PERSPECTIVAS SOBRE LAS ESTIMACIONES ECONÓMICAS DE LOS COSTES CLIMÁTICOS DEL SECTOR DE LA AVIACIÓN DEBIDOS A LA GESTIÓN AÉREA EN 2018-19

INSIGHTS ON THE ECONOMIC ESTIMATES OF THE CLIMATE COSTS OF THE AVIATION SECTOR DUE TO AIR MANAGEMENT IN 2018-19

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ABSTRACT:

Air navigation service providers ensure that aircrafts keep safely apart by prescribing vertical and horizontal distances to each other. In the European Union and its associated members, regulation is carried out via a performance scheme which measures and sets targets for the different key performance areas. For the environmental area, targets in terms of CO_2 and other pollutants were set by assuming that there would be continuous improvements for the Key performance Environment indicator based on actual trajectory. However, although a higher Horizontal Flight Efficiency (HFE) measurement usually means a more direct flight trajectory, this does not necessarily translate into a climate optimal trajectory. Thus, vertical flight efficiency also needs to be considered. There is also an interdependency between airspace and Air Traffic Management Capacity and Environment: when the offered capacity falls short of the demand for flights, ground delays, holdings and traffic shifts to adjacent areas occur. This entails detours and a deterioration of the HFE-indicator.

Results show that total climate costs for 2018 and 2019 may be as high as 1 bn EUR, of which about 34% is due to CO_2 emissions. In particular, the climate costs of CO_2 emissions due to capacity constraints range from 54 to 301 million EUR, depending on whether CO_2 costs are measured in terms of avoidance costs or under the EU Emissions Trading System (EU ETS). Following the first criterion and the short to medium run up to 2030, the estimated costs would amount to 112 million EUR. In the long run, from 2040 to 2060, these costs would amount to 301 Million EUR. With the estimates of the EU ETS, the cost by 2030 would be close to 54 million EUR and 153.5 million EUR for the long run. Volatility of carbon pricing may play a very significant role, but fortunately can be hedged.

Therefore, a shortfall of capacity leads to delay costs and considerable environmental costs. As capacity is planned in the medium to long-term, traffic forecasts are a crucial element. This means that further research is warranted into the

RESUMEN:

Los proveedores de servicios de navegación aérea garantizan que las aeronaves se mantengan separadas de forma segura prescribiendo las distancias verticales y horizontales entre ellas. En la Unión Europea y sus miembros asociados, la regulación se lleva a cabo a través de un sistema de rendimiento que mide y establece objetivos para las diferentes áreas de rendimiento clave. Para el área medioambiental, los objetivos en términos de CO2 y otros contaminantes se fijaron asumiendo que habría mejoras continuas para el indicador clave de rendimiento medioambiental basado en la trayectoria real. Sin embargo, aunque una medición más alta de la eficiencia de vuelo horizontal (HFE) suele significar una trayectoria de vuelo más directa, esto no se traduce necesariamente en una trayectoria óptima desde el punto de vista climático. Por lo tanto, también hay que tener en cuenta la eficiencia de vuelo vertical. También existe una interdependencia entre el espacio aéreo y la capacidad de gestión del tráfico aéreo y el medio ambiente: cuando la capacidad ofrecida es inferior a la demanda de vuelos, se producen retrasos en tierra, retenciones y desplazamientos del tráfico a zonas adyacentes. Esto conlleva desvíos y un deterioro del indicador HFE.

Los resultados muestran que los costes climáticos totales para 2018 y 2019 pueden ascender a 1.000 millones de euros, de los cuales aproximadamente el 34% se debe a las emisiones de CO2. En particular, los costes climáticos de las emisiones de CO2 debidos a las limitaciones de capacidad oscilan entre 54 y 301 millones de euros, dependiendo de si los costes de CO2 se miden en términos de costes de evasión o en el marco del Sistema de Comercio de Emisiones de la UE (EU ETS). Siguiendo el primer criterio y a corto y medio plazo, hasta 2030, los costes estimados ascenderían a 112 millones de euros. A largo plazo, de 2040 a 2060, estos costes ascenderían a 301 millones de euros. Con las estimaciones EU ETS, el coste hasta 2030 se acercaría a los 54 millones de euros y 153,5 millones de euros a largo plazo. La volatilidad del precio del carbono puede desempeñar un papel muy importante, pero afortunadamente se puede cubrir.

Por lo tanto, un déficit de capacidad conlleva costes de retraso y considerables costes medioambientales. Como la capacidad se planifica a medio y largo plazo, las previsiones de tráfico son un elemento crucial.

interdependency of traffic forecasts, capacity and environmental costs.

Keywords: climate economic cost, aviation sector, capacity management

Esto significa que está justificado seguir investigando la interdependencia de las previsiones de tráfico, la capacidad y los costes medioambientales.

