Impacts of a CO_2 ceiling for Dutch aviation

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Content

Executive summary

The Civil Aviation Policy Memorandum contains the aim to limit CO_2 emissions of Dutch aviation to 2005 levels by 2030, reduce them by 50% (relative to 2005) by 2050 and to zero by 2070. In order to safeguard that the goals will be met, the Memorandum proposes to implement a so-called CO_2 emissions ceiling for the international aviation sector (the 'CO_2 ceiling'). The aim of this measure is to set clear limits for permitted in-sector CO_2 emissions, with the possibility for the aviation sector to earn growth within those boundaries by introducing technological innovations.

This report presents policy options for the CO_2 ceiling and assesses their impacts on the aviation sector, as well as their environmental, economic and social impacts.

There are three main options for the implementation of a CO_2 ceiling:
1. Airport options: A national CO_2 ceiling divided over airports and embedded in airport permits, comparable to limit values for airports with regard to noise and local air quality.
2. Fuel supplier options: A fossil fuel ceiling, which limits the amount of fossil fuels which fuel suppliers are allowed to supply to aircraft by auctioning permits.
3. Airline options: A national Emissions Trading Scheme, which establishes a closed ETS for airlines departing from Dutch airports.

Effectiveness in ensuring that the climate objectives for Dutch aviation are met

All three options of the CO_2 ceiling are effective instruments for securing the CO_2 objectives set out in the Aviation Policy Document.

Airports have the weakest control over CO_2 emissions of the three potential regulated entities. When emissions risk to exceed the ceiling, their main instrument of control is to adjust the airport capacity. Because airports cannot regulate where airlines fly to and which aircraft types they use, the CO_2 reduction would depend on the airlines' choices. Fuel suppliers have more control over CO_2 emissions, since the quantity of emission allowances auctioned would limit fuel sold to airlines and as a consequence the remissions. However, airlines could increase the amount of fuel they carry on board when arriving at Dutch airports, which would undermine the effectiveness. Airlines have the most direct control over CO_2 emissions.

The feasibility of implementation varies across the design variants: the airport options are easiest to implement for the government as it can build on existing airport regulation and is least likely to give rise to international retaliation. In the fuel supplier and airline options, the regulated entity has more control over CO_2 emissions but both would require new legislation, new monitoring and enforcement systems and would therefore be harder to implement. In addition, the airline options would regulate foreign airlines, and would therefore carry a larger risk of raising objections from other States.

Impacts of the CO_2 ceiling

When the CO_2 ceiling is restrictive, i.e. when business as usual emissions exceed the ceiling, the ceiling would have impacts on the aviation sector, the environment, and the wider economy. Whether this is likely depends on various external factors such as economic growth, European climate policy, Dutch capacity constraints and additional Dutch climate policy. To explore these uncertainties, the study distinguishes 54 baseline scenarios. In most of these scenarios, the CO_2 ceiling is not restrictive. In these scenarios, therefore, there are no side effects except limited implementation and administrative costs.

In nine out of 54 scenarios, the ceiling would be restrictive for more than a few years. In those cases, the aviation sector can respond by flying less, flying shorter distances, by using more efficient aircraft or by mixing more sustainable fuel (SAF). Sector parties make a strategic decision on the type of emission reduction to be applied. The mix of actions depends on the policy option and on the exceedance of the ceiling.

When airports are regulated, all CO_2 reduction results from flying less (because the emission reduction is achieved by constraining airport capacity). When fuel suppliers or airlines are regulated, there is a direct incentive to become less carbon-intensive. As a result, part of the required reduction will be achieved through flying shorter distances, efficiency improvements and, if the CO_2 price is high enough, additional blending of SAF. The differences between de options increase as the CO_2 ceiling becomes more restrictive.

Impact on the aviation sector

When airports are regulated, the reduction in the number of European and intercontinental flights is relatively large. If fuel suppliers or airlines are regulated, the CO_2 ceiling can lead to a reduction of the intercontinental network, but the European network remains unaffected or even increases. When the auction revenues are channelled back into the aviation sector, the impact on aviation is the smallest.

Costs for the sector, the government and the Dutch economy

By far the most important cost item is the cost of purchasing CO_2 rights. Costs for the sector and the government differ greatly between variants. When fuel suppliers or airlines are regulated, costs are incurred by the sector for the auctioning of allowances (these are revenues for the government), unless the revenues are returned to the sector. When airports are regulated there are no auctioning costs.

When fuel suppliers or airports are regulated and the auction revenues are for the state, the impact on the Dutch economy is positive. The impact is slightly positive when the airports are regulated, while the impact on the economy is negative when the auction revenues are returned.

Climate impact

The climate impacts depend on the direct climate impact of the Dutch aviation sector and the indirect climate impact through rerouting to foreign airports, changing transport mode to land transport, potential increases in emissions in other EU ETS sectors and the change in non-CO_2 climate impacts of aviation. In all options, the global greenhouse gas emissions are reduced if the ceiling is restrictive.

Local environmental impact

All design variants have a positive impact on air pollution and noise around airports. The positive effects are greatest when airports are regulated, as in these design variants the number of flights taking off and landing is reduced the most.

Summary

This report presents the results of an impact assessment study of the proposed Dutch CO_2 ceiling for international aviation.

The proposal for a CO_2 ceiling was introduced in the Civil Aviation Policy Memorandum ('Luchtvaartnota 2020-2050') of 2020 as a policy instrument which ensures that the CO_2 emissions of commercial international flights departing from Dutch airports do not exceed the in-sector CO_2 targets set by the government in that same policy memorandum. The Dutch Parliament has supported the introduction of a CO_2 ceiling through two separate motions. The Coalition Agreement of the current Dutch Government has reaffirmed the commitment to introduce a CO_2 ceiling. The political assignment (or mandate) is to introduce a CO_2 ceiling per airport. Two additional design options were included in the process to be able to make a comparison with those policy alternatives.

The aim of the CO_2 ceiling is to turn the CO_2 targets into enforceable targets that have to be reached by the aviation sector. Implementation of the CO_2 ceiling would shift the responsibility of reaching the targets from the government to the sector. It would also allow the sector to grow within clear environmental constraints.

Policy options

There are three main options for the implementation of a CO_2 ceiling:

1. Airport options: A national CO_2 ceiling divided over airports and embedded in airport permits, comparable to limit values for airports with regard to noise and local air quality.
2. Fuel supplier options: A fossil fuel ceiling, which limits the amount of fossil fuels which fuel suppliers are allowed to supply to aircraft by auctioning permits.
3. Airline options: A national Emissions Trading Scheme, which establishes a closed ETS for airlines departing from Dutch airports.

The first option, labelled the 'airport option' (because the airports are the regulated entities), has as its main features that the government allocates top-down which share of the overall CO_2 ceiling goes to which airport. Airports would then have to ensure that the emissions of departing flights stay within that limit. They would use their capacity declaration as a means to do so, as well as other means they have at their disposal. This option has many similarities with the way airports in the Netherlands are already regulated with regard to noise and local air quality.

For this impact assessment, three suboptions for the airport ceiling were identified, which differ in the duration of their compliance cycle (1 or 3-years) and the way the national CO_2 budget is divided over airports (only based on historical CO_2 emissions or also based on the available capacity in existing permits):

- With a 3-year compliance cycle and a division of the national ceiling over airports based on actual historical emissions of international commercial flights departing from Dutch airports in the period 2017-2019.
- With a 1-year compliance cycle and a division of the national ceiling over airports based on actual historical emissions of international commercial flights departing from Dutch airports in the period 2017-2019.

- With a 3-year compliance cycle and a division of the national ceiling over airports based on adjusted emissions of international commercial flights departing from Dutch airports in the period 2017-2019, taking into account the fact that two airports operated below their capacity in this period.

The second option, labelled the **'fuel supplier option'** (because the fuel suppliers would be the regulated entities), entails that fuel suppliers (the entities selling fuel) at Dutch airports need to surrender allowances for each quantity unit of fossil fuels they supply to aircraft engaged in international aviation. They could acquire these allowances at auctions, organised by the State at regular intervals, or on the secondary market. The State would limit the total number of allowances to be auctioned each year to the level of the national CO_2 ceiling.

Three suboptions have been defined for the fuel supplier option, differing in how the auctioning revenues are used (added to the general fiscal budget or funnelled back to the aviation sector) and whether or not a market stability mechanism is introduced:
1. The auction revenues are treated as fiscal revenues for the state and added to the general budget, and a market stability mechanism is implemented to ensure a well-functioning market.
2. The auctioning revenues are funnelled back to the sector, and a market stability mechanism is implemented to ensure a well-functioning market.
3. The auction revenues are treated as fiscal revenues for the state and added to the general budget, and no market stability mechanism is introduced.

The third option, labelled the **'airline option'** (because aircraft operators are the regulated entities), would require airlines to surrender emission allowances for CO_2 emissions on international commercial flights from Dutch airports. As with the previous option, airlines could acquire these allowances at auctions, organised by the State at regular intervals, or on the secondary market. The State would limit the total number of allowances to be auctioned each year to the level of the national CO_2 ceiling. The system would not allow emission allowances of other emissions trading schemes nor offsets or credits to be used for compliance, in line with the Civil Aviation Policy Memorandum definition of the CO_2 ceiling as a cap on national sectoral emissions.

Two suboptions of the airline option have been defined for the purpose of this study, differing in how the auctioning revenues are treated:
1. The auction revenues are treated as fiscal revenues for the state and added to the general budget, and a market stability mechanism is implemented to ensure a well-functioning market.
2. The auctioning revenues are funnelled back to the sector, and a market stability mechanism is implemented to ensure a well-functioning market.

Baseline scenarios

It is customary in Dutch policy analyses to use two baselines, called WLO high and WLO low, denoting two scenarios for socio-economic development which capture much of the range of plausible variation. WLO high is characterised by a relatively high demographic growth and an economic growth rate of about 2% per year. WLO low has comparatively lower population growth and also a lower economic growth rate of about 1% per year.

However, a number of policy decisions that will be taken in the near future could have significant impacts on the emissions of Dutch aviation, which are not sufficiently reflected in the WLO scenarios. These are:

- The capacity of Dutch airports. The Coalition Agreement states that a decision about the capacity at Schiphol and Lelystad Airport will be taken in 2022, in an integrated solution that takes into account the hub function of the former airport and the ambition to reduce the impacts of aviation on people, environment and nature.
- The proposals of the European Commission in the Fit for 55 Package. The European Commission has published a proposal which would, if adopted, require airlines to use increasing shares of Sustainable Aviation Fuels SAF (ReFuelEU Aviation) as well as proposals which would, if adopted, increase the costs of using fossil fuels (Energy Taxation Directive and the EU ETS Directive).
- National climate policy for aviation, and in particular the plan to increase the use of SAF at Dutch airports included in the Civil Aviation Policy Memorandum.

In order to take the uncertainties arising from these future policy decisions into account, additional baselines have been developed, based on WLO high and WLO low, with for each of the policy decisions three options (low, middle and high). In total, therefore, 54[1] baselines have been developed.

For each baseline, emissions of commercial international flights from Dutch airports have been modelled for the period up to 2050. The results are summarised in Table 1. In 39 out of 54 possible policy scenarios, the projected emissions do not exceed the CO_2 ceiling. This means that in the majority of potential scenarios a CO_2 ceiling would have no impact other than creating a safeguard against potential setbacks in the foreseen CO_2 reductions and administrative costs. In six scenarios, they exceed the CO_2 ceiling for 5 years or less in the period between 2025 and 2050, by up to a few percent. Four baselines project emissions to be above the CO_2 ceiling for a period between 5 and 15 years, by up to 50%. Finally, five scenarios project emissions to be above the CO_2 ceiling for more than 15 years, by up to 70% in the most extreme baseline.

Table 1 - Number of years for which baseline scenarios exceed the **CO_2** ceiling

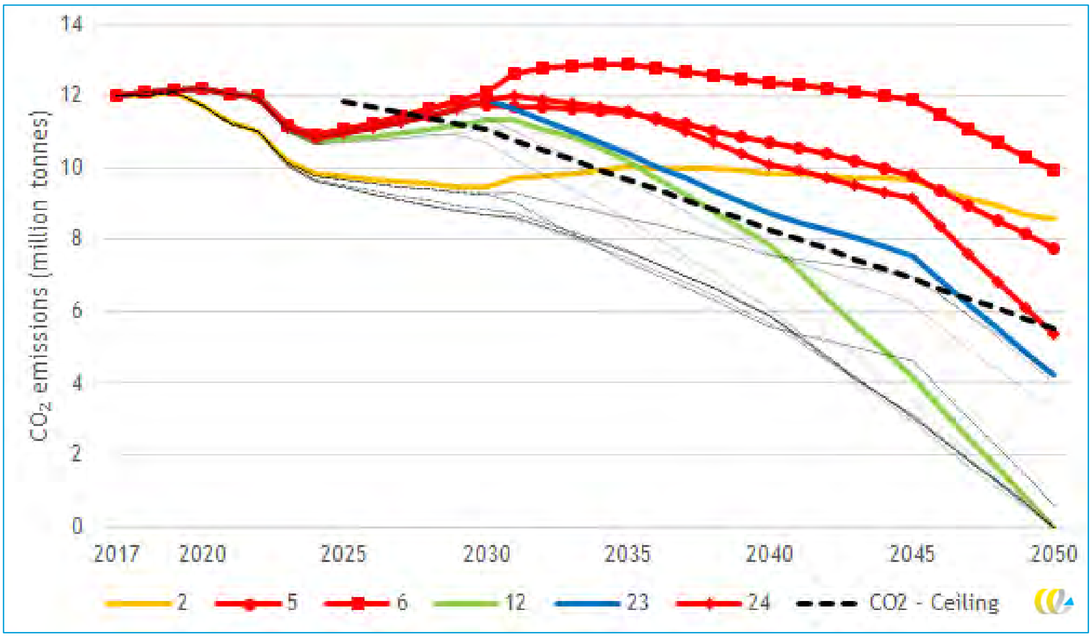
	National SAF blending	WLO low			WLO high		
		Airport Capacity Low	Airport Capacity Middle	Airport Capacity High	Airport Capacity Low	Airport Capacity Middle	Airport Capacity High
Fit for 55 reduced	Reduced ambition	1	2	3	4	5	6
	As proposed	7	8	9	10	11	12
	Increased ambition	13	14	15	16	17	18
Fit for 55 as proposed	Reduced ambition	19	20	21	22	23	24
	As proposed	25	26	27	28	29	30
	Increased ambition	31	32	33	34	35	36
Fit for 55 increased ambition	Reduced ambition	37	38	39	40	41	42
	As proposed	43	44	45	46	47	48
	Increased ambition	49	50	51	52	53	54
Status baseline emissions	Never above ceiling		< 5 years above ceiling	5-15 years above ceiling		> 15 years above ceiling	

Source: Own calculations.

