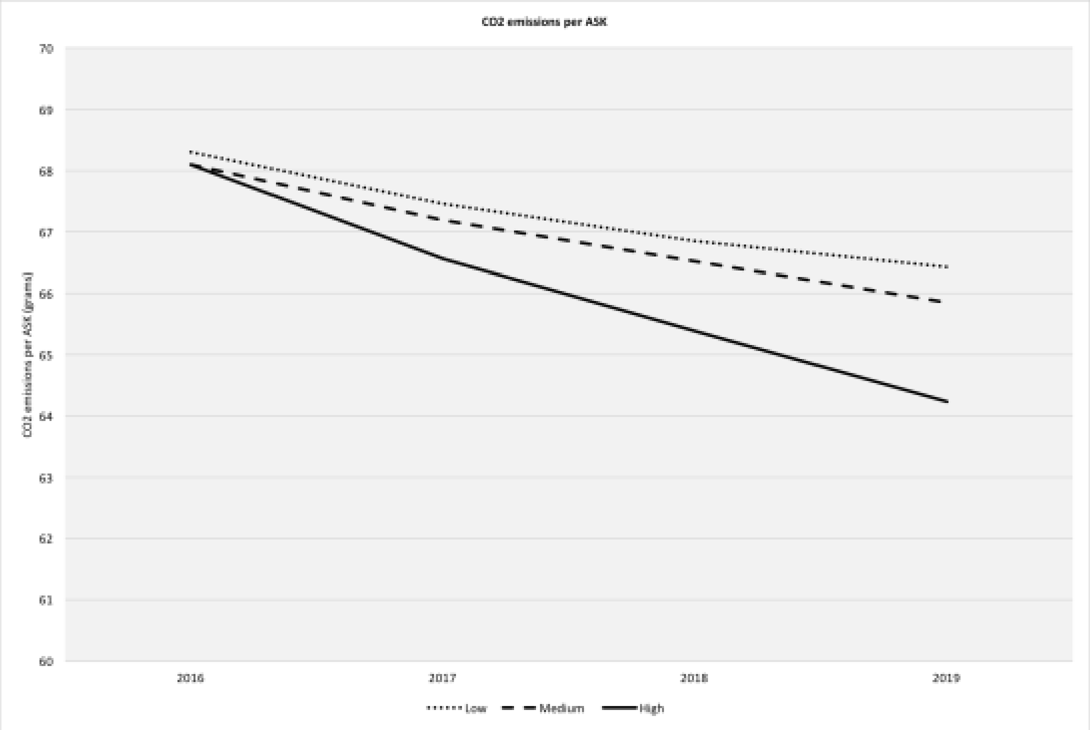

Figure 3. Projected CO_2 per ASK for Low, Moderate and High Scenarios, 2016-2019

As shown in Figures 2 and 3, for each scenario the airline is able to effectively increase the capacity on their network (i.e. an increase in ASK) while maintaining or slightly reducing the quantity of CO_2 emitted per ASK. For example, under the 'Moderate' scenario it is shown that ASK rise from 95.3 billion in 2016 to 118.2 billion in 2019. Over the same time period it can be seen that the quantity of CO_2 emitted per ASK falls slightly from 68.1g CO_2/ASK in 2016 to 65.9g CO_2/ASK in 2019. Similar trends are observed for both the 'Low' and 'High' scenarios. Indeed, the reduction in CO_2 emitted per ASK is most pronounced for the 'High' scenario, falling from 68.1 CO_2/ASK in 2016 to 64.2g CO_2/ASK in 2019. The findings indicate that by progressively replacing smaller aircraft with larger variants, or at least increasing the number of seats flown, an airline can increase its network capacity while simultaneously reducing CO_2 per ASK and only marginally impacting total fuel burn.

These findings and their associated management implications, as well as those already addressed earlier in the paper, are discussed in the following section.

Discussion and Management Implications

Initially the findings from the analysis may seem surprising, as intuitively the predominance of more fuel-efficient aircraft in a fleet should lead to significant reductions in fuel use and CO_2 emissions. However, in reality it may not be as straightforward as this. As the analysis indicates, one of the key benefits of new aircraft is that in the longer term they can help to increase capacity in a network while keeping overall fuel burn and emissions the same, or increasing them only marginally.