Palabras clave: costes climáticos, sector de la aviación, gestión de la capacidad

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1.-INTRODUCTION

Some sectors that generate a substantial amount of CO_2 emissions are difficult to decarbonize. This is the case of aviation, long-distance transport, shipping and production of steel and cement [1]. For instance, these authors using 2014 data show that the aviation emissions are of 0.8 Gt of CO_2, account for 2% of total emissions. CO_2 emissions from aviation have risen rapidly over the past two decades, reaching nearly 1 Gt in 2019, or about 2.8% of global CO_2 emissions from fossil fuel combustion. The energy intensity of commercial passenger aviation has decreased 2.8% per year on average [2].

Air navigation service providers are public or private legal entities that provide air navigation services (the European Air Navigation Services system covers 27 providers, such as ENAIRE in Spain and DFS in Germany). They are natural monopolies and ensure that aircraft on the ground and in the air under all weather conditions keep safely apart by prescribing vertical and horizontal distances to each other. Due to the nature of this activity, there can only be one player in a national market and therefore the operation needs to be regulated. In the European Union and its associated members, regulation is carried out via a performance scheme which measures and sets targets for the different key performance areas of safety, capacity, environment and cost effectiveness [3].

The targets for the 2015-2019 period (the so-called “second reference” period or “RP2”) have been laid down in the European Commission Implementing Decision of 11 March 2014 [4]. For the environmental area, the target aims to reduce the actual trajectory of a flight to minimise fuel consumption and thus greenhouse gas (GHG) emissions. Targets were set for RP2 assuming that there would be continuous improvements for the Key performance Environment indicator based on Actual trajectory (KEA) (or actual trajectory to Great Circle Distance), which is the shortest distance between two points on the surface of a sphere, measured along the surface of such sphere. This is reflected by a steady decrease of the KEA target from 2.96% in 2015 to 26% in 2019. In the assessment of horizontal flight efficiency (HFE) –defined as the comparison between the length of a trajectory and the shortest distance between its endpoints—targets, all planned network changes were taken into account, including the average use of military restricted areas. It should be noted that this regulation does not take into account actual wind- and temperature conditions nor the presence of significant weather along the route, which may have a comparable impact on the flight time and fuel burn. In Figure 1 we can see annual values for the Single European Sky (SES) area, so-called SES-RP2 area. That is the one regulated under the Performance Scheme of SES in RP2. Note that KEP stands for Key Performance Indicator Horizontal Flight Efficiency with respect to the Flight Plan as defined in Implementing Regulation 390/2013, Annex I.

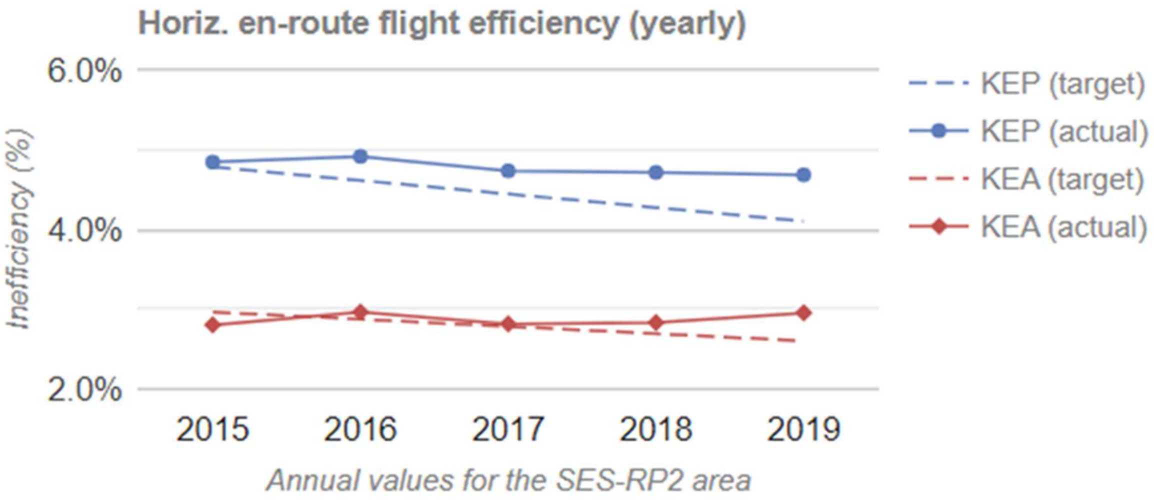


Fig. 1. Annual values for the Single European Sky (SES-RP2) area. Source: [5]

It is interesting to note that a higher horizontal flight efficiency measurement usually means a more direct flight trajectory, but this does not necessarily translate into a climate optimal trajectory. The optimal climate trajectory refers to the flying trajectory that minimises the amount of Greenhouse Gas Emissions (GHG). A big number of variables are involved in the way this can be calculated, such vertical and horizontal efficiency.