1 2 (WLO scenarios) * 3 (capacity) * 3 (Fit for 55) * 3 (national SAF blending) = 54.

Six scenarios have been used to assess the impacts against (Scenarios 2, 5, 6, 12, 23 and 24 as indicated in Table 1). This selection only included scenarios that exceed the ceiling. The emissions of these scenarios are presented in Figure 1 in red, yellow, blue and bright green against a background of the other scenarios in dotted thin lines. It can be seen that the selected baseline scenarios are heavily skewed towards scenarios which exceed the CO_2 ceiling. The reason for this is that the scenarios which remain below the ceiling have very small impacts, if any.

Figure 1 - Baseline scenarios of which impacts have been assessed



Source: This report.

Note: grey lines represent scenarios that are not modelled. In most of these scenarios, CO_2 emissions remain below the ceiling. These scenarios are not shown in the legend.

The scenario WLO high, Fit for 55 as proposed, airport capacity middle and no additional Dutch SAF policy (number 23 in Figure 1) has been chosen as a reference scenario. This scenario is indicated by the blue line in Figure 1. The corresponding WLO low scenario (number 20 in Figure 1) remains below the ceiling. The impacts of the policy options in reference scenario are presented first in the summary, followed by the impacts in the other scenarios.

An update of the impact assessment is foreseen for later in the year when the uncertainty about future policy developments will be reduced and the number of baselines can also be much smaller. This way, more specific assumptions can be taken on board and more certainty is created about the likelihood of the scenario(s) studied.[2]

[2] This update will also take into account the announced capacity restriction at Schiphol airport, which was presented after all model runs of this study had already been finalized.

Impacts of the CO_2 ceiling on the aviation sector in the reference scenario

The impacts of the CO_2 ceiling depend on the baseline emissions. When baseline emissions are below the ceiling, the implementation of the CO_2 ceiling will give rise to new administrative tasks, but will not require the aviation sector to reduce its emissions. In that case, there will hardly be any impacts on aviation. When, however, CO_2 emissions exceed the CO_2 ceiling, aviation activity will need to change in order to reduce emissions to the level prescribed by the ceiling. This section analyses the impacts in case the policy requires aviation to change its activity. We focus on four of the eight presented suboptions, since the results of the other four options are based on these fully modelled options.[3]

When the CO_2 ceiling is restrictive, airlines need to reduce their CO_2 emissions. They can do so in four different ways:
1. Reducing the fuel use by decreasing the average length of flights, for example by realizing a shift from intercontinental aviation to intra-EU aviation.
2. Reducing the fuel use by decreasing the number of flights.
3. Efficiency improvements (in this study, we only quantified efficiency improvements due to fleet renewal).
4. Additional blending of SAF.

Airlines will act rationally and therefore choose the least costly option to reduce CO_2 emissions. The main difference between the different options for the CO_2 ceiling is that in the airport option there is no direct incentive to reduce CO_2 emissions, which means that not all options for CO_2 reduction are utilized. Figure 2 shows per ceiling option the relative share in the CO_2 reduction from the different possible responses from the airlines. In the ceiling per airport option with strict allocation all CO_2 reduction is obtained by a reduction of aviation volumes (mostly by a reduction of the number of flights). In the fuel supplier/airline option where the auctioning income is for the state, efficiency improvements also have some share in the CO_2 reduction and a shift to shorter flights is seen more clearly. Until 2040, no extra SAF blending is used, because the costs of doing so are too high. The differences in fuel use between the options are shown in more detail in Figure 3. In all options, the fossil fuel use is reduced in line with the CO_2 ceiling. It only becomes viable to blend extra SAF to allow for more flights from 2042 onward.

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[3] The following list summarizes how the eight suboptions are modelled and presented in the figures:
- airport - Strict allocation (3-year cycle): fully modelled ‘Airport strict allocation’;
- airport - Strict allocation (1-year cycle): adapted from Airport - Strict allocation (3-year cycle), not shown;
- airport - Soft allocation (3-year cycle): fully modelled, not shown for readability reasons, results are almost identical with ‘Airport strict allocation’;
- fuel supplier - Auctioning state: fully modelled ‘Fuel/Airline Auctioning State’, modelling identical with Airline - Auctioning state;
- fuel supplier - Auctioning funnelled back: fully modelled ‘Fuel/Airline Funneled back, modelling identical with Airline - Funneled back;
- fuel supplier - no stability: adapted from Fuel supplier - Auctioning state, not shown;
- airline - Auctioning state: fully modelled ‘Fuel/Airline Auctioning State’, modelling identical with Fuel Supplier - Auctioning state;
- airline - Funnelled back: fully modelled ‘Fuel/Airline Funneled back, modelling identical with Fuel Supplier - Funneled back.

Figure 2 - Relative CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the reference scenario

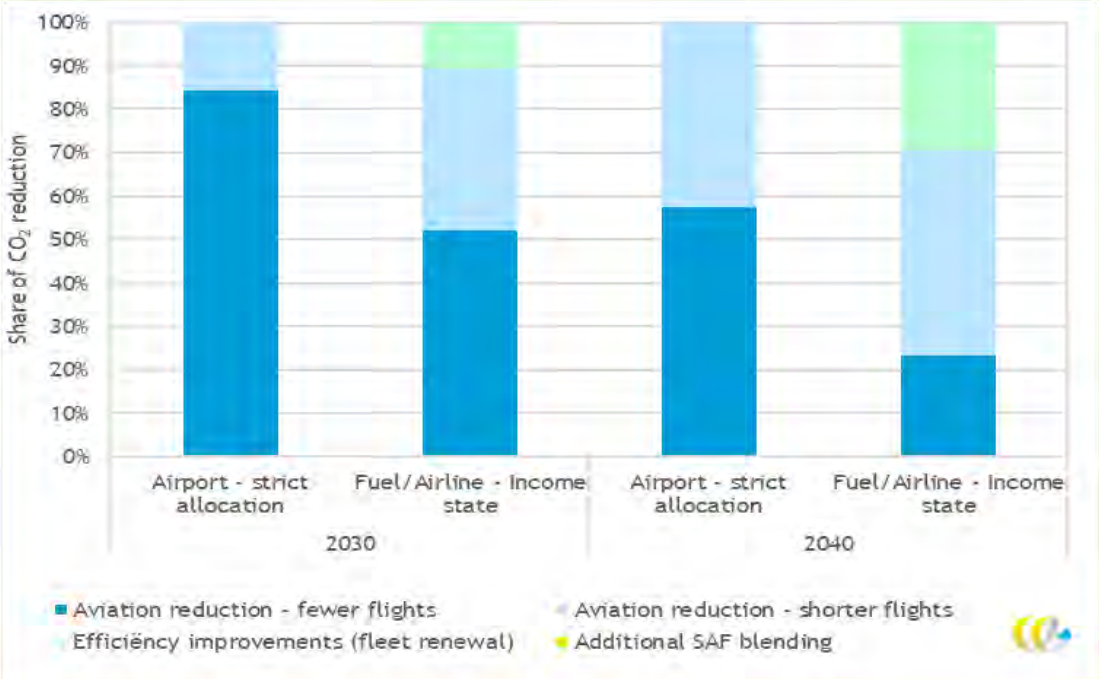
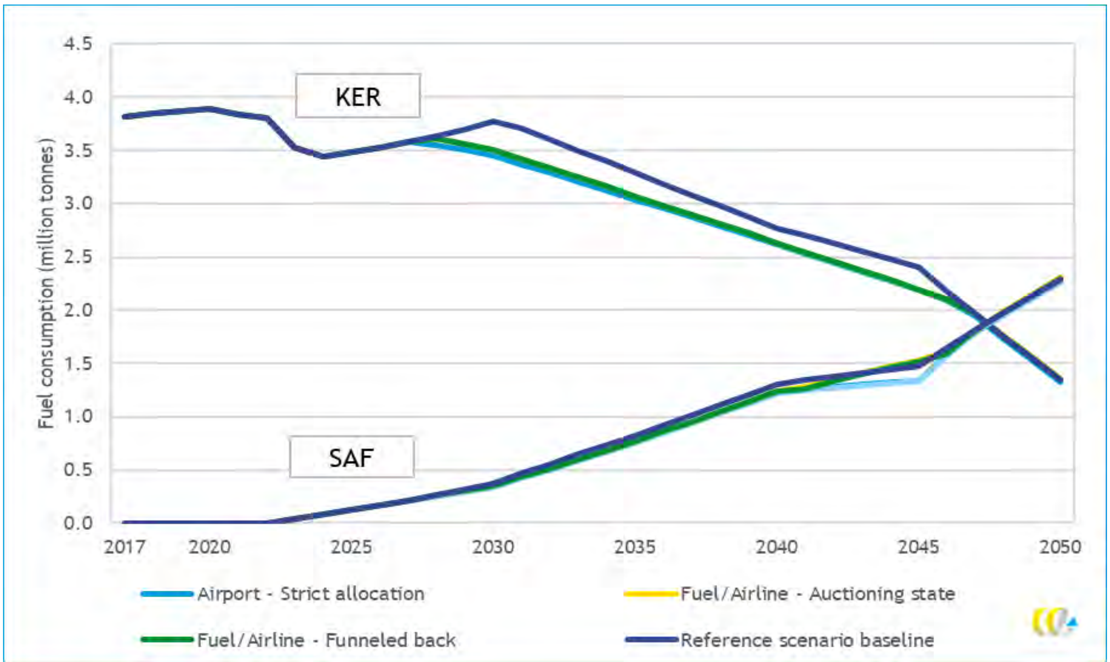
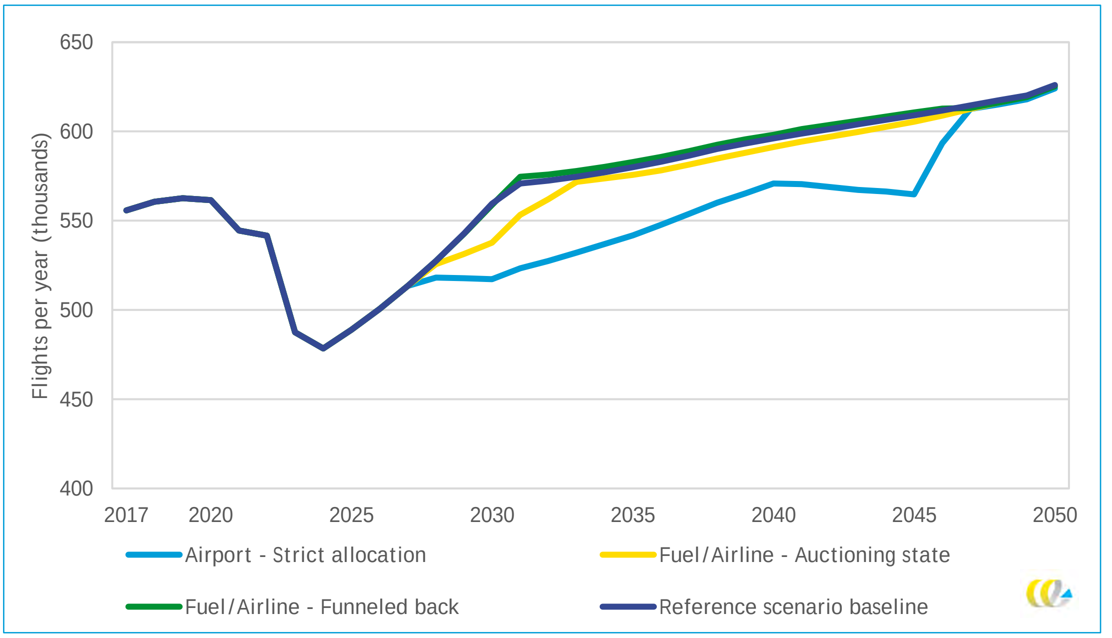


Figure 3 - Development of the consumption in fossil kerosene and SAF at Dutch airports in the reference scenario



The CO_2 ceiling has an impact the number of flights in scenarios where emissions exceed the ceiling (Figure 2). In the airport options, both intra-EEA and intercontinental flights are reduced compared to the baseline when airlines act in their own interest and do not take voluntary action to reduce emissions (Figure 5 and Figure 6). In the fuel supplier and airline options, the number of intercontinental flights is reduced to almost the same level as in the airport option. However, because the airport capacity is not changed in these options, this allows for an increase in intra-EEA flights, which have significantly lower emissions than intercontinental flights. The overall number of flights is hardly affected by the airline and fuel supplier options.

Figure 4 - Total number of flights at Dutch airports in the reference scenario



Note: the stepwise development in the airport option is the result of the stepwise development of SAF blending mandate in Fit for 55, the linear reduction of the CO_2 ceiling and the modelling of the airport option in which no additional SAF is blended in voluntarily by airlines.