In this case, by progressively replacing the smaller A319 aircraft with the larger A320neo aircraft, the airline is able to increase the overall number of seats they can sell on their network while incurring roughly the same annual fuel costs. This inevitably has important implications in terms of airline strategic management and fleet planning, since emissions and fuel costs per seat are lower, contributing to the financial health of the airline and facilitating cheaper ticket prices. Nevertheless, our results may also taper any expectations that the introduction of these so-called ‘next generation’ more fuel-efficient aircraft will lead to rapid, substantial reductions in overall emissions in the short term. This might be especially true in case fuel prices remain at low levels and the incentives for a quick fleet replacement are reduced.

There are also important environmental considerations that need to be taken into account in terms of related processes across the whole life cycle of these new aircraft such as production and maintenance, and not just emissions from the aircraft itself. Indeed, recent research assessing the environmental impacts of modern aircraft highlight various possible dis-benefits across their life-cycle, including increased fossil fuel use during the manufacturing phase (see Howe et al. 2013), especially where composite materials are used (Timmis et al. 2015). While beyond the scope of this study, accounting for the full life cycle impacts of aircraft 'from cradle to grave' is a necessary exercise in determining their environmental contribution.

Where possible then it may be desirable to implement 'cleaner' practices and processes with existing aircraft. An example of this is the relatively common practice of retrofitting older aircraft with 'winglets' or 'sharklets' to improve the aerodynamic efficiency of the airframe. Such measures have the benefit of being relatively timely to implement, which is important given the long life cycle of aircraft and the amount of time it takes for the impact of new aircraft technologies to 'trickle down.' Given that older aircraft progressively become less fuel efficient as they age, finding ways to maintain levels of fuel efficiency in older aircraft for longer is arguably as important as developing new aircraft technologies.

Indeed, a key question relates to the extent to which next generation aircraft do actually deliver improved levels of fuel efficiency, and how long this is sustained across the life cycle of the aircraft. Equally, it will be important to see how the improved efficiency (if that is indeed the case) is distributed across different phases of the flight stage. For example, fuel efficiency is generally highest during the cruise phase and lowest during landing and take-off. If, say, new aircraft types improve fuel efficiency predominantly during the cruise phase of operations, but use similar levels of fuel for landing and take-off as current generation aircraft, then the benefit for short haul operations is likely to be more modest compared with medium or long haul operations, where proportionally more time is spent in the cruise phase and thus intuitively where the greatest benefits might be accrued.

As discussed earlier, compliance with existing and forthcoming environmental legislation and/or market based measures such as the EU-ETS represent key drivers for airlines to reduce their fuel burn and emissions profile. This is likely to remain the case for the foreseeable future, and it seems reasonable to suggest that airlines that are already active in modernising their fleet are likely to be those best placed to respond to any future changes in the regulatory environment should they occur. Even if more stringent environmental based legislation is not forthcoming, there are still competitive advantages to reducing fuel burn as an airline, and as such the ability to invest in newer more fuel efficient aircraft represents something of a 'win-win' for these carriers. European low-cost carriers such as easyJet, Ryanair, Norwegian Air Shuttle, Vueling and others in particular have embraced this philosophy in recent years, and consequently operate some of the youngest fleets in the industry. A possible avenue for future research may therefore involve a comparative examination of the fuel and emissions impacts of future fleet development for low-cost carriers, but also for full service carriers in order to examine the influence of varying approaches to network configurations, business models and fleet structures.

Traditionally, much of the attention on aircraft emissions has focused on the role of CO_2. From an environmental perspective it is important that this attention is not at the expense of other equally important emission products such as nitrous oxides, methane or water vapour, which also play an important role in terms of local air quality and climate change. In particular, it is important that the perpetual drive to reduce CO_2 emissions from aviation is not at the expense of failing to address the reduction of other pollutants. Similar potential trade-offs are also significant with regards to the interdependency between emissions and aircraft noise. Policy makers have a key role to play in this regard in ensuring that environmental incentivisation is applied in a considered way that does not inadvertently lead to unintended negative consequences. Examining these various trade-off and interdependencies forms an important avenue for future research.

To some extent it could be argued that a point of diminishing returns has been reached with regards to fuel burn efficiency gains from new aircraft technology, given that savings may be largely outweighed by overall growth in demand. Where new aircraft are used to significantly grow a fleet, or are used to replace smaller, shorter range aircraft that were less fuel intensive in the first place (as was the case here), the environmental ‘benefits’ of these new aircraft are less clear cut. However, from an airline strategic management and fleet planning perspective the ability to increase capacity on a network with only marginal increases in fuel burn and emissions may presents considerable commercial opportunities for the airline in question.

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