2.-FLIGHT EFFICIENCY AND THE ENVIRONMENT

To relate to environmental issues of air navigation sector, the Regulator uses the actual distance flown, as this correlates with fuel burn and therefore CO_2 emissions. However, vertical flight efficiency also needs to be considered in any measure of climate optimal trajectories and other circumstances - such as wind or the possible occurrence of contrails - also need to be taken into account. In addition, the latest scientific research indicates that CO_2 emissions are not the sector's only climate change impact. CO_2 represents approximately 34% of the Effective Radiative Forcing (ERF) of the whole sector; around 66% of ERF comes from non-CO_2 impacts, mainly contrail cirrus and emissions of nitrogen oxides (NOx) [6].

At the same time, it is important to note that there is an interdependency between the different Key Performance Areas (see definition in [3]) as we have pointed out in earlier work [7]. One example is the link between airspace and Air Traffic Management (ATM) Capacity and Environment: when the offered capacity falls short of the demand for flights, ground delays, holdings and traffic shifts to adjacent areas occur. This entails de-tours and a deterioration of the HFE-indicator. The demand for flights refers to the desire to get flights and has to be matched with the capacity to manage all those flights. Delays between 2015 and 2017 were in the same approximate order of magnitude but increased sharply in 2018 and remained close to this peak level in 2019 as shown in Figure 2.

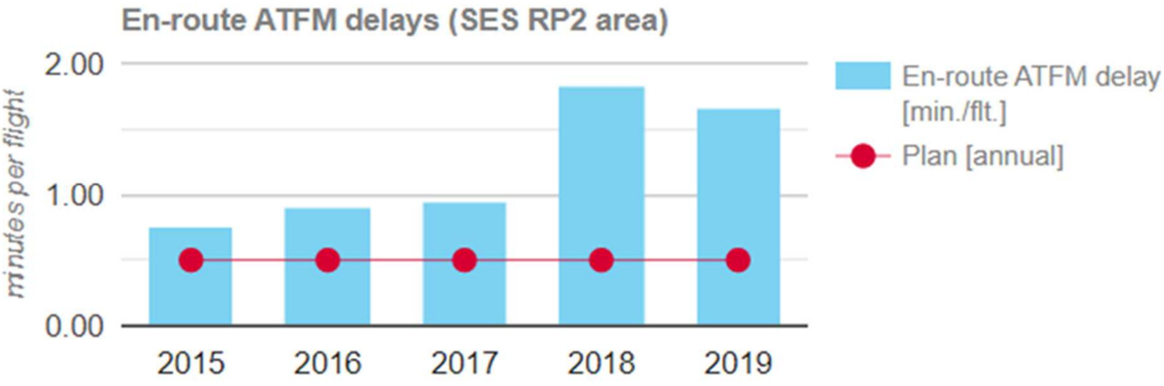
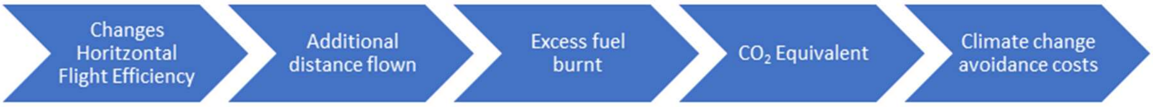


Fig. 2 En-route ATFM delays in SES RP2 area. Source: [5]

For actual HFE, it should be noted that the target of 2.78% of KEA was met in 2017 but afterwards deteriorated to 2.95% - a difference of 0.17 points - which was a clear reflection of the shortfall of capacity and the increase in delays.

There are many interesting factors which can be analysed from these calculations, including how changes in HFE can be translated into costs. The diagram below shows the logic:



Changes in horizontal flight efficiency refers to the changes between the length of a trajectory and variations from the shortest distance between two points. This induces additional number of miles flown due to changes in trajectory and consequently an excess fuel is burnt. Additional number of kerosene liters will be needed to cover a given distance due to deviation from the optimal route. Thus, increasing the CO_2 equivalent (CO_{2e}) metric. A measure used to compare the emissions from various GHG on the basis of their Global Warming Potential (GWP), by converting amounts of other gases to the equivalent amount of CO_2 with the same (GWP). Finally, the avoidance cost method is used to calculate the evaluation of environmental economic effects associated to avoid the emission of a ton of CO_{2e}.

In [8] there is an in-depth analysis of the situation in 2019/2020 and how the sharp decrease of traffic due to the COVID pandemic had an impact on both capacity (in terms of delays) and on the environment (in terms of HFE). As part of this analysis, Performance Review Report 2020 (PRP) concluded that an improvement of 0.3 points in HFE leads to savings of 16.02 million NM (or 29.7 million km) in distance (see page 32), or 0.1 points leads to 5.4 million NM (or 9.9 million km).

It is possible to conclude that if the same amount of capacity as in 2017 had been available in 2018 and 2019, the improvement in HFE would have met the set targets. This is noted in Table 1.