Figure 5 - Total number of intercontinental flights at Dutch airports in the reference scenario

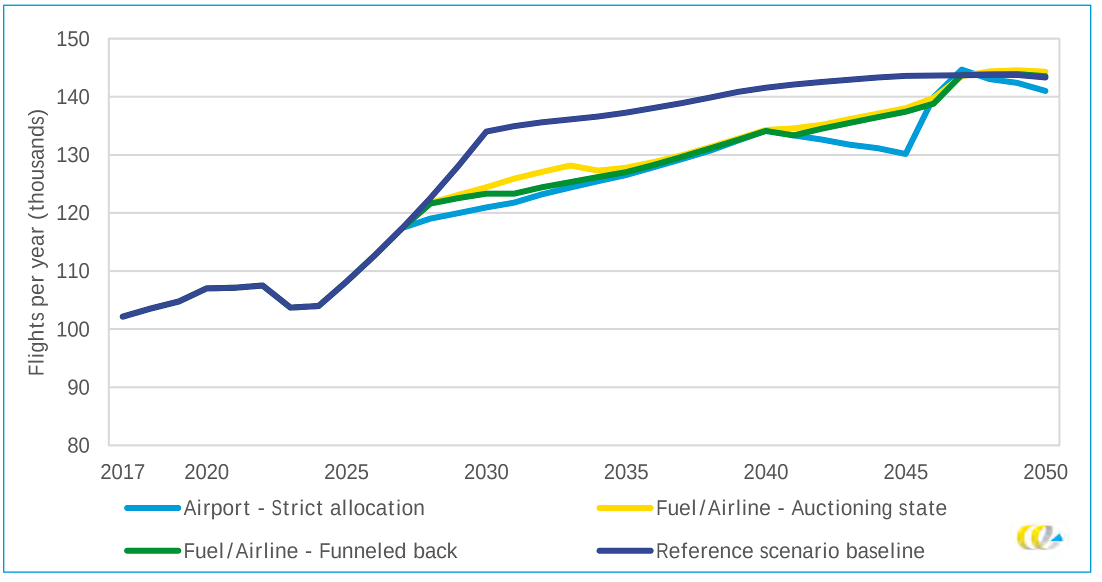
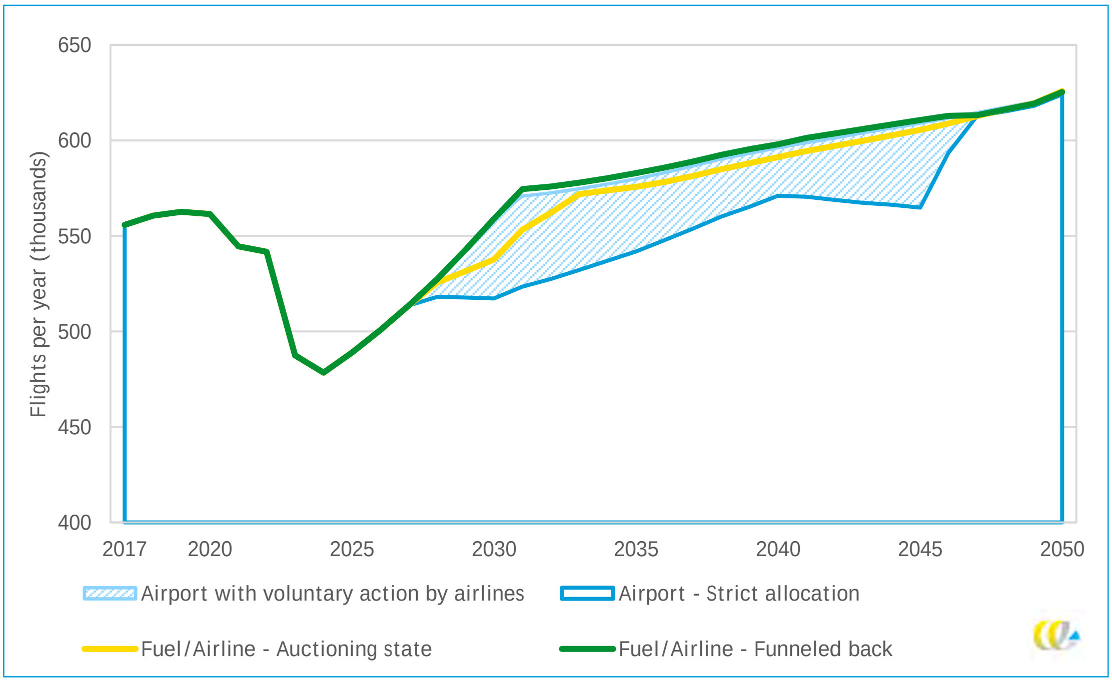


Figure 6 - EEA flights at Dutch airports in the reference scenario

In case airlines would take voluntary action to prevent a reduction in the number of flights in the airport option (e.g. by tankering fuel, by increasing the amount of SAF used on flights departing from the Netherlands), the impacts on the number of flights would be reduced and would become more similar the fuel supplier and airline options. The shaded area in Figure 7 indicates there the number of flights could end up if airlines would take voluntary action.

Figure 7 - Total number of flights at Dutch airports in the reference scenario when airlines voluntarily reduce their emissions in order to avoid a reduction in airport capacity



The number of passengers changes approximately in line with the number of flights. The number of transfer passengers at Dutch airports is reduced compared to the baseline in all policy options because the costs of transferring at Schiphol increases and transfer passengers have a high price elasticity of demand. The number of OD passengers is lower than the baseline in the airport options, because the number of flights is reduced. It remains close to the baseline in the fuel supplier and airline options in which the auctioning revenue flows in the general government budget because (intercontinental) transfer passengers are replaced by (intra-European) OD passengers and it increases when the revenues are funnelled back, because ticket prices, especially on intra-EEA flights, are lower than when revenues are retained by the State so the number of OD passengers increases further.

A share of the OD passengers who will no longer fly to or from Dutch airports, will fly to or from airports in neighbouring countries instead (evasion). In 2030, this share is about 60% in the airport options. In the fuel supplier and airline options we see an increase in Dutch OD passengers with EEA destinations, therefore there is no evasion for EEA passengers. However, for passengers with intercontinental destinations we also see about 60% evasion in these options. Note that the percentages mentioned here are shares of the decrease in OD passengers using Dutch airports. If we look at the share of the total number of OD passengers in baseline, we are talking about 1.0 to 2.6% evasion to foreign airports. For transfer passengers evasion is possible by either flying via another hub or flying direct. We find that evasion of transfer flights is similar for all options in 2030, about 60-70% of the decrease in Dutch transfer passengers use a foreign hub and about 25-35% take a direct flight instead. If we look at the share of the total number of transfer passengers in baseline, we are talking about 7.8 to 10.4% evasion to foreign hubs or direct flights. The fact that passengers use other airports implies that the competitiveness of Dutch airports is reduced.

The impact of the CO_2 ceiling on the competitiveness of Dutch airlines depends on the policy option. In the airport options, airline margins are increased because they reap scarcity rents, and Dutch airlines, as the major users of Dutch airports, benefit more from this than foreign airlines. On the other hand, the number of flights is reduced, and in the market for OD passengers, SkyTeam has the one-but largest decrease of all alliances and other airline groupings. This suggests that Dutch airlines are less able to compete on the OD passenger market, but, as a result of their higher margins, would gain competitiveness in other markets, including outside the Netherlands. In the fuel supplier and airline options, there are no scarcity rents due to the CO_2 ceiling. When auctioning revenues are retained by the State, the cost base for airlines increases and their ability to compete would be negatively affected. In that case, SkyTeam is also the second-worst affected on the market for OD passengers. When auctioning revenues are funnelled back, the impact on competitiveness depends on how they are funnelled back.

In the reference scenario, the impact of the CO_2 ceiling on fuel use is almost the same in all options: the use of fossil fuel decreases in line with the CO_2 ceiling while the use of SAF increases with the ReFuelEU Aviation requirements. Because the baseline emissions are only a few percent above the CO_2 ceiling, it is possible to reach the ceiling by reducing the number of flights (in the airport options) or by increasing the costs of using fossil fuels (in the fuel supplier and airline options).

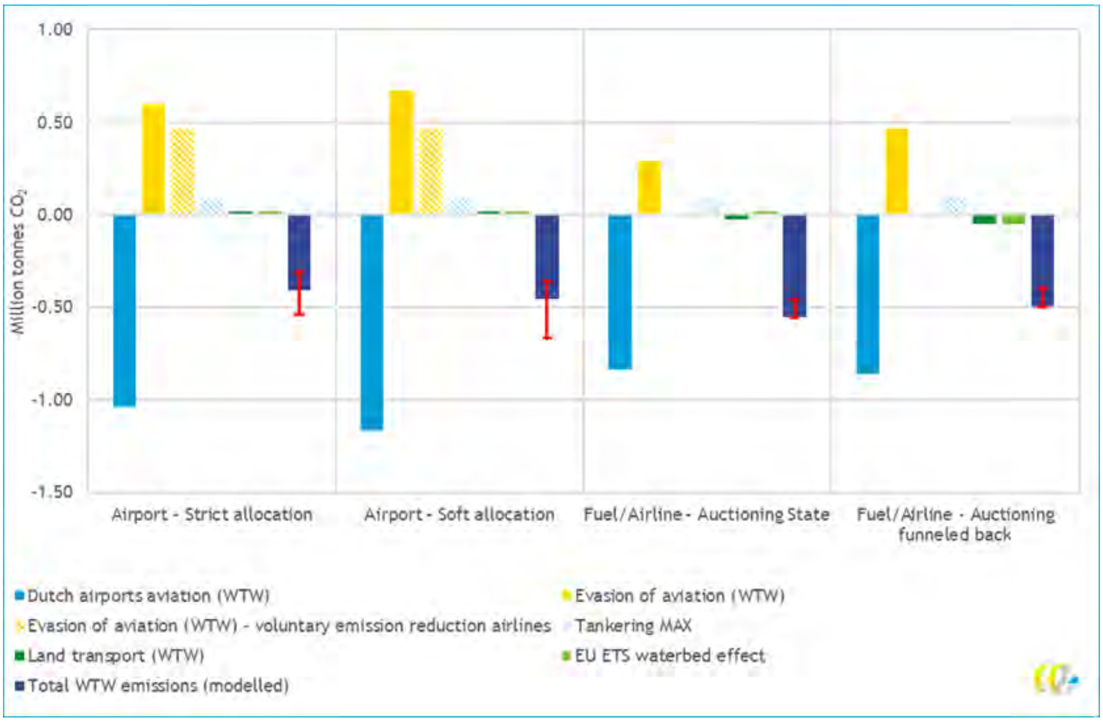
Environmental impacts of the CO_2 ceiling in the reference scenario

The main environmental impact of the CO_2 ceiling is the certainty it provides that the tank-to-wing CO_2 emissions from international commercial flights departing from Dutch airports do not exceed the ceiling (tank-to-wing emissions are the emissions caused by burning fuel).

The impacts on well-to-wing emissions (i.e. including emissions generated in fuel production) are somewhat higher than tank-to-wing emissions, because most sustainable aviation fuels have lower upstream emissions than fossil kerosene. In addition to these effects, there are other effects, some of which could be modelled and others which have been estimated. The modelled effects are higher emissions of flights from airports in other countries (because of rerouting OD and transfer passengers away from Dutch airports), higher emissions of land transport caused by mode choice adaption from air to road and rail, and (in some options) higher emissions of other installations in the EU ETS. All these impacts are presented as solid bars in Figure 8. The resulting impact on global CO_2 emissions is always negative (a decrease in emissions) and amounts to 39% of the reduction achieved at Dutch airports in the airport options to 58-66% in the fuel supplier and airline options.

The impact on emissions of flights departing from other countries depends on whether airlines take action to voluntarily reduce emissions, as discussed above. Such action cannot completely avoid rerouting of passengers, but the minimum emissions are indicated in a shaded column in Figure 8. Another possible behavioural response is an increase in tankering, also indicated as a shaded bar. The total effects of these behavioural responses are visualised with the error bar. We can see that the net global CO_2 emissions would still decrease in all cases, as indicated in Figure 8.

Figure 8 - Change in CO_2 emissions in the reference scenario



Note: in this figure we used a red error bar to show the uncertainty in the total WTW emissions due to voluntary emission reduction of airlines and increased inbound tankering.

The reduction of non-CO_2 climate impacts of aviation is of a similar magnitude as the CO_2 impacts when expressed in global warming potential over a 100-year period.

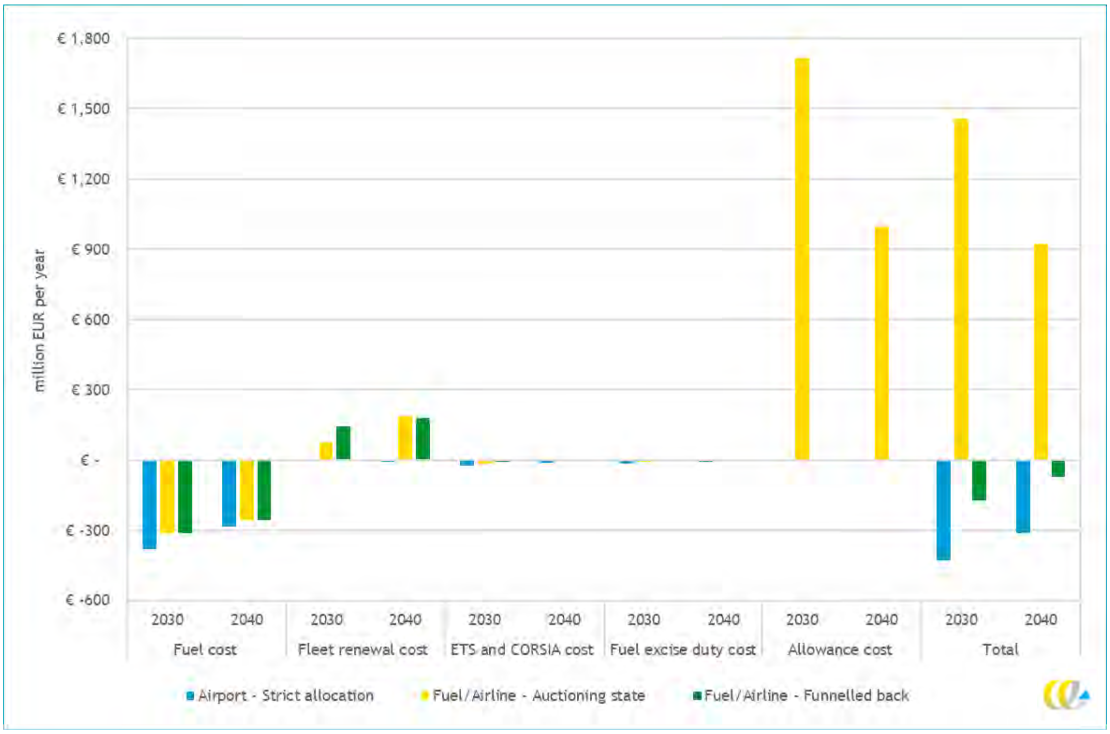
Air pollutant emissions at Dutch airports are decreased as a result of the reduction in the amount of (fossil) fuel used during landing and take-off. The reduction is larger in the airport options than in the other options because the number of flights is reduced to a greater extent (unless airlines voluntarily reduce their emissions to maintain airport capacity).

The impacts on airport noise are small. At Schiphol, the number of houses within the 58 dB Lden contour decreases by up to 13% (800 houses). The decrease is larger in the airport options, because the number of flights is reduced, than in the fuel supplier and airline options. At regional airports, the number of houses or severely annoyed persons in the noise contours changes by -1% - +8% against a rapidly declining baseline. The increase is the result of the increase in intra-EU flights in the fuel supplier and airline options.

Economic impacts of the CO_2 ceiling in the reference scenario

The compliance costs for airlines comprise fuel costs, fleet renewal costs, ETS costs, and excise duty, as well as costs of allowances and funnelled back revenues in some options. In all options, total fuel use decreases, which results in lower fuel costs (and also lower revenues, which are by definition not included in the compliance costs). Except for the options in which auctioning revenues are added to the general fiscal budget, the net compliance costs are negative because the decrease in fuel costs exceed cost increases in other items (see Figure 9).

Figure 9 - Compliance costs of CO_2 ceiling in the reference scenario



The administrative costs depend on the number of regulated entities and on whether empirical data are used to monitor compliance or modelled data. The costs vary from 0.5 million euro in the airport option to 5 million euro per year in the airline option, which is a few percent of the compliance costs at most.
Implementation of the CO_2 ceiling has a range of fiscal impacts. Most items are less than 50 million euro per year, except for two. The auctioning revenue in the fuel supplier and airline options when auctioning revenues are added to the general budget amount to 2 billion euro in 2030 and 1 billion in 2040. Indirect taxes on expenditures in the Netherlands (VAT, excise duties, etc.) would be reduced by 150 million euro in 2030 and 130 million in 2040 in the fuel supplier and airline options when the auctioning revenue is funnelled back to the sector, because the number of outbound tourists increases, who spend more abroad and less domestically.

