Committed to the Environment

Corrigendum to CE Delft, 2022, Social costs and benefits of advanced aviation fuels, Delft: CE Delft
Jasper Faber, 5 December 2022

Introduction

This is a corrigendum to CE Delft, 2022, *Social costs and benefits of advanced aviation fuels*, Delft: CE Delft. It corrects and updates the findings of the report. The main conclusion of the report remains unchanged, i.e. that it is beneficial for society to hydrotreat aviation fuels so that the content of sulphur and aromatics is reduced, because the climate and health benefits exceed the costs of hydrotreatment.

Reason for this corrigendum

The report has been released for publication in 2022, after having been submitted to the Client early in 2020. There were various reasons for the long period between finalisation of the report and publication, which are not relevant for this corrigendum.

An external review by a volunteer with a background in refining has brought a few issues to light that need to be corrected. In addition, the publication of Lee et al. (2021)[1] after the finalisation of the report has made it possible to calculate the value of climate impacts more accurately than was possible at the time of finalisation of the report.

New summary table

The summary table in CE Delft, 2022, *Social costs and benefits of advanced aviation fuels*, Delft: CE Delft presents the social costs and benefits of the use of low-sulphur, low-aromatics and low-naphthalene fuels instead of conventional jet fuel as annual figures for the year 2018 (price level 2018). It should be corrected as:

Table 1 - Overview SCBA results (compared to the baseline scenario, million euro, 2018 price level)

		HT1	HT2	HT3
Direct effects	Additional costs of advanced aviation fuels	192	322	2,966
	Fuel costs savings	-209	-494	-1,484
	Maintenance costs	+ PM	+ PM	+ PM
	Retrofit costs	+ PM	+ PM	+ PM
Indirect effects	Change in consumer surplus	0.04	0.1	9
	Change in producer surplus	0	0	0
External effects	External effects: Air pollution	-73	-85	-91
	External effects: Aviation climate impacts*	-6,700	-10,704	-13,001
	External effects: GHG emissions from fuel production	340	490	3,376
	Total	**-6,000**	**-10,000**	**-8,000**

* *The calculation of the climate effects, and especially the effects on contrail cirrus formation, have a higher degree of uncertainty than other items in the cost-benefit analysis.*

[1] https://doi.org/10.1016/j.atmosenv.2020.117834

New conclusion

The use of low- sulphur, low-aromatics and low-naphthalene fuels probably has significant social benefits, because the climate benefits (and also the fuel cost savings and air pollution benefits) exceed the additional production costs and the external effects of emissions from fuel production.
The scientific understanding of the link between fuel composition on the one hand and contrail formation and induced cirrus cloudiness on the other is evolving. Likewise, the assessment of the climate impact of induced cirrus cloudiness has a significant degree of uncertainty. Hence, it would be recommended to keep a close watch at scientific publications on this topic.

Technical Annex

For reference, the original publication had the following summary table:

Table 2 - Overview SCBA results (compared to the baseline scenario, mln €, 2018 price level)

Type of effects	Specific effects	HT1	HT2	HT3
Direct effects	Additional costs of advanced aviation fuels	192	322	2,966
	Fuel costs savings	-209	-494	-1,484
	Maintenance costs	- PM	- PM	- PM
	Retrofit costs	+ PM	+ PM	+ PM
Indirect effects	Change in consumer surplus	0.04	0.11	9.00
	Change in producer surplus	0	0	0
External effects	Air pollution	-73	-85	-91
	GHG emissions	-687	-677	-1,224
	Emissions from fuel production	0.00	0.00	0.01
Net results	**Costs minus benefits**	**-778 +/- PM**	**-934 +/- PM**	**177 +/- PM**

The following changes have been made to the calculation:

1. A mistake in the spreadsheet relating to the CO_2 emissions of hydrotreating fuels was corrected, resulting in a significantly higher estimate for GHG emissions from fuel production.
   The CO_2 emissions associated with hydrotreating the fuels amount to 11, 16 and 112 kg per tonne of fuel for HT1, HT2 and HT3, respectively. About 90% of these emissions are from the production of hydrogen by steam reforming natural gas. If instead green hydrogen would be used, the CO_2 emissions from fuel production would be 90% lower, but the additional costs of advanced aviation fuels would be much higher.