	2017	2018	2019
KEA (target)	2.78	2.69	2.60
KEA (actual)	2.78	2.83	2.95
Difference	0.00	0.24	0.35

Table 1. KEA comparisons between target and actual

If we now apply the differences in Table 1 and use the equivalence above from the PRP (2020), we can estimate the additional distance flown per year as:

2017: 0 NM additional distance flown

2018: 2.4 x 5.4 million NM = 12.96 million NM

2019: 3.5 x 5.4 million NM = 18.9 million NM

That is, in the period 2018 to 2019 something close to 31.86 million NM was flown beyond optimal distances as a result of capacity constraints.

3.-THE ENVIRONMENTAL COST

3.1.-AVOIDANCE COST

According to [9] there was an average fuel burn for departing and arriving Instrument Flight Rules flights in the European Civil Aviation Conference (ECAC) region of 10.011 kg on an average flight length of 946 NM (see page 55). This means that per NM flown, some 10.58 kg of fuel was burnt. One kg of fuel burnt leads to an emission of 3.15 kg of CO_2; 1.237 kg of H_2O; and 0.00084 kg of SO_2 (see page 24). That is, for the 31.86 million NM additional distance flown in the period 2018 to 2019, 337,156,934 kg of fuel was burnt, corresponding to 1.06 million tonnes of CO_2.

If we now use the ECTL Standard Inputs Climate Change Avoidance Costs measure shown in the table below, it is possible to quantify the carbon cost of that extra distance flown. The avoidance costs may vary depending on whether costs are measured over short-to-medium terms (up to 2030) or the long term (from 2040 to 2060). Costs may also vary depending on the calculated EUR-per-tonne of CO_2 equivalent, which ranges due to regulatory and political uncertainty between 63 EUR and 524 EUR (Table 2).

Forecast	**Low**	**Medium**	**High**
Short and medium run (up to 2030)	63	105	199
Long run (from 2040 to 2060)	164	283	524

(adjusted from € 2016 to € 2019 prices)

Table 2. Climate change avoidance costs in Euros per tonne of CO_2 equivalent Source: [9]

If we take the short to medium run up to 2030, the estimated costs would amount to 112 million EUR (1,062,044 tonnes of CO2 times 105 EUR). In the long run, from 2040 to 2060 - and again taking the medium value of ECTL Standard Inputs of 283 EUR per tonne of CO_2 equivalent - the costs would amount to 301 Million EUR (1,062,044 tonnes of CO_2 times 283 EUR).

To sum up, the environmental costs of CO_2 emissions due to capacity constraints in 2018 and 2019 range from 112 to 301 million EUR as summarized below:

If we now note, as stated above from [6], that CO_2 emissions account for only 34% of the total climate impact of aviation, one could argue that the total costs may be up to three times higher than the figures calculated for CO_2 only. That is, the environmental costs of aviation for 2018 and 2019 can be estimated to be ranging from 336 to 903 million EUR.

3.2.-EU ETS COST

Also, note that the values offered represent the Standard Inputs Climate Change Avoidance Costs which may significantly differ from the European Emissions Trading Scheme (EU ETS) carbon prices. Aviation being one of the sectors included in the EU ETS since 2012, the price of carbon will be determined by the market. Under this situation and considering the price of CO_2 in the future market in the period 2021-2027 (see Figure 3), it is possible to estimate a carbon price ranging from 50.81€ in 2030 to 144.6€ by the end of the century (linear regression results are available upon request), which will be significantly lower than the Standard Inputs Climate Change Avoidance Costs economic estimates for the long run. In such a case, the cost by 2030 will be close to 54 million EUR and 153.5 million EUR for the long run. And consequently, the total cost varies from 162 to 460.5 million EUR.

So, all in all, the climate or environmental cost values will be ranging between 162 and 903 Million EUR depending on the carbon price used for the estimation.