The upstream and downstream economic impacts of the CO_2 ceiling have been calculated on the basis of changes in household expenditures. A change in the number of OD passengers results in a change in expenditures of non-residents in the Netherlands as well as a change in expenditures of those residents that do not travel. In all options in which the number of OD passengers decreases (i.e. all options except for the fuel supplier and airline options in which auction revenues are funnelled back), expenditures of non-residents decrease and expenditures of residents in the Netherlands increase. The latter effect is about twice as high as the former, and the overall balance is an increase of household expenditures in the Netherlands by 50 million to 150 million euro per year. Conversely, when the number of OD passengers increases, the total expenditures decrease by 350 million euro per year.

The CO_2 ceiling will have a small but positive impact on innovation, especially in the options that increase the costs of using fuel (i.e. the fuel supplier and airline options). In those options, existing emission reduction measures become more cost-effective. More radical innovations are unlikely because of the small scale of the Dutch emissions ceiling.

Social and safety impacts of the CO_2 ceiling in the reference scenario

The CO_2 ceiling has a negative impact on employment in the aviation sector which is larger for the options in which the number of flights or passengers is more reduced. At most, the sectoral employment could decrease by 8%.

The impacts on external safety are small but positive.

Impacts in other scenarios

As shown in Figure 1, emissions are projected to remain below the CO_2 ceiling in most other scenarios. In those scenarios, the impacts of the ceiling are constrained to administrative efforts, which could have a small impact on the costs of flying and consequently a small impact on aviation demand. This impact will be several orders of magnitude smaller than the impacts of the reference scenario.

A few scenarios project emissions to increase further above the CO_2 ceiling than in the reference scenario. The most extreme scenario is WLO High, Fit for 55 reduced, increased Dutch airport capacity and no additional Dutch SAF blending mandate. In that scenario, emissions increase to 70% above the ceiling (see Figure 1).

In this extreme scenario, the difference in impacts across the different policy options is more pronounced. The number of flights (Figure 10) in the airport options is reduced to well below the available capacity in order to keep CO_2 emissions below the ceiling. In contrast, the number of flights in the fuel supplier and airline options is reduced to a lesser extent or even tracks the available capacity when auctioning revenues are funnelled back to the sector.

Figure 10 - Total number of flights at Dutch airports in the highest growth scenario (Scenario 6)

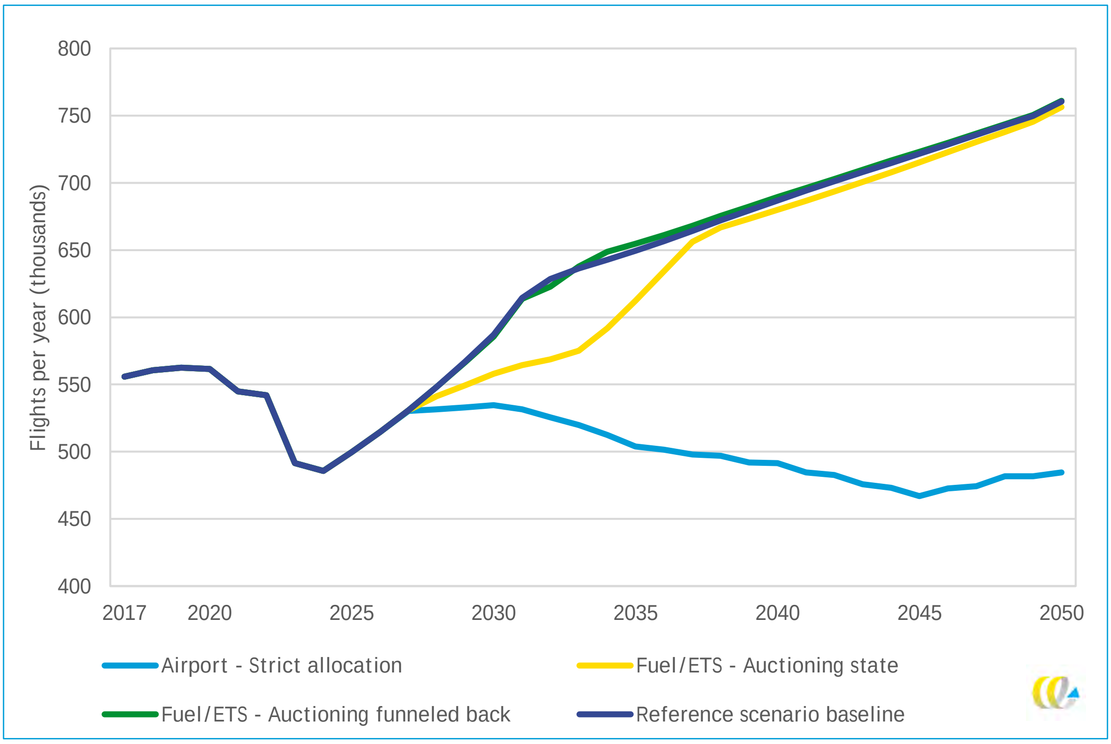


Figure 11 shows how airlines choose to reduce their CO_2 emissions in the different suboptions. Compared to the reference scenario (see Figure 2) the CO_2 reductions are much higher in the extreme scenario. This results in higher CO_2 costs, which make additional SAF blending cost-effective before 2040. The differences in fuel use between the options are shown in more detail in Figure 12. In all options, the fossil fuel use is reduced in line with the CO_2 ceiling. However, in the Fuel/Airline options a significant amount of extra SAF is blended from 2033. Because of the additional SAF blending and efficiency improvements, the effects on the network quality are relatively small compared to the airline option.

Figure 11 - Relative CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the extreme scenario

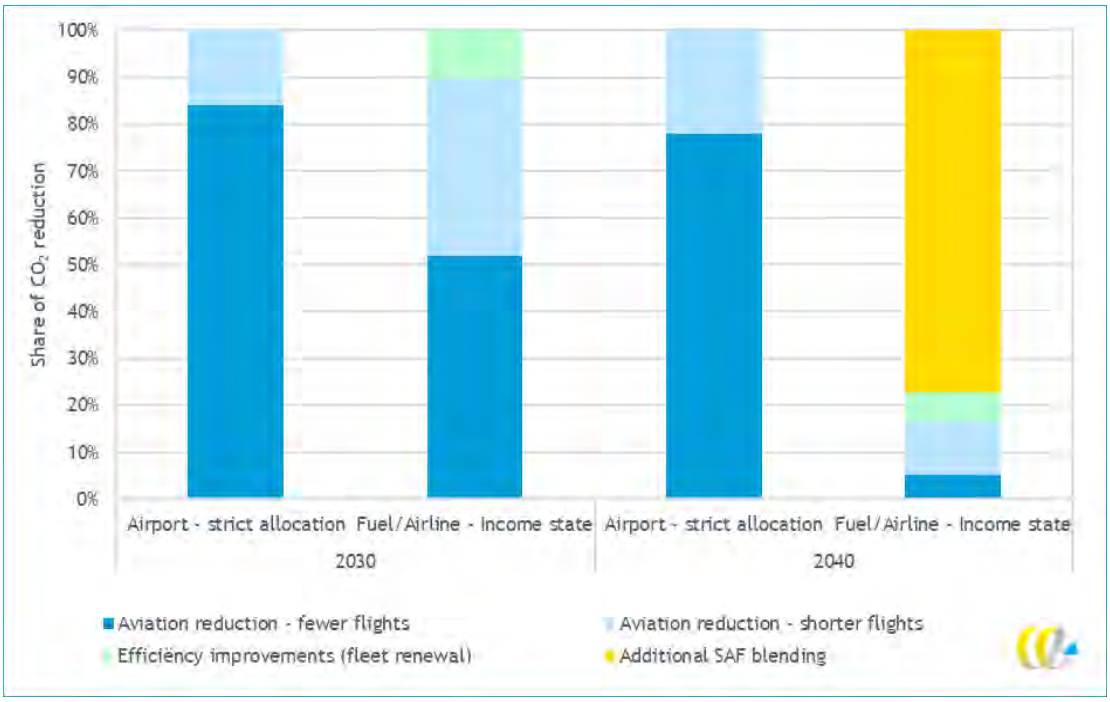
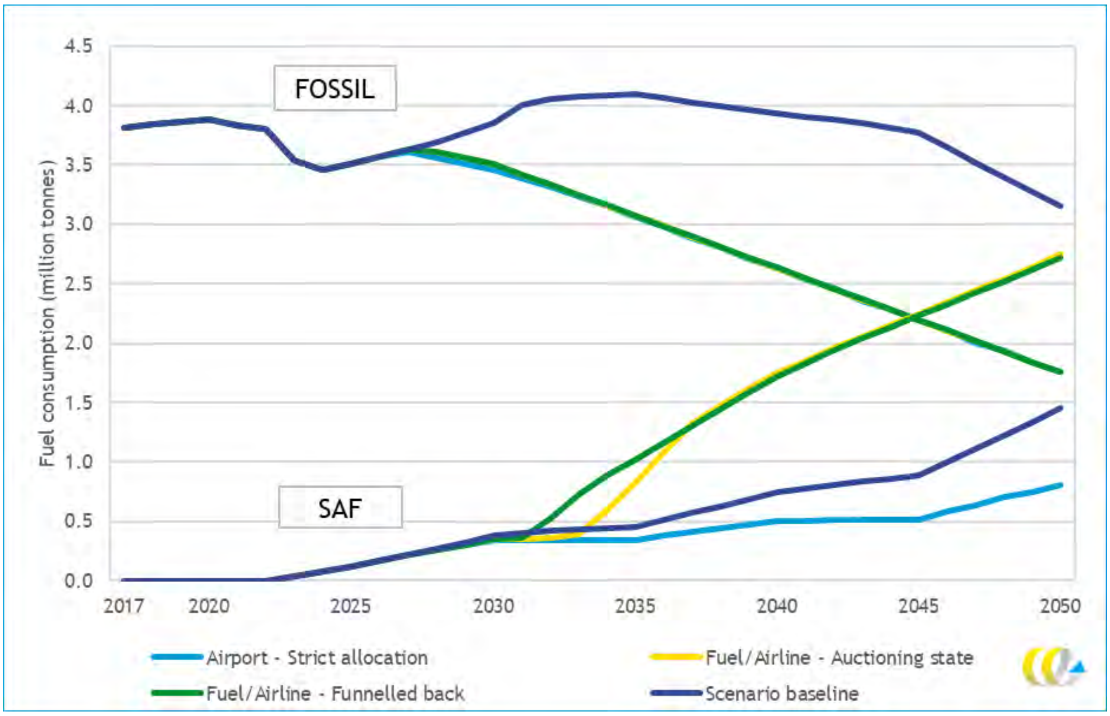


Figure 12 - Fossil fuel and SAF consumption in the highest growth scenario (Scenario 6)



How do the options compare?

The main objective of the CO_2 ceiling is to safeguard that the emission limits which were set by the Dutch government are not surpassed. In general, all suboptions are able to meet this requirement. However, the airport option with a 3-year enforcement cycle (either soft- or strict allocation) scores better compared to the alternatives on this point in the multicriteria analysis. This is mainly because the implementation is reasonably simple (within the existing airport permits) and the risk of international retaliation is comparably low. In addition, the number of regulated entities (Dutch airports) is small (compared to the airlines in the airline option) and all entities are situated in the Netherlands. However, the regulated entities have less direct control over CO_2 emissions than fuel suppliers and airlines. Because of the limited flexibility the airport option with a one year enforcement cycle scores lower than the airport options with strict allocation.

The CO_2 ceiling is designed to achieve its main objective, but by doing so it also causes other effects. When comparing the options with respect to the other effects, it becomes clear that different suboptions perform well on different criteria. All options lead to a significant overall CO_2 reduction. In the airport option this is mainly achieved by a reduction in the number of aircraft movements at Dutch airports, whereas in the fuel supplier option and the airline option blending additional SAF and contributes significantly to the additional CO_2 reduction. The ceiling per airport suboptions score well on overall costs and local environmental impacts. Furthermore, there are differences between the suboptions where the auctioning income is for the state versus the suboptions where the income is funnelled back: the latter scores better on overall costs and impacts on the aviation sector. Also the impacts on the Dutch GDP are negative for these suboptions. It is important to consider that the state revenues that are generated in suboptions of the fuel supplier and the airline option can be used for other purposes, for instance to subsidize the development of sustainable aviation or contribute to other benefits for the society.

A fundamental difference between the options is who benefits from measures that decrease CO_2 emissions. In the airport option the benefits are collectively distributed, which means that more slots become available for the collective of airlines operating at Dutch airports. In the fuel supplier and airline options airlines are individually stimulated to decrease emissions, because additional costs are attached to CO_2 emissions. In case the collective stimulus would lead to unintended reactions of the airlines, the Dutch government could decide to implement additional measures to correct for this.

It should also be noted that in the majority of baseline scenario's the emissions never reach the ceiling. In those scenario's, only the feasibility of implementation, administrative costs and the risk of retaliation are relevant. Only if the ceiling would be surpassed in the baseline, the CO_2 ceiling has additional impacts on the aviation sector, the environment and the economy.

In this study we did not determine a preferred policy option, since this implies that relative weights are given to the different criteria. This is a political decision that should not be made by the research team. The main arguments for the airport option are the rather straight forward implementation in the existing airport permits and the relatively low risk of international retaliation. The main argument for the fuel supplier and the airline option are that the regulated entities have better possibilities to control over the CO_2 emissions and that airlines are individually stimulated to reduce their CO_2 emissions.

The outcomes of the multicriteria analysis are summarized in Table 2.

Table 2 - Comparison of all the criteria in the multicriteria analysis

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Certainty about aviation CO_2 emissions	+	0	+	0	0	0	0	0
Total climate impacts	++	++	++	++	++	++	++	++
Overall costs	0	0	0	0	-	0	-	-
Overall impact on the local environment of airports	++	++	++	+	+	+	+	+
Impacts on aviation sector	-	-	-	-	0	-	-	0

1 Introduction

The Civil Aviation Policy Memorandum contains the aim to limit CO_2 emissions of Dutch aviation to 2005 levels by 2030, reduce them by 50% (relative to 2005) by 2050 and to zero by 2070 (Ministerie van Infrastructuur en Waterstaat, 2020). In order to safeguard that the goals will be met, the Civil Aviation Policy Memorandum proposes to implement a so-called CO_2 emissions ceiling for the international aviation sector (the 'CO_2 ceiling'). The aim of this measure is to guarantee that agreed emission goals are met. Thus, it sets clear limits for permitted CO_2 emissions, with the possibility for the aviation sector to earn growth within those boundaries by introducing technological innovations.