2. The CO_2 emissions reduction from using low-aromatics fuels has been adjusted for HT1 and HT2. This reduction is caused by the fact that saturated hydrocarbons have a higher energy density than aromatics and unsaturated hydrocarbons, as a result of which less fuel needs to be burned per unit of energy provided. The lower calorific value (LCV) of HT1 is 0.1% higher than of the reference Jet A1; HT2 has a 0.2% higher LCV and HT3 0.7%. This results in a reduction of the External effects: Aviation climate impacts for HT1 and HT2.

3. The findings from Lee et al (2021) on the climate impacts of sulphur oxide emissions have been taken into account in the calculation of External effects: Aviation climate impacts. This has resulted in a significantly higher impact (a cost to society) because sulphate particles reflect

sunlight, so fewer particles result in more sunlight reaching the earth's surface. The report used a different method to arrive at a climate impact of 3 Mt CO_2e. Lee et al (2021) estimate the total climate impact of aviation sulphate emissions to be 84 Mt CO_2e in 2018.[2] The sulphur content of HT1 is 85% lower than of the reference Jet A1; HT2 has a 98% lower sulphur content and HT3 95%. Applying these percentages to the 84 Mt CO_2e and multiplying by the damage costs of EUR 104 per tonne of CO_2e yields a climate cost of EUR 7-8 billion.

4. The findings from Schripp et al. (2022)[3] on the relation between fuel composition and nvPM emissions have been combined with the findings from Lee et al (2021) on the climate impacts of aviation contrails and induced cirrus to recalculate the climate impact of reduced contrail formation in the item External effects: Aviation climate impacts. This has results in a significant increase of this benefit.
   a Schripp et al. (2022) indicates that a ~50% reduction in naphthalene content reduces the number of particles by ~33% in flight (figure 8), and a 90% reduction reduced EI PM by ~44%. Voigt et al. (2022)[4] places the reduction in particle number at slightly more than 50% for a 90% reduction in naphthalene such as the one from the baseline fuel to HT2 and HT3.
   b HT1 has a 50% lower naphthalene content and HT2 and 3 >90%, so using HT1 would reduce the number of particles by 33% and HT2 and HT3 by 44%, using the relations from Schripp et al. (2022) (noting that following Voigt et al. (2022) would result in larger reductions).
   c There is much uncertainty about the relation between the nvPM emissions and cirrus cloudiness, but if we take Burkhardt et al. (2018), an 80% reduction in emissions would result in a 50% reduction in cloudiness.
   d This means that HT1 would reduce the impact of contrail induced cloudiness by (5/8)*33%= 21% and HT2 and 3 by (5/8)*44%=28%.
   e Lee et al. (2021) estimates the impact of contrail cirrus to be 652 Mt CO_2e on a GWP100 basis.
   f So, the global use of HT1 would bring a contrail cirrus benefit of 137 Mt CO_2e, and HT2 and HT3 182 Mt CO_2e. Multiplied by EUR 104 per tonne of CO_2e, the value of this climate benefit amounts to EUR 14 billion for NT1 and EUR 19 billion for HT2 and 3.

Table 3 shows the calculation of the aviation climate impacts.

Table 3 - External effects: Aviation climate impacts*

	HT1	HT2	HT3
Total impact on CO_2 emissions because of higher energy density of hydrotreated fuels	-99	-234	-2,212
Total impact on sulphate particles	7,399	8,531	8,270
Total impact on BC (unchanged)	0	-1	-59
Total impact on contrail cirrus	-14,000	-19,000	-19,000
Total External effects: Aviation climate impacts	**-6,700**	**-10,704**	**-13,001**

* *The calculation of the climate effects, and especially the effects on contrail cirrus formation, have a higher degree of uncertainty than other items in the cost-benefit analysis.*

[2] Note that the reference fuel of Lee at al (2021) has a sulphur content of 600 ppm, whereas the Jetscreen reference fuel contains 300 ppm sulphur. It is beyond the scope of this corrigendum to analyse the consequences of these differences in more detail.

[3] www.doi.org/10.1016/j.fuel.2022.124764

[4] 10.1175/bams-d-21-0012.1