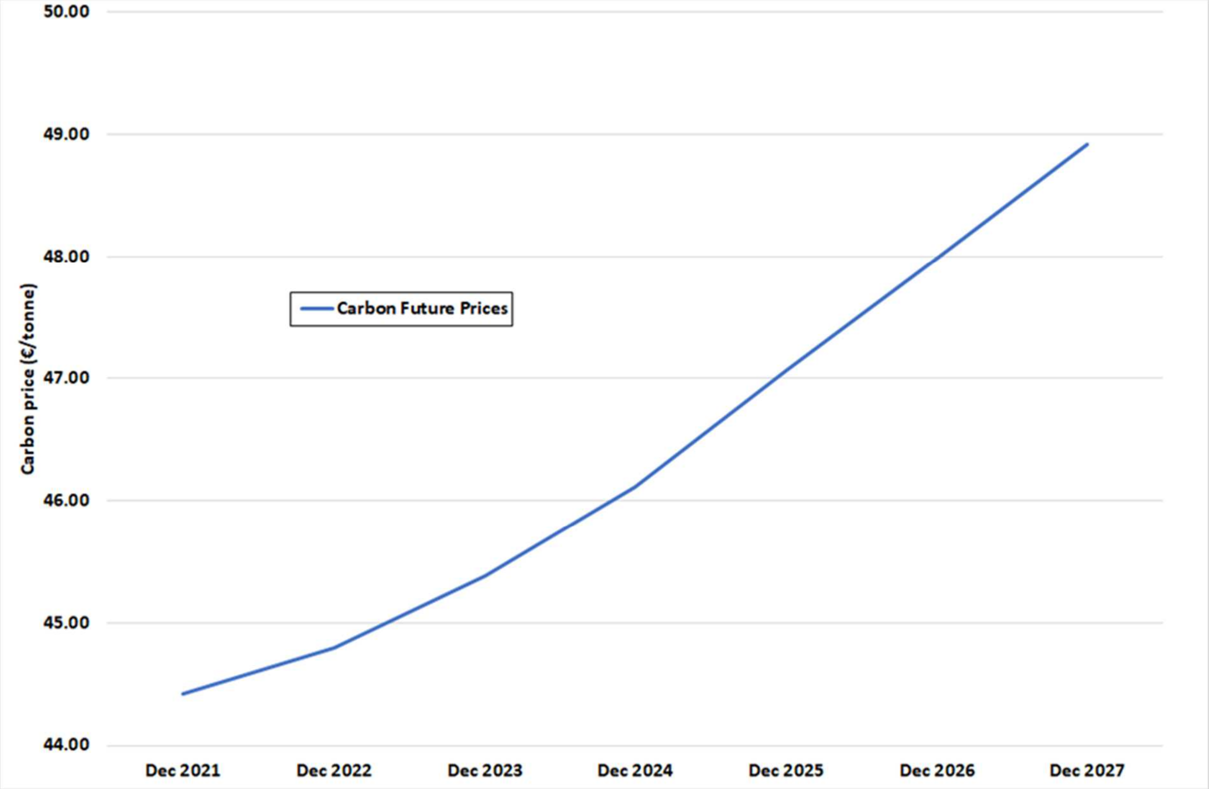


Fig. 3. Future prices of carbon. Source: Market data CE EUA FUTURES PRICES for Mon, Apr 19th, 2021

3.3.- OTHER CONSIDERATIONS

Besides HFE, a vertical flight efficiency measure is also a very important aspect of operations, as aircrafts burn more fuel when flying at lower altitude as a result of capacity constraints and when they follow non-optimal flight profiles [8]. In addition, ECTL Network Manager has introduced the so-called “level caps”, meaning that, for flow control purposes, an aircraft can be told to fly at a lower level than usual, leading to excess fuel burn. Furthermore, the number of occasions when environmentally friendly procedures such as Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO) has fallen by some 5 to 10 per cent, as they cannot be flown during periods of high traffic density. This has also caused additional fuel burn. (See Figure 4). However, this cannot be quantified with the current available data.

Considerations on emerging challenges for ATM due to imminent effects of climate change and variability. Several studies performed by aviation meteorological institutions and associations (KNMI, WMO, EUMETNET, Met Alliance) have indicated an increased risk of severe weather linked to climate change and variability affecting the efficiency and economy of air traffic and its management. Increased frequency and intensity of convective weather situations (thunderstorms, electric storms, intense precipitation and excessive wind speeds) affect not only the smooth operation of air traffic management and in particular, flow management, but also the predictability of demand-capacity imbalances. Such conditions require a highly flexible and well-trained staff of ANSP, and a close cooperation with meteorological service providers to minimize adverse effects of significant (adverse) weather on actual length of routes flown. Current research on the possibility of reducing, for example, the formation of long-lasting contrail-cirrus by avoiding areas and levels of ice-supersaturated volumes of air indicate the potential for significant environmental (climate change related) benefits, but require, again, a very close cooperation between the ANSP, operators and meteorological service providers. This cooperation can only be realized if sufficient capacity for training, education and collaborative decision-making processes is available and funded.