The aim to introduce a CO_2 ceiling has been reaffirmed by the current government of The Netherlands in its Coalition Agreement. Moreover, the Dutch Parliament has supported the introduction of a CO_2 ceiling through two separate motions.[4] As part of the preparation for a legislative proposal, the ministry of Infrastructure and Water Management has commissioned an integral impact assessment of various options for implementation of the CO_2 ceiling.[5]

1.1 Introduction to the report

This is the report of the impact assessment of a CO_2 emissions ceiling for international commercial flights departing from Dutch airports.

The purpose of the impact assessment is to:
- evaluate ex-ante the effectiveness of the CO_2 emissions ceiling in safeguarding that the agreed emission targets are met;
- analyse which impacts a CO_2 emission ceiling would have on the aviation sector, the environment, the economy and in the social domain;
- assess when those effects are likely to occur and what their magnitude would be.

The study has been commissioned by the Dutch Ministry of Infrastructure and Water Management and written by a consortium led by CE Delft and comprising ADECS Airinfra, ADSE, Erasmus University Rotterdam and TAKS.

1.2 Outline of the report

The report starts with a definition of the problem in Chapter 2. This chapter introduces the political and legal context, presents projections of CO_2 emissions in the baseline scenarios and analyses why the Dutch government should act to ensure that emissions remain below the ceiling. It defines the objectives and analyses the options to achieve the objectives. Chapter 3, 4, 5 and 6 present the impacts on respectively Dutch aviation, the economy, the environment and on jobs and safety. Chapter 7 compares the policy options by presenting a multicriteria analysis. Chapter 8 contains the conclusions.

[4] Motie Paternotte/Stoffer over een CO_2-emissieplafond voor de gehele Nederlandse commerciële luchtvaart - Luchtvaartbeleid - Parlementaire monitor.
Motie Paternotte/Amhaouch over een uitwerking van het CO_2-emissieplafond aan de Kamer voorleggen - Luchtvaartbeleid - Parlementaire monitor

[5] Kamerstuk 31936, nr. 889 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

In the annex additional detailed information on the scenarios and the results are presented. This includes a note written by To70 and SEO with the title ‘Second opinion – airport and airline response to CO_2 ceiling per airport’ (Annex I).

2 Problem definition

2.1 Political and legal context

The Civil Aviation Policy Memorandum contains the aim to limit CO_2 emissions of Dutch aviation to 2005 levels by 2030, reduce them by at least 50% (relative to 2005) by 2050 and to zero by 2070 at the latest (Ministerie van Infrastructuur en Waterstaat, 2020). These in-sector emission targets apply to commercial international flights departing from Dutch airports. Emission reductions achieved in other sectors or countries do not count towards achieving the goal, regardless of whether they result from mandatory legislation (e.g. EU ETS or CORSIA) or are the result of voluntary action.
In order to meet the CO_2 emission goals a number of emission reduction measures can be used, such as using sustainable aviation fuels (SAFs), fleet renewal, hybrid-electric or electric flying, airspace optimalisation and implementation of the Single European Sky (Duurzame Luchtvaarttafel, 2019). At the time of drafting the Sustainable Aviation Agreement, participants recognised that while the contribution of these measures is uncertain, the overall target was found to be achievable because the total technical reduction potential of all the measures combined exceeded the targets (Delft & TAKS, 2018). In other words, if one or a few measures would deliver fewer emission reductions, the contribution of others to the overall target could increase.

In order to safeguard that the CO_2 emission goals will be met, the Civil Aviation Policy Memorandum proposes to implement a so-called Dutch CO_2 emissions ceiling for the international aviation sector (the 'CO_2 ceiling'). The CO_2 ceiling can be regarded as a guarantee that the CO_2 emission reduction targets are actually being achieved. It does not directly mandate emission reductions, as there are other policy instruments which do so, both at a national, European and global level, in addition to voluntary action by stakeholders. Thus, the CO_2 ceiling is part of a three-pronged approach, in which the emission targets describe what is to be achieved, the CO_2 ceiling safeguards that the targets are achieved and the other climate instruments determine how they are achieved.

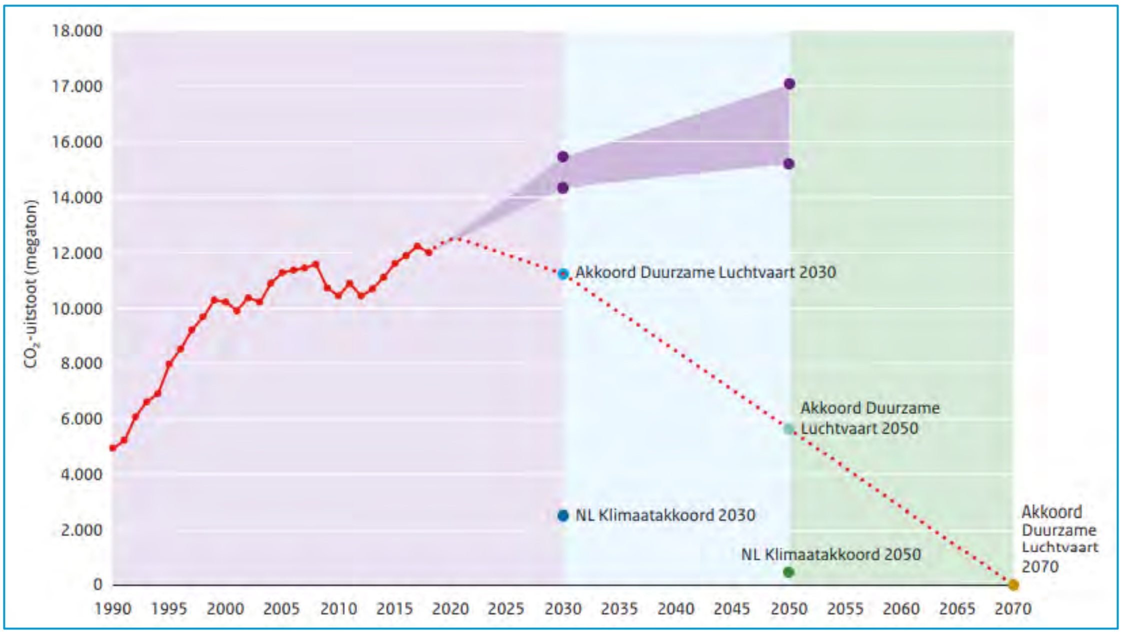
The aim to introduce a CO_2 ceiling has been reaffirmed by the current government of The Netherlands in its Coalition Agreement and supported by the Dutch Parliament in two parliamentary motions.[6]

2.2 Objectives: what is to be achieved

The Civil Aviation Policy memorandum contains explicit goals for 2030, 2050 and 2070, as well as a graph indicating the historical and projected emission of aviation, a hyphenated line between the targets in the target years, and a comparison with other Dutch targets for the wider economy: 50% reduction by 2030 relative to 1990, and 95% reduction by 2050 relative to 1990. The graph is reproduced below as Figure 13.

6 Motie Paternotte/Stoffer over een CO_2-emissieplafond voor de gehele Nederlandse commerciële luchtvaart - Luchtvaartbeleid - Parlementaire monitor
Motie Paternotte/Amhaouch over een uitwerking van het CO_2-emissieplafond aan de Kamer voorleggen - Luchtvaartbeleid - Parlementaire monitor

Figure 13 - Historical and projected CO_2 emissions of Dutch aviation, aviation CO_2 emission targets



Source: (Ministerie van Infrastructuur en Waterstaat, 2020).

The temperature goals agreed in the Paris Agreement depend on the concentration of greenhouse gases in the atmosphere, which, for long-lived greenhouse gases like CO_2, depend on the cumulative emissions. This notion, often referred to as the 'carbon budget' (Lahn, 2020), is relevant for determining the shape of the curve between the target years. It is clear that a concave curve between the target years generates higher cumulative emissions until 2070 than a convex curve. Moreover, the targets for 2030, 2050 and 2070 are on a straight line. A non-linear connection between the target years would result in discontinuities in the pace of emission reductions which could weaken the predictability of the ceiling. Hence, a linear line between the target years is the middle ground and arguably also the most policy neutral interpretation of the CO_2 ceiling.

As stated in Section 2.1, the purpose of the CO_2 ceiling is to guarantee that the emission goals are met.

2.3 Projections of aviation emissions and problem definition

The impacts of the CO_2 ceiling depend on how emissions would evolve without intervention.

Dutch regulatory impact assessments are generally based on two long-term socio-economic scenarios, called WLO High and Low, representing a relatively high and a relatively low economic growth scenario, respectively, the scenarios have been designed to capture a significant share of the plausible variation, but not the extremes (CPB & PBL, 2016). For aviation, two scenarios have been developed which apart from demographic and economic projections take airport capacity constraints into account (CPB & PBL, 2016).

The WLO scenarios for aviation have been defined in 2015 and updated in 2018. They do not take into account the impacts of the Covid-19 pandemic. The scenarios have been adjusted to incorporate the speed and share of the recovery of demand, as described below.

In addition, there are three policy decisions that will be taken in the near future and which could have significant impacts on the emissions of Dutch aviation. These decisions are not sufficiently reflected in the WLO scenarios. These are:
1. Government policy on capacity at Dutch airports.
2. The legislative proposals of the European Commission in the Fit for 55 package addressing aviation emissions.
3. Dutch climate policy for aviation, in particular SAF blending policy.

New baseline scenarios have been developed to take the uncertainty emerging from these decisions into account. Each will be described below.

The speed and share of the recovery of demand from the COVID-19 pandemic

With regards to the speed and share of the recovery of demand from the COVID-19 pandemic, this study follows the assumptions of the Climate and Energy Outlook 2021 of the Dutch Environmental Assessment Agency (PBL Netherlands Environmental Assessment Agency, 2021), which makes the following assumptions:
1. Overall leisure demand returns to 2019 levels by 2024; Business demand is reduced by 5% relative to 2019.
2. Ticket prices are 3% higher between 2024 and 2030 in order for airlines to pay back emergency loans.
3. Accelerated growth rates of demand between 2024 and 2038 so that by 2038, leisure demand is back on its pre-COVID path by 2038 and business demand is 5% lower.

These assumptions are applied to the WLO High and WLO Low passenger demand baselines in the AOLUS model.

Government policy on capacity at Dutch airports

In order to account for the uncertainty about the future development of airport capacity in the Netherlands, three scenarios have been developed:
1. High airport capacity (Capacity at Schiphol is gradually increased to 630,000 aircraft movements per year in 2050, which is considered to be the maximum within current operational and safety constraints; Lelystad Airport gradually expands to 45,000 movements by 2050; and the capacity at Eindhoven is gradually increased to 55,000 movements by 2050).
2. Middle airport capacity (Capacity at Schiphol is kept constant at the current limit of 500,000 movements; Lelystad and Eindhoven develop in the same way as in the high capacity scenario).
3. Low airport capacity (the mirror image of high capacity).

For each of these scenarios, a set of baselines has been developed.

Fit for 55

The European Commission has issues four legislative proposals which affect aviation fuel or emissions, notably the ReFuelEU Aviation policy proposal (EC, 2021e), the proposed revision of the Renewable Energy Directive (EC, 2021d), the Energy Tax Directive (EC, 2021a) and the Directive for the European Emissions Trading Scheme (EC, 2021b). The Council and the

Parliament have agreed on positions on ReFuelEU Aviation, RED, and EU ETS. They will start a trilogue in the second half of 2022 in order to agree on legislative texts to be adopted. In this process, provisions and levels of ambition may change. In order to reflect possible outcomes of this process, three scenarios have been developed:
1. Increased ambition (EU ETS, RED and ETD are implemented as proposed, and the blending targets of ReFuelEU Aviation are multiplied by 150%).
2. As proposed (all proposals are adopted as proposed).
3. Reduced ambition (EU ETS and RED are implemented as proposed, the energy tax for aviation fuels is not adopted and the blending targets of ReFuelEU Aviation are multiplied by 50%).

For each of these scenarios, a set of baselines has been developed.

Dutch climate policy for aviation

The Civil Aviation Policy Memorandum contains the aim to blend 14% SAF in 2030 and 100% in 2050. In view of the ReFuelEU Aviation proposal, which also requires SAF to be blended, it is not clear whether the Netherlands will implement legislation to reach these targets. In order to reflect this uncertainty, three scenarios have been developed:
1. Increased ambition (an annual growth rate twice as high as proposed).
2. Ambition as proposed (14% SAF by 2030 and 100% by 2050 with constant annual growth rates for the years in between).
3. Reduced ambition (no additional Dutch SAF blending).

For each of these scenarios, a set of baselines has been developed.

In total, 54 baselines have been developed (see Table 3). More information is provided in Annex B. For 36 baseline scenarios, emission projections have been made with the AEOLUS model (in the other eighteen scenarios, emissions will remain below the CO_2 ceiling for the entire period, because increased Dutch SAF blending reduces emissions to well below the ceiling).

Table 3 - Overview of baseline scenarios

EU policy	NL SAF policy	WLO Low			WLO High		
		Airport capacity			Airport capacity		
		Low	Middle	High	Low	Middle	High
Fit for 55 reduced ambition	Reduced ambition	1	2	3	4	5	6
	As proposed	7	8	9	10	11	12
	Increased ambition	13	14	15	16	17	18
Fir for 55 as proposed	Reduced ambition	19	20	21	22	23	24
	As proposed	25	26	27	28	29	30
	Increased ambition	31	32	33	34	35	36
Fit for 55 increased ambition	Reduced ambition	37	38	39	40	41	42
	As proposed	43	44	45	46	47	48
	Increased ambition	49	50	51	52	53	54

Figure 11 and Figure 12 present the CO_2 emission projections in scenarios in which the Fit for 55 proposals of EU ETS, ReFuelEU Aviation and the Energy taxation Directive are implemented as proposed by the Commission, in WLO high and WLO low respectively. In WLO high (Figure 11), passenger and freight demand are higher than in WLO low (Figure 12) because GDP and GDP per capita are higher. As a result, CO_2 emissions are higher in WLO high than in WLO low for otherwise similar scenarios.

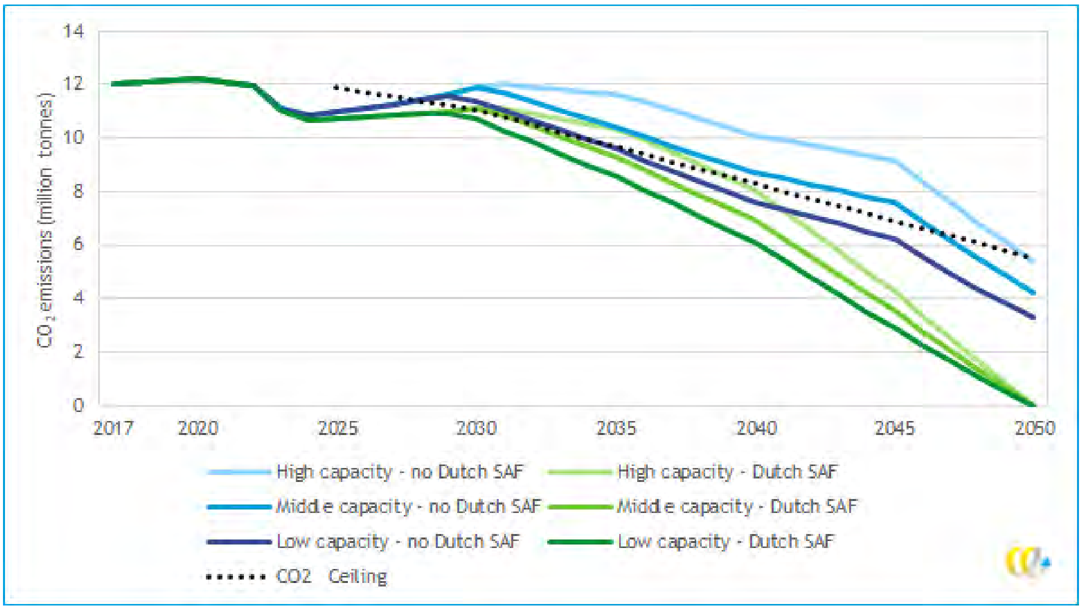
The blue lines represent scenarios without additional Dutch SAF blending (SAF is just blended up to the levels required by RefuelEU Aviation). In that case, emissions are higher than when more SAF is blended, as indicated by the green lines.

When the airport capacity is reduced over time ('low capacity'), there are fewer aircraft movements from Dutch airports and consequently lower emissions than when capacity is increased by a smaller number of flights ('middle capacity') or by a higher number of flights ('high capacity').

In WLO high (Figure 14), the emissions exceed the CO_2 ceiling when there is no additional SAF blending in the Netherlands. When a Dutch SAF blending policy is introduced as announced in the Civil Aviation Policy Memorandum, emissions stay below the ceiling unless the airport capacity is increased.

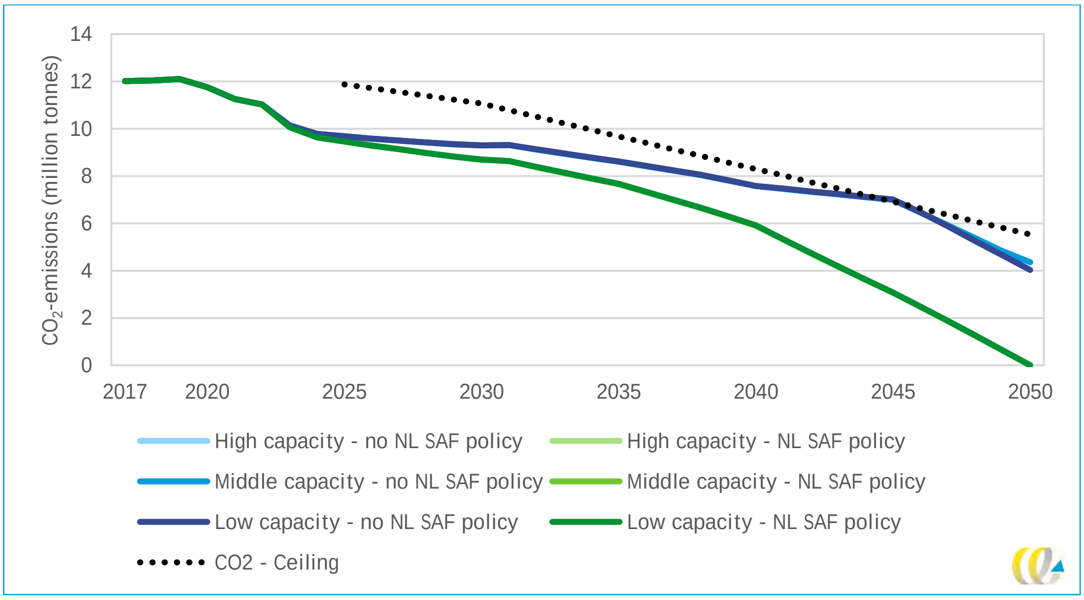
In WLO low (Figure 15), emissions are projected to remain below the ceiling with the exception of a short period around 2045 in case there is no Dutch SAF blending policy (after 2045, the required SAF blending stemming from ReFuelEU Aviation increases significantly, pushing down CO_2 emissions).

Figure 14 - **CO_2** emission projections in baseline scenarios WLO high, Fit for 55 as proposed



Source: This report.

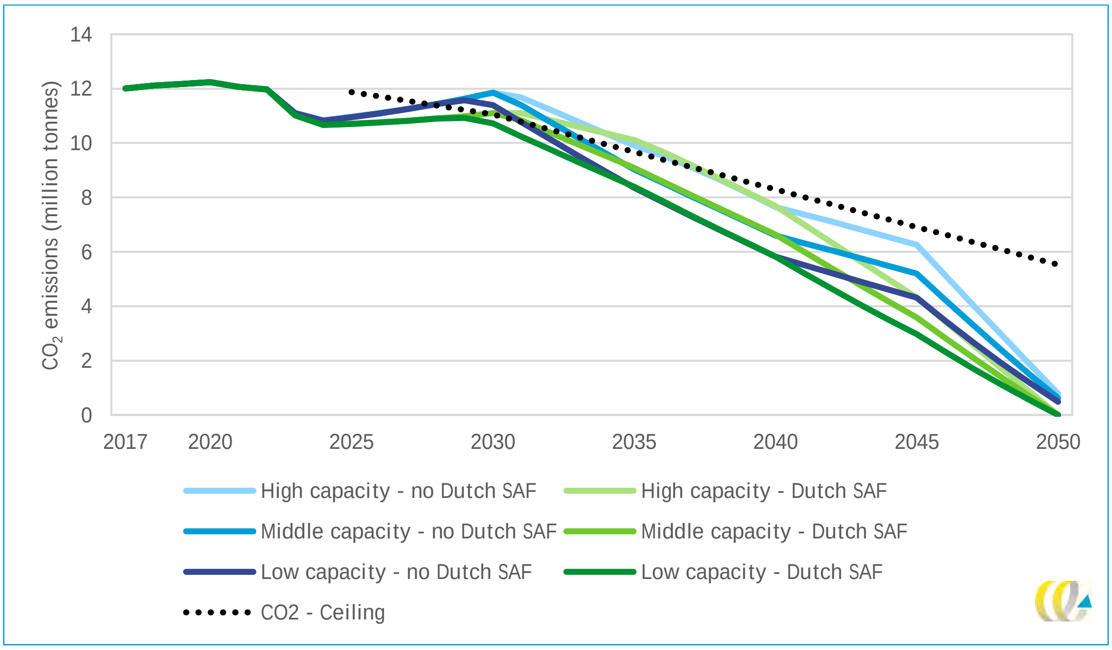
Figure 15 - CO_2 emission projections in baseline scenarios WLO low, Fit for 55 as proposed



Source: This report.

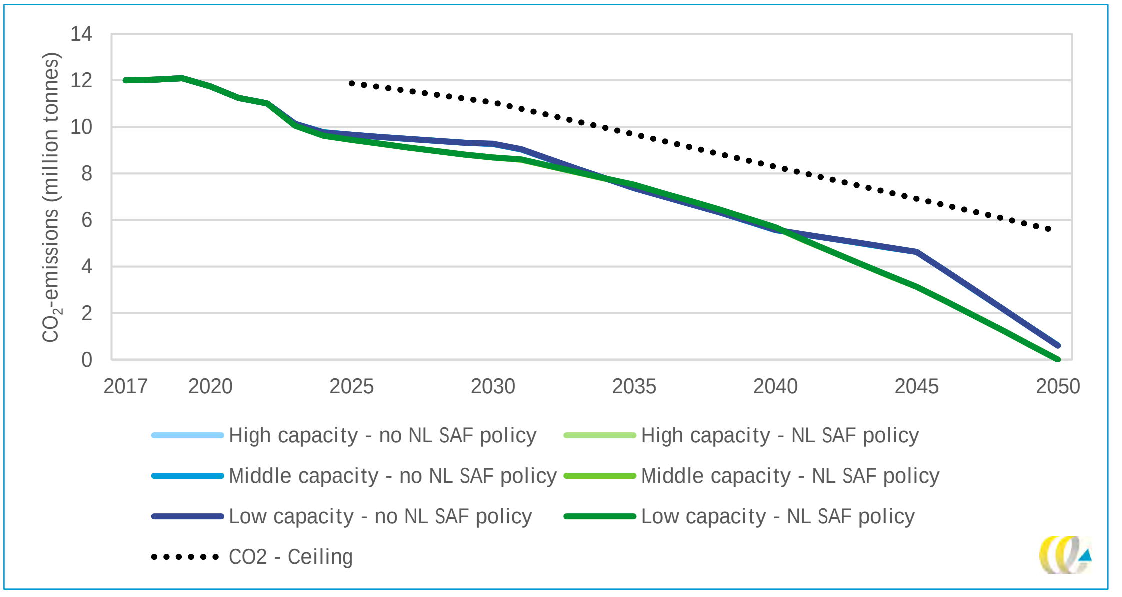
Figure 16 and Figure 17 present emission projections in case the ambition of the Fit for 55 proposals is increased. Because this implies a higher SAF blending under ReFuelEU Aviation, emissions decrease. As a result, emissions are projected to be above the ceiling for a relatively limited amount of time in WLO high (Figure 16) and will remain below the ceiling in WLO low (Figure 17).

Figure 16 - CO_2 emission projections in baseline scenarios WLO high, Fit for 55 increased ambition



Source: This report.

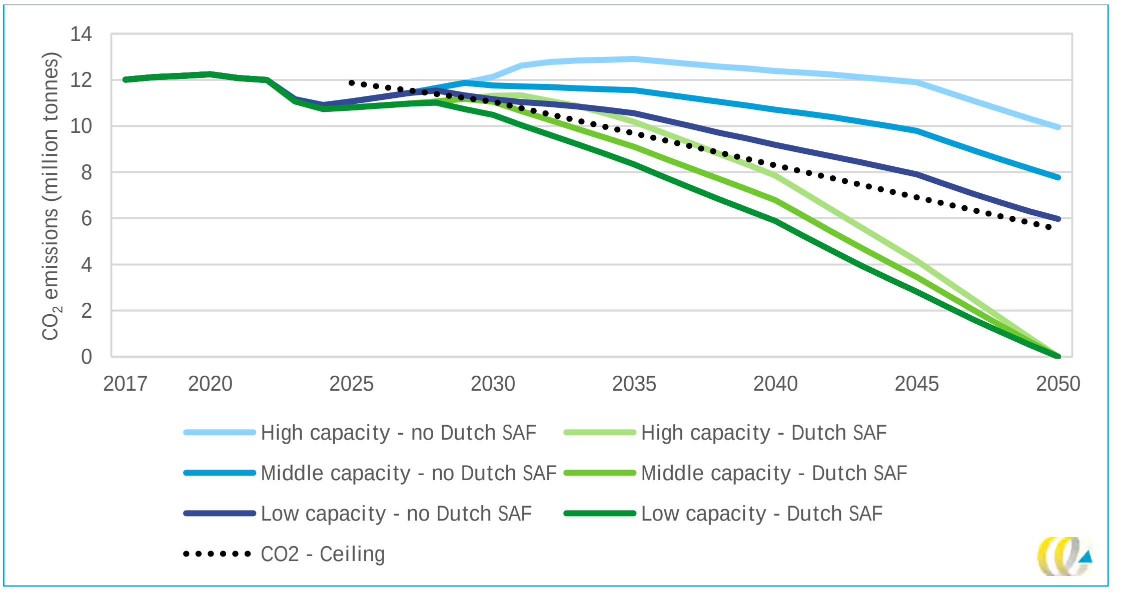
Figure 17 - CO_2 emission projections in baseline scenarios WLO low, Fit for 55 increased ambition



Source: This report.

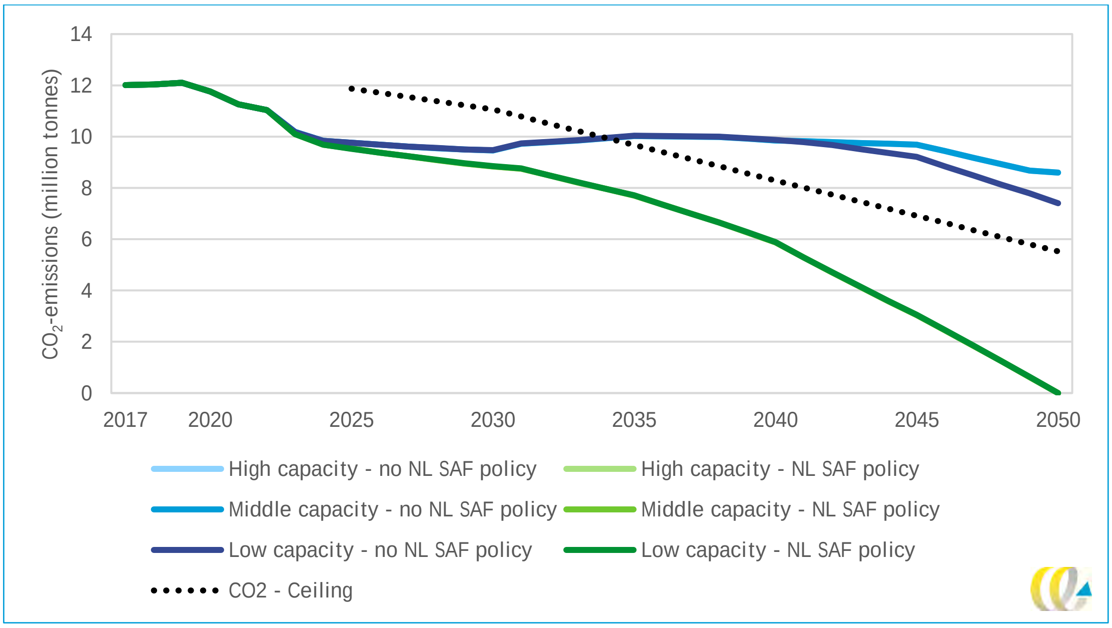
Figure 18 and Figure 19 show the projected emissions in case the levels of ambition of the Fit for 55 proposals is reduced. In that case, emissions are projected to remain above the CO_2 ceiling in absence of an additional Dutch SAF policy, regardless of the WLO scenario or the airport capacity. In WLO high, emissions surpass the ceiling between 2025 and 2030, and in WLO low around 2035. When a Dutch SAF policy is introduced, emissions are projected to remain below the ceiling except for the WKLO high scenario coupled with an increase in airport capacity.

Figure 18 - CO_2 emission projections in baseline scenarios WLO high, Fit for 55 reduced ambition



Source: This report.

Figure 19 - CO_2 emission projections in baseline scenarios WLO low, Fit for 55 reduced ambition



Source: This report.