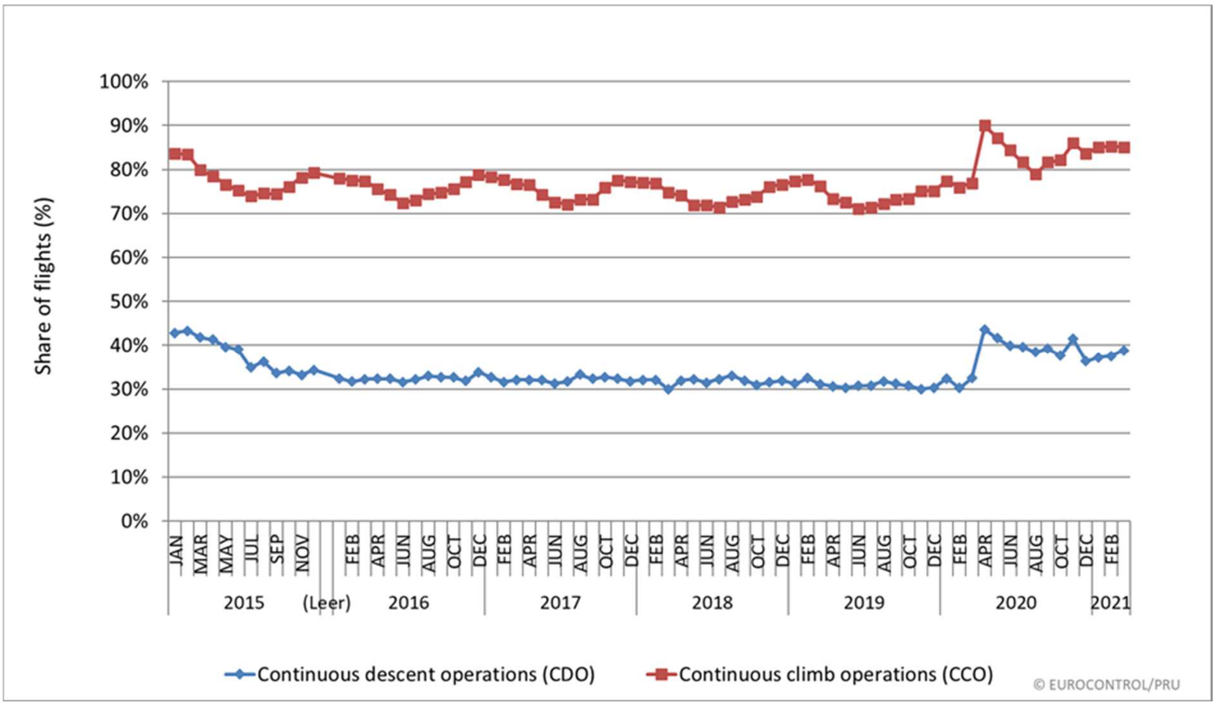


Fig. 4 Changes in continuous descent operations and continuous climb operations from January 2015 to March 2020 Source: [10]

Another significant consideration is delay costs. A shortfall of capacity leads to delay costs and consequently in considerable environmental costs. The cost of delay depends on many factors such as the type of airplane, passengers carried, fuel burn, etc. and changes significantly with the number of minutes of the delay. It is not possible to give a fixed figure (see [11]-[12]-[13] for an example of cost quantification).

4.-MANAGING THE RISKS OF A VOLATILE CARBON PRICE

4.1.-METHODOLOGY FOR CARBON PRICE RISK

In this subsection a methodology is developed to analyse carbon risk and how to manage it. We have illustrated earlier in section 3 what the environmental cost will look like depending on the price of carbon. As the aviation sector in the EU is affected by EU ETS, changes in the price of carbon may represent and additional risk that should be managed. The volatility of EU ETS is considerable and therefore, we devote this section to better addressing this point.

Figure 5 below shows the spot carbon price growth from 2018-2021. It can be noted that this time series have a maximum of 39.92 €/tonne. In addition to their increasing price, as stated, carbon prices show high volatility. Fortunately, financial economics can help to better understand this.

The first step for analyse and manage carbon price behaviour is to choose a stochastic diffusion model that fits well to the behaviour of its prices. The carbon price can be modelled as a stochastic diffusion using the geometric brownian motion model (gbm), that model fits its behaviour fairly well [14]. This is illustrated below.

Fig. 5 Historic spot carbon prices (from March 2018 to February 2021)

Equation (1) shows the gbm:

$$dC_t = \propto C_t dt + \sigma C_t dW_t \qquad (1)$$

Where C_t is the carbon spot price at time t, ∝ is the expected growth rate, σ is the instantaneous carbon price volatility and dW_t is the increment to a standard Wiener process that is normally distributed with zero mean and variance dt. The right part of Equation 1 has two terms, the first $\propto C_t\, dt$ is the deterministic part and the second $\sigma C_t\, dW_t$ is the stochastic part. In the gbm stochastic model carbon price follows a lognormal distribution. According with this model the carbon price grows according to its deterministic part, but this behaviour is constantly altered by the stochastic part.

The second step is to make a transformation to facilitate the model treatment using natural logarithms of carbon prices. Defining $X_t \equiv \ln C_t$ and applying it the Equation (2) is obtained [14].

$$dX_t = (\propto - \frac{\sigma^2}{2})dt + \sigma dW_t \qquad (2)$$

In this Equation (2) the carbon price volatility is a relevant parameter because generates information on the probabilities of exceeding a certain level of future carbon prices. That is, the expected future carbon price can be exceeded in the future and reach higher levels with greater probability if volatility is high.