Table 4 summarises the baseline scenarios by colour coding them according to the number of years they exceed the CO_2 ceiling. There is an increased risk that aviation emissions exceed the CO_2 ceiling when a) the adopted legislation under the Fit for 55 package is weaker than the proposals made by the Commission; or b) the airport capacity is increased. The risk of exceeding the CO_2 ceiling is smaller when a) the adopted legislation under the Fit for 55 package is stronger than the proposals made by the Commission; b) the airport capacity is decreased; or c) when Dutch SAF blending follows the pathway proposed in the Civil Aviation Policy Memorandum.

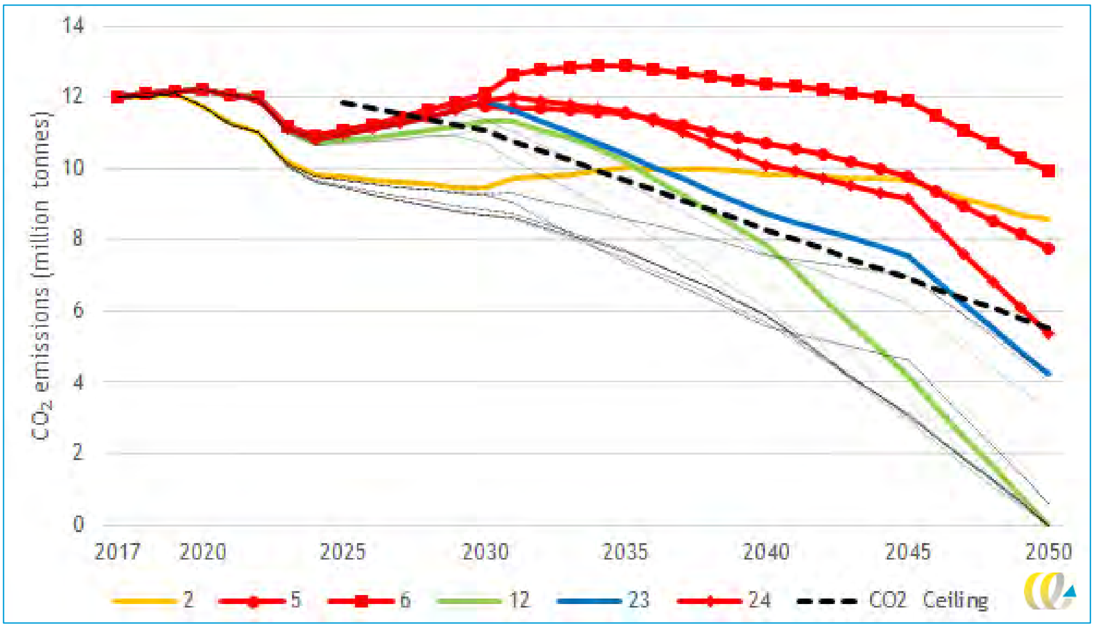
Table 4 - Number of years for which baseline scenarios exceed the CO_2 ceiling

	National SAF blending	WLO Low with COVID-19 recovery			WLO High with COVID-19 recovery		
		Airport Capacity Low	Airport Capacity Middle	Airport Capacity High	Airport Capacity Low	Airport Capacity Middle	Airport Capacity High
Fit for 55 reduced	Reduced ambition	1	2*	3	4	5*	6*
	As proposed	7	8	9	10	11	12*
	Increased ambition	13	14	15	16	17	18
Fit for 55 as proposed	Reduced ambition	19	20	21	22	23*	24*
	As proposed	25	26	27	28	29	30
	Increased ambition	31	32	33	34	35	36
Fit for 55 increased ambition	Reduced ambition	37	38	39	40	41	42
	As proposed	43	44	45	46	47	48
	Increased ambition	49	50	51	52	53	54

Status baseline emissions	Never above ceiling	< 5 years above ceiling	5-15 years above ceiling	> 15 years above ceiling
	Scenarios indicated with a * have been modelled			

Six scenarios have been used to assess the impacts against (2, 5, 6, 12, 23 and 24 in Figure 1). These scenarios have been selected because emissions exceed the ceiling and they have middle assumptions (23) or can be compared to each other by changing one variable: 5 and 24 differ from 23 in one aspect (ambition of Fit for 55 and airport capacity, respectively); and 2 and 6 differ from 5 in one aspect (WLO and airport capacity, respectively). Scenario 23, the blue line in Figure 20, is the reference scenario throughout this report.

Figure 20 - Baseline scenarios of which impacts have been assessed



Source: This report.

Note: grey lines represent scenarios that are not modelled. In most of these scenarios, CO_2 emissions remain below the ceiling. These scenarios are not shown in the legend.

In summary, in a range of plausible scenarios the CO_2 emissions of commercial international flights departing from Dutch airports are projected to be above the CO_2 ceiling for a number of years. In some scenarios, especially when the ambition of the Fit for 55 proposals is reduced, they will remain above the ceiling for the entire period up to 2050.

2.4 Why should the Dutch government act?

The CO_2 emission targets of the Civil Aviation Policy Memorandum are embedded in the global effort to address the climate impacts of aviation and the national and European efforts to contribute to the temperature and emission goals of the Paris Agreement (Ministerie van Infrastructuur en Waterstaat, 2020). As such, they can be seen as part of the Dutch commitment to the global effort to address climate change. The CO_2 targets indicate the minimal level of effort which the Netherlands will make in this respect (minimal because the Civil Aviation Policy Memorandum emphasises that the ambition can be increased to align with global developments).

Without government action, aviation emissions could exceed the CO_2 targets, even when the proposals of the Fit for 55 package are implemented as proposed. This would go against the policy goals as stated in the Civil Aviation Policy Memorandum and undermine the credibility of the Dutch efforts.
Ensuring that the CO_2 emissions of Dutch aviation do not exceed the ceiling provides certainty to market actors with regards to supply and demand of sustainable aviation fuels and aircraft innovation. It provides clarity to the aviation sector about the limits within which growth is possible according to the policy framework set by the Dutch government.

2.5 Three policy options for implementing the CO_2 ceiling

There are three options for implementing a CO_2 ceiling in line with the Civil Aviation Policy Memorandum:
1. A national CO_2 ceiling divided over airports and embedded in airport permits, comparable to limit values for airports with regard to noise and local air quality.
2. A fossil fuel ceiling, which limits the amount of fossil fuels which fuel suppliers are allowed to supply to aircraft by auctioning permits.
3. A national Emissions Trading Scheme, which establishes a closed ETS for airlines departing from Dutch airports.

The 'airport option' is explicitly referenced in the Civil Aviation Policy memorandum and the Coalition Agreement, as well as in two parliamentary motions.[7] Its main features are:
- the government allocates a CO_2 ceiling to the Dutch international airports based on historical emissions/historical permits;
- airports have to ensure that the emissions of departing flights stay within the limit;
- if necessary, airports use their capacity declaration to stay below the ceiling.

The main features of the 'fuel supplier option' are:
- fuel suppliers (the entities selling fuel) at airports need allowances for the quantity of fossil fuels they supply to aircraft engaged in international aviation;
- allowances are auctioned at regular intervals; the number of allowances is reduced in line with the CO_2 ceiling;
- fuel suppliers have the right to trade allowances amongst themselves (no trading with other sectors).

The main features of the 'airline option' are:
- airlines are required to surrender emission allowances for CO_2 emissions on international flights from Dutch airports;
- Dutch State auctions allowances;
- allowances are transferrable between airlines, but not with other sectors;
- allowances are auctioned at regular intervals; the number of allowances is reduced over time in line with the emissions ceiling.

Each option will be described in more detail in the following section.

7 Motie Paternotte/Stoffer over een CO_2-emissieplafond voor de gehele Nederlandse commerciële luchtvaart - Luchtvaartbeleid - Parlementaire monitor.
Motie Paternotte/Amhaouch over een uitwerking van het CO_2-emissieplafond aan de Kamer voorleggen - Luchtvaartbeleid - Parlementaire monitor

2.6 Description of policy options

This section provides a description of the policy options and covers the regulation, their implementation, main obstacles to be overcome, the anticipated reactions of airlines (the emitting entities) and the accuracy with which the option can be modelled. More details on the design of the options can be found in Annex C.

2.6.1 A national CO_2 ceiling divided over airports and embedded in airport permits

This option would entail that the Dutch CO_2 ceiling is divided over airports, which would then be required to make sure that the CO_2 emissions of flights taking off from those airports do not exceed the airport ceiling. The airport-specific ceiling would be included in the airport permit, the Luchthavenverkeerbesluit (in case of Schiphol) or Luchthavenbesluit (in case of the regional airports), which currently also regulate external safety, airport noise and emissions of air pollutants. Thus, CO_2 emissions would be placed on an equal footing as noise and air pollutant emissions in the operating permit of airports.

This study has defined three suboptions for this policy option. Two suboptions differ in the way in which the national CO_2 ceiling is allocated to airports. One possibility is to use the historical emissions in the period 2017-2019 (i.e. before the COVID-19 pandemic reduced aviation demand) as a key to divide the CO_2 ceiling over airports. This is labelled 'strict allocation'. This option does not take into account that some of the smaller airports operated below capacity in those years. A second option has therefore been defined, labelled 'soft allocation', in which the emissions of flights departing from airports which operated below capacity are artificially increased to their capacity, and the resulting hypothetical emissions are used as a distribution key.

The second parameter for defining suboptions is the compliance period. Here, one suboption has a one-year compliance period, and two suboptions have a three-year compliance period. The latter allows airports more flexibility to deal with natural variations in aviation demand and emissions (see Annex C).

Hence, the suboptions are:
- strict allocation of shares of the national CO_2 budget to individual airports; 3-year compliance cycle;
- strict allocation of shares of the national CO_2 budget to individual airports; 1-year compliance cycle;
- soft allocation of shares of the national CO_2 budget to individual airports; 3-year compliance cycle.

Once implemented, airports would need to estimate the CO_2 emissions of departing commercial international flights based on information received from airlines about planned operations. Airports generally receive such information one year before the start of an IATA season. If the estimated CO_2 emissions exceed the CO_2 ceiling, airports would need to adjust their capacity declaration, and the slot coordinator would issue the adjusted number of slots (To70, 2021). Capacity declarations are drafted by airports and approved by the Ministry. Slot allocation is done independently by the slot coordinator ACNL, and is subject to EU Regulation 95/93, as amended.

The airport option would introduce CO_2 emissions as an additional environmental constraint in airport permits, next to noise and air pollutant emissions. For all these constraints, airports have no direct control, but stay within their environmental boundaries by differentiating fees, adjusting capacity declarations and other means at their disposal.

The main obstacles which airports would have to overcome when implementing this option, are the uncertainty about ex-ante emissions estimates and the limited control which they have over CO_2 emissions.

First, there will inevitably be an uncertainty margin in the CO_2 emissions estimated in the capacity declaration, because CO_2 emissions per aircraft movement vary considerably as destinations, aircraft type, engine type, load factors and - in the future - CO_2 emissions factor of the fuel change. Emissions modelled by flight plans submitted by airlines may provide a reasonably good indication. Even when these flight plans are known to be subject to change, the impact of changes on CO_2 emissions may be limited.

In case the ex-ante emission projections exceed the ceiling, airports may resort to adjusting their capacity (or take other action as indicated further below). In most scenarios modelled in this report, the adjustment implies a lower growth rate. In extreme cases, however, the absolute number of slots will be reduced.

It is not certain how airlines will use their reduced number of slots in case the number of slots is reduced as a result of an adjusted capacity declaration. A slot is a right to use the runway at a specific time and has no conditions or restrictions with regards to aircraft type, destination, load factor or CO_2 emissions factor of the fuel. In theory, an airline can exchange a short-haul flight with a regional aircraft for a long-haul flight with a widebody, the CO_2 emissions of which may differ by a factor 40 or more, in extreme cases.[8] In practice, the fluctuations are restricted by the market which airlines serve and by slots they have at destination airports, so it is unlikely that destinations are swapped *en masse*. However, airlines may, for strategic reasons, wish to hold on to their intercontinental schedule and reduce the number of short- and medium haul flights more than long-haul flights, perhaps increasing the capacity on short- and medium haul routes in order to attract the same amount of transfer passengers for their long-haul network. Such a reaction could result in an increase of average CO_2 emissions per slot. Historically, the average CO_2 emissions per aircraft movement have been more stable at large airports than at smaller airports, having decreased about 6% at Schiphol between 2015 and 2019, and increased by about 10 and 30% at Eindhoven and Rotterdam, respectively, in the same period (To70, 2021).

Second, if, during a season, CO_2 emissions are higher than anticipated, an airport has no means to interfere. Hence, if the CO_2 emissions during a season exceed the CO_2 ceiling, the remedy is to make up for the overshoot in a next season.

When airlines operating from a certain airport risk to collectively exceed the CO_2 ceiling, they have a collective incentive to reduce their emissions, e.g. by increasing the amount of SAF used, changing destinations or aircraft, or reducing the number of flights. The latter three options are harder to implement in the short run, as tickets may already have been sold and airlines have an obligation towards their passengers. However, they could be implemented before ticket sales start, which, depending on the airline, may be six to twelve months before the start of a season.

8 Using the ICAO Carbon Emissions Calculator, CO_2 emissions of an Embrear 90 flying from Amsterdam to Bremen are estimated to amount to 1.68 tonnes, whereas emissions of a Boeing 777 flying from Amsterdam to Tokyo Narita are estimated to amount to 72.99 tonnes (ICAO, 2022).

While the reduction in emissions would benefit all airlines collectively, the costs of an adjustment would be borne by each airline individually. As a result, economic theory predicts that airlines have an relatively weak incentive to reduce emissions.[9] The outcome would change when airlines enter into a voluntary agreement to reduce emissions, e.g. by increasing the amount of SAF used. Collective action cannot be enforced so it will only occur when the costs are low, e.g. when the cost differences between using SAF and using fossil fuel decrease. When the costs of collective action are high, either because reducing emissions is expensive or if the value of the slots that are created in that way are high , collective action becomes increasingly unlikely.

The outcome of this analysis could also change when one airline is responsible for a major share of the emissions. In that case, costs and benefits are more aligned and the most emitting airline could have an incentive to reduce emissions (while the other airlines would still have no incentive to reduce emissions).

It is conceivable that the government would step in to promote collective action. This would be a new policy measure beyond the scope of this report, which therefore has not been modelled.

The modelling done for this impact assessment assumes that airports, when faced with emissions higher than the airport-specific CO_2 ceiling, reduce the number of flights until the ceiling is met. This is done by introducing scarcity shadow costs. The modelling does not take into account that airlines reduce their emissions in other ways than the forced reduction in the number of flights.