As a third step, there are some standard results in financial economics for the gbm model shown in Equation (3) and (4). With an initial actual carbon price of C_0 the expected value $E_0(C_t)$ at time t can be calculated using the Equation (3).

$$E_0(C_t) = C_0 e^{\propto t} \qquad (3)$$

And the variance using the Equation (4)

$$Var(C_t) = C_0^2 e^{2\propto t}(e^{\sigma^2 t} - 1) \qquad (4)$$

As fourth step, the methodology for a risk-neutral valuation is presented. In the real word the value of $\propto$ cannot be calculated with the necessary precision. Because of this, usually all the calculations are done in the risk-neutral world, that is using the futures markets of carbon, where the risk has been removed because hedging or speculation positions are guaranteed by the market.

Equation (5) is the risk-neutral version of Equation (1).

$$dC_t = (\propto - \lambda) C_t dt + \sigma C_t dW_t \tag{5}$$

Where λ denotes the risk premium.

Using the expected value in the futures carbon markets $E_0^Q(C_t)$ of Equation (6), the value of $\propto - \lambda$ can be calculated easily

$$E_0^Q(C_t) = C_0 e^{(\propto - \lambda)t} \tag{6}$$

In a fifth step the methodology for simulate future prices using Monte Carlo methods is presented below.

Because the volatility there are the possibility of greater carbon prices. We can simulate the possible carbon prices at time t, using Equation (7).

$$C_t = C_o e^{\left(\propto - \lambda - \frac{\sigma^2}{2}\right)t + \sigma\sqrt{t}\varepsilon_t} \tag{7}$$

Where ε_t is a standard Gaussian white noise, the corresponding values can be obtained easily taking samples for a normal N(0,1) distribution.

4.2.-RESULTS FOR CARBON PRICE RISK

Using the second methodology step the carbon price volatility of three years was σ=0.4764. This value can be calculated as standard deviation of values $(C_{(t+1)} - C_t)/C_t$ multiplied for √(260) being 260 the annual days with carbon quotes. Figure 6, using a 50 days window (that is calculating the volatility for period of 50 days), shows that this volatility was not constant in this three-year period.

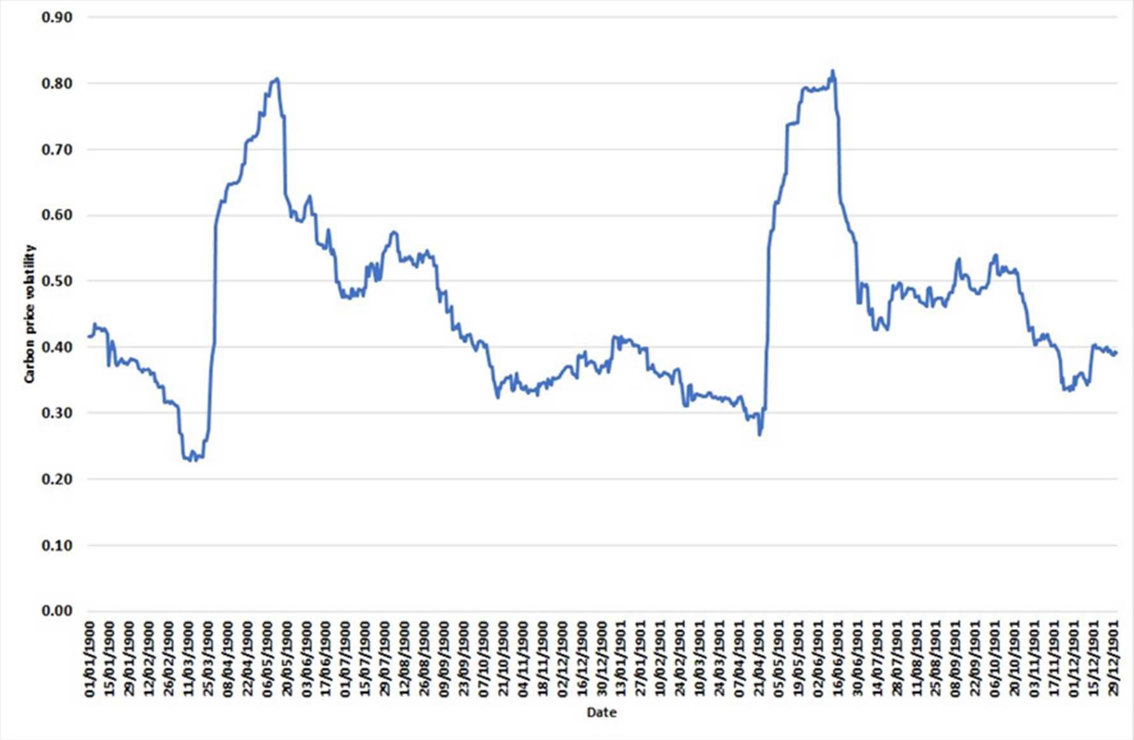


Fig. 6 50 days window for carbon price volatility

Using the fourth step of methodology with the EUA futures prices for Monday, Apr 19th, 2021 (See Figure 3) a value of $\propto$-λ= 0.01494 is calculated with 95% confidence interval of (0.01336, 0.01652). Where C_0=44.42 €/tonne corresponding to carbon futures with expiration December 2021.