2.6.2 A fossil fuel ceiling, which limits the amount of fossil fuels which fuel suppliers are allowed to supply to aircraft

This option limits the amount of fossil fuels that can be supplied to international commercial flights departing from Dutch airports by requiring that fuel suppliers surrender a fossil fuel supply right for each unit of fuel they supply. The State would issue fossil fuel supply rights and limit the number of rights to match the CO_2 ceiling. The rights would be auctioned to fuel suppliers at regular intervals. In contrast to fossil fuels, the amount of sustainable aviation fuel supplied to aircraft would not be limited. Because the aim of the CO_2 ceiling is to ensure that the in-sector targets are met, the fossil fuel supply rights cannot be exchanged with other sectors or countries and cannot, for example, be part of the proposed ETS RTB.

This study has defined three suboptions for this policy option. One difference is how the auctioning revenues are handled. In two suboptions, the revenue is treated as fiscal income for the State and added to the general budget. This means that, on average, costs for airlines increase. The other suboption funnels back the revenues to the sector (note that this is not customary in current auctioning systems and goes against governmental budget

9 Noise (and LTO emissions of air pollutants) are also limited collectively but dependent on actions of individual airlines. However, there are a number of differences which make a direct comparison difficult. First, noise and emissions of air pollutants are on average below the applicable limits and do not, therefore, constrain the number of movements (Schiphol, 2021). There are a number of local points where noise limits are exceeded, but because these are local they could, in principle, be addressed by rerouting aircraft or changing runway use (Inspectie Leefomgeving en Transport, 2020). Second, when noise was a limiting factor, norms have been adjusted or flight routes have been changed. Because CO_2 emissions are hardly affected by runway use, these solutions are not feasible to comply with the CO_2 ceiling.

rules).[10] The other difference is whether the trading system has a market stability mechanism or not. One of the suboptions lacks such a mechanism, which means that prices are less predictable due to fluctuations in emissions.

Thus, the suboptions are:
1. Auctioning revenues are retained as fiscal income for the state and a market stability mechanism is introduced;
2. Auctioning revenues are funnelled back to the aviation sector and a market stability mechanism is introduced;
3. Auctioning revenues are retained as fiscal income for the state and there is no market stability mechanism.

Because the amount of fossil supplied to aircraft is currently not regulated, implementing a fossil fuel ceiling would require adopting new legislation. In case the Commission proposal ReFuelEU Aviation (EC, 2021e) is adopted as proposed, fuel suppliers will enter the total amount of fuel sold per airport and the volume of SAF sold per airport in a database to which EU Member States have access. The legislation of the fossil fuel ceiling could use the same data to monitor compliance. The rights system would need to be set up from scratch. This entails setting up a permit system for fuel suppliers and a registry for fossil fuel supply rights.

With a dozen or so fuel suppliers at Dutch airports, it is not certain that there will be a liquid market in fossil fuel supply rights. Therefore, the auction needs to be organised in a way that maximises the chances that rights will be sold at efficient prices. In principle, suppliers could try to buy more rights than they need and try to exert market power. However, due to the low barriers to entry, and the relatively low costs of moving aviation fuel to other countries, the strategic benefits of such behaviour would be questionable. A successful implementation of the fossil fuel ceiling requires that there is no physical shortage of SAF, in which case the price of fossil fuel supply rights would increase to the point where demand for aviation is reduced to the same extent as in the airport option.

The fossil fuel ceiling results in an increase of the price of fossil aviation fuel. The increase is limited by the price of SAF, because if the price of the fossil fuel supply rights exceeds the price difference between fossil aviation fuel and SAF, suppliers will opt to supply SAF instead of driving up the price of fossil fuel supply rights. The price of SAF depends on the marginal type of SAF required to meet the objective, which depends on the difference between the baseline emissions and the CO_2 ceiling.

Airlines will experience the fossil fuel option as an increase in the price of fuel and will react in the same way as to increased fuel prices, i.e. by accelerating fleet renewal and increasing ticket prices and freight rates. Passengers and logistics providers will react to increasing prices by reducing demand.

Airlines will also respond by changing their tankering. Currently, it is estimated that for intra-European flights, outbound tankering occurs because aviation fuel prices at Dutch airports tend to be lower than at many other European airports (Peeters et al., 2021). It is unknown but possible that for some intercontinental destinations, inbound tankering occurs as well. When fuel prices at Dutch airports increase, outbound tankering on intra-EU flights will diminish. When prices increase further, inbound tankering could become more widespread. The maximum amount that can be tankered may be limited by anti-tankering provisions in ReFuelEU Aviation, if these are adopted as proposed. Changes in tankering

[10] In the AEOLUS modelling, the revenues are funnelled back in the form of a lump sum payment per passenger.

have not been modelled in AEOLUS but the maximum impact on CO_2 emissions has been estimated separately.

In the suboption in which the auctioning revenues are funnelled back, the impacts depend on how they are returned to the sector. If the basis is the number of passengers transported (as modelled in this study), airlines have an incentive to increase the number of passengers (while at the same time reducing emissions). If another basis would be chosen to funnel back the revenues, the effects could be different.

2.6.3 A national Emissions Trading Scheme, which establishes a closed ETS for airlines departing from Dutch airports

This option limits the emissions of commercial international flights departing from Dutch airports directly by introducing a closed emissions trading scheme for aircraft operators executing these flights. Airlines would have to monitor and report emissions of each outgoing flights and surrender emission allowances at the end of the year for CO_2 emissions from fossil fuel. They would be able to buy these allowances at an auction organised by the Dutch State at regular intervals. The system would be closed, meaning that allowances from other emissions trading schemes or credits from offsets could not be used for compliance (CE Delft et al., 2005). An open system would defeat the purpose of the CO_2 ceiling which is to guarantee that the in-sector CO_2 emission targets are met.

With a few airlines responsible for most emissions on flights departing from Dutch airports, it is not certain that there will be a liquid market in emission allowances. Therefore, the auction needs to be organised in a way that maximises the chances that rights will be sold at efficient prices. In principle, airlines could try to buy more rights than they need and try to exert market power. This could put other airlines, with insufficient number of allowances, in a difficult position: they would either have to buy more SAF, fly to destinations closer by or choose not to fly. In the latter case, they would risk losing a slot if they cannot fly the slot for 80% of the time. This confluence of closed emissions trading and slot regulation could give rise to undesirable strategies in which airlines would try to force others out of the market.

In this option, airlines would be faced with rising costs as a result of the need to surrender allowances. In response, make a choice between buying allowances and taking emission reduction measures such as increased SAF blending, fleet renewal, and operational changes. All these options would increase costs, and thus impact demand. Because the number of allowances is limited, and aircraft operators cannot execute flights without having allowances, the CO_2 ceiling would be met.

Airlines will experience the airline option as an increase in the costs of using fossil fuel and will react in the same way as to increased fuel prices, i.e. by accelerating fleet renewal and increasing ticket prices and freight rates. Passengers and logistics providers will react to increasing prices by reducing demand. Airlines may also respond by changing their tankering. The difference between this option and the fuel supplier option is that in this option, airlines are directly confronted with possible limits in emission allowances, and not by a price signal. As a result, they may respond more directly.

Two suboptions have been defined for this policy option, one in which the auction revenue is treated as fiscal income for the State and added to the general budget. This means that, on average, the costs of airlines increase. The other suboption funnels back the revenues to the sector.

Because a national emissions trading scheme for aviation currently does not exist, such a system would need to be established. Since emissions on flights between airports in the European Economic Area (EEA) and flights between airports in the EEA and Switzerland, and flights to and from the UK, are included in the EU ETS, there is a risk of double coverage of emissions. On these flights, both EU emission allowances and Dutch emission allowances would need to be surrendered. This study has assumed that the national emissions trading scheme would exist on top of the EU ETS.

The national emissions trading scheme is modelled in the same way as the fossil fuel ceiling, because both increase the cost of using fuel and incentivise using SAF when the price of allowances exceeds the difference between SAF prices and fossil fuel prices.

In the suboption in which the auctioning revenues are funnelled back, the impacts depend on how they are returned to the sector. If the basis is the number of passengers transported (as modelled in this study), airlines have an incentive to increase the number of passengers (while at the same time reducing emissions). If another basis would be chosen to funnel back the revenues, the effects could be different.

When the EU ETS was originally implemented with the aim to cover all emissions on flights to and from EU airports, various foreign airlines and their States objected to being included in the system. The consequences of such actions have not been modelled. In face of this, the EU decided to limit the scope to intra-EEA emissions.

2.7 Which impacts are assessed

This report assesses the impacts of the eight options of the CO_2 ceiling in the reference scenario (Scenario 23). The analysis of the different impacts is presented in Chapters 3 through 6. In addition to the reference scenario we indicate briefly impacts in Scenario 6 (the extreme scenario) at the end of each impact section. All outcomes of the impacts in the six scenarios (2, 5, 6, 12, 23 and 24) are presented in the Excel Results Spreadsheets.

Chapter 3 presents the impacts on the aviation sector, in particular the impacts on flights destinations and network; the impacts on ticket prices and freight rates; the impacts on passenger volumes; and on freight volumes; the impacts on fleet renewal; on fuel consumption and fuel use; and on international relations.

Chapter 4 presents the economic impacts, in particular the compliance costs; the administrative costs; the auction revenue and revenue use; fiscal impacts; the costs of enforcement; upstream and downstream economic effects; and the impacts on innovation.

Chapter 5 presents the environmental impacts, in particular the impacts on aviation CO_2 emissions, both nationally and globally, both tank-to-wing and well-to-wing; land transport CO_2 emissions; impacts on EU ETS and CORSIA; and the impacts on global CO_2 emissions. The impacts on LTO emissions of air pollutants and on airport noise are also presented in this chapter.

Chapter 6 presents the impacts on jobs in the aviation sector and on external safety.

In Chapter 7 the results of the preceding chapters are combined to compare the impacts of the different suboptions by means of a multicriteria analysis.

Finally, the conclusions are presented in Chapter 8.

3 Impacts on Dutch aviation

3.1 Introduction

In this Chapter, we present the impacts on Dutch aviation for the 'reference scenario' (Scenario 23). This scenario assumes that the Fit For 55 package is adopted as proposed, that there are no additional Dutch blending obligations, middle airport capacity and high socio-economic development (WLO high scenario) (see Section 2.2). Note that this is only 1 of the 54 scenarios identified. If we would range the scenarios from non-restrictive to very restrictive, this scenario would be on the more restrictive end (Scenario 23 is one of the five scenarios where the CO_2 ceiling is restrictive for over fifteen years). The impacts are also assessed for five other scenarios (Scenario 2, 5, 6, 12 and 24), the results of the most restrictive scenario - Scenario 6 - can be found in Annex H, the results of the other four scenarios are presented in the Excel Results Spreadsheets . An overview of the precise assumptions of the reference scenario, as well as the assumptions and outcomes of the other baseline scenarios is included in Annex B.

In these analyses, the effects of different suboptions of the CO_2 ceiling are compared to the baseline scenarios in which there is no CO_2 ceiling. An overview of the different suboptions is included in Annex C.

In this chapter, we first assess the different actions that airlines can take to reduce their CO_2 emissions (Section 3.2). Thereafter, we discuss the different effects of these behavioural responses. The impact on passengers travelling via Dutch airports is discussed in Section 3.2. We then look at the impacts on ticket prices and freight rates (Section 3.3), followed by the impacts on flights, destinations and network quality (Section 3.4). We will discuss air freight (Section 3.5), followed by a discussion of the additional fleet renewal due to the CO_2 ceiling (Section 3.6). After that we discuss the demand for fossil kerosene as well as different types of sustainable alternatives (Section 3.8). In Section 3.9 the impacts on international relations are discussed.

3.2 How do airlines reduce their CO_2 emissions?

When the CO_2 ceiling is restrictive, airlines need to reduce their CO_2 emissions. They can do so in four different ways:
1. Reducing the fuel use by decreasing the average length of flights, for example by realizing a shift from intercontinental aviation to intra-EU aviation.
2. Reducing the fuel use by decreasing the number of flights.
3. Efficiency improvements (in this study, we only quantified efficiency improvements due to fleet renewal).
4. Additional blending of SAF.

Airlines will act rationally and therefore choose the least costly option to reduce CO_2 emissions. Table 5 gives a schematic overview of the way in which the different behavioural responses will be utilized by the airlines. The main difference between the different options for the CO_2 ceiling is that in the airport option there is no direct incentive to reduce CO_2 emissions, which means that not all options for CO_2 reduction are utilized. This is true given the assumption that there is a prisoners dilemma which causes collective action not to be taken.

Table 5 - Schematic overview of the responses to different CO_2-ceiling options by airlines

	Option to reduce CO_2 emissions	Airport option	Fuel supplier option	Airline option
Large effects on aviation	Fewer flights	This option will be used, because the number of available slots is reduced	Since there is a direct incentive for airlines to decrease CO_2 emissions (buying CO_2 permits costs money), there is an incentive to utilize the most cost-effective option. Therefore, efficiency improvements and SAF blending will be chosen whenever this is more cost-effective compared to changing the flight schedule (i.e. when the CO_2 prices are high).	Since there is a direct incentive for airlines to decrease CO_2 emissions (buying CO_2 permits costs money), there is an incentive to utilize the most cost-effective option. Therefore, efficiency improvements and SAF blending will be chosen whenever this is more cost-effective compared to changing the flight schedule (i.e. when the CO_2 prices are high).
	Shorter flights	There is no direct incentive for airlines to focus on shorter flights*		
	Efficiency improvements	There is no direct incentive for airlines to improve the efficiency of aircraft*		
Small effects on aviation	Additional SAF blending	There is no direct incentive for airlines to blend additional SAF*		

* This is because there exists a prisoners dilemma, which results in a situation where it is not beneficial for individual airlines to invest in reducing CO_2 emissions individually.

The chosen action by the airlines to reduce emissions determines the effects on the aviation sector. Later in this chapter, we discuss these effects in more detail: the effects on aviation volumes are discussed in Section 3.3, Section 3.5 and Section 3.6; the effects on fleet renewal are discussed in Section 3.7 and the effects on SAF use are discussed in Section 3.8.

Figure 21 shows per ceiling option the absolute CO_2 reduction from the different possible responses from the airlines. First of all, it can be seen that in the ceiling per airport option more CO_2 reduction is obtained compared to the other options. The reasons for this are clarified in Section 5.2. Furthermore, it can be seen that in the ceiling per airport options all CO_2 reduction is obtained by a reduction of aviation volumes (mostly by a reduction of the number of flights). In the fuel supplier/airline option where the auctioning income is for the state, efficiency improvements also have some share in the CO_2 reduction and a shift to shorter flights is seen more clearly. In the fuel supplier/airline option where the auctioning income is funnelled back, almost all reduction of CO_2 emissions is obtained by a shift to shorter flights. The average distance of flights is reduced to such an extent that even more flights are possible compared to the baseline (the negative blue bars). Figure 22 shows the same data as relative shares of the CO_2 reduction.

Figure 21 - Absolute CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the reference scenario