All futures market prices can be discounted to the riskless rate because they are reduced by the risk premium. In the European Area is assumed that the risk-free rate is the corresponding to the long-term German debt. Because the German debt to 10 years have negative interest rate, is assumed in the log-term a discount rate of r=0%, that is the present value is the same that futures carbon prices.

The estimated futures carbon price values, using the Equation (6), are:

Expiring	Dec-2025	Dec-2050	Dec-2075	Dec-2100
$E_0^Q(C_t)$ Price (€/tonne)	47.16	68.51	99.53	144.60

A simulation with 2 million random samples was done, and the histogram of Figure 8 is calculated for the year 2025.

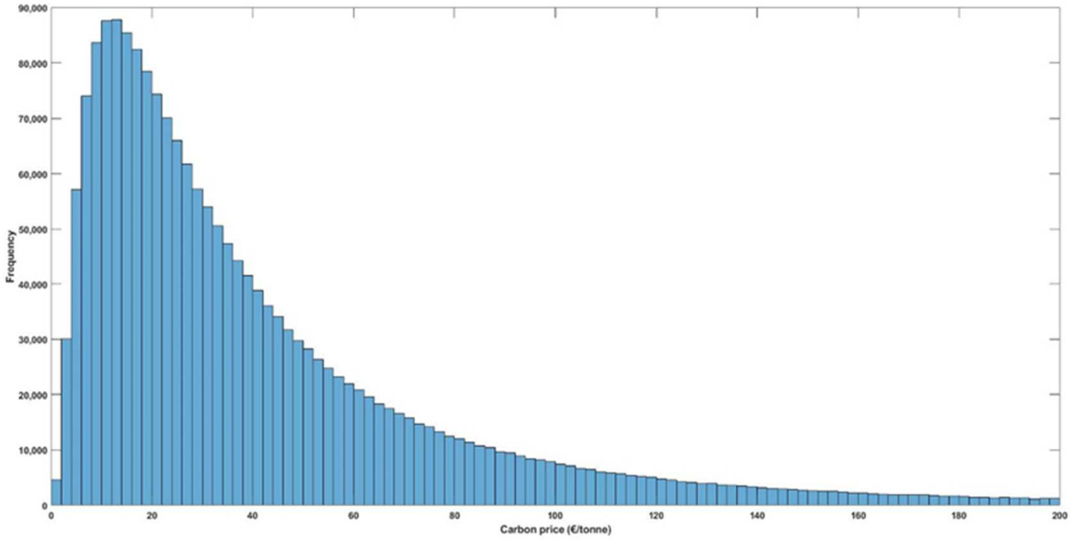


Fig. 7 Histogram of 2025 futures prices

With very high volatility there may be a non-negligible probability of reaching high values of future carbon prices. The Table below shows that if the volatility remains high and similar to its historical values (σ=0.4764) in 80% of case the prices will be between 8.84 and 101.69 €/tonne, but in 10% of cases the price will be greater than 101.69 €/tonne. With lower volatility are less likely that in the medium term the future carbon prices will be significantly high compared to today.

Expiring	Dec-2025		
Volatility	$\sigma = 0.4764$	$\sigma = 0.25$	$\sigma = 0.125$
Percentile 90% €/tonne	101.69	79.04	62.99
Percentile 10% €/tonne	8.84	21.94	33.18

The future carbon price volatility generates important risks for the aviation firms that may also affect the calculation of environmental costs. Fortunately, these risks can be hedged today in futures markets. If the necessary emission rights are not hedged in the market, the final prices paid may be much lower or much higher than expected, depending on its probabilities of the future volatility. Therefore, it becomes necessary an active management of the carbon risk for the aviation firms.

5.-CONCLUSION AND FURTHER RESEARCH

There are many issues that have to be taken into consideration when defining targets in the performance scheme for air navigation services. This paper has shown that the total economic cost perspective is a very important one and needs to be adequately considered. A shortfall of capacity leads to delay costs - which we have already investigated in [7] - and considerable environmental costs, which we have outlined in this paper. As capacity is planned in the medium to long-term, traffic forecasts are a crucial element. Therefore, further research is warranted into the interdependency of traffic forecasts, capacity and environmental costs.

In addition, one should not ignore the role that volatility of carbon prices may play for the calculation of the environmental cost, and therefore for the topic of traffic forecast and capacity. We have illustrated this with the so-called stochastic modelling, an area of economics that can help a lot to better understand the risks associated to carbon pricing volatility. Fortunately, the existence of CO_2 markets may allow to hedge this risk.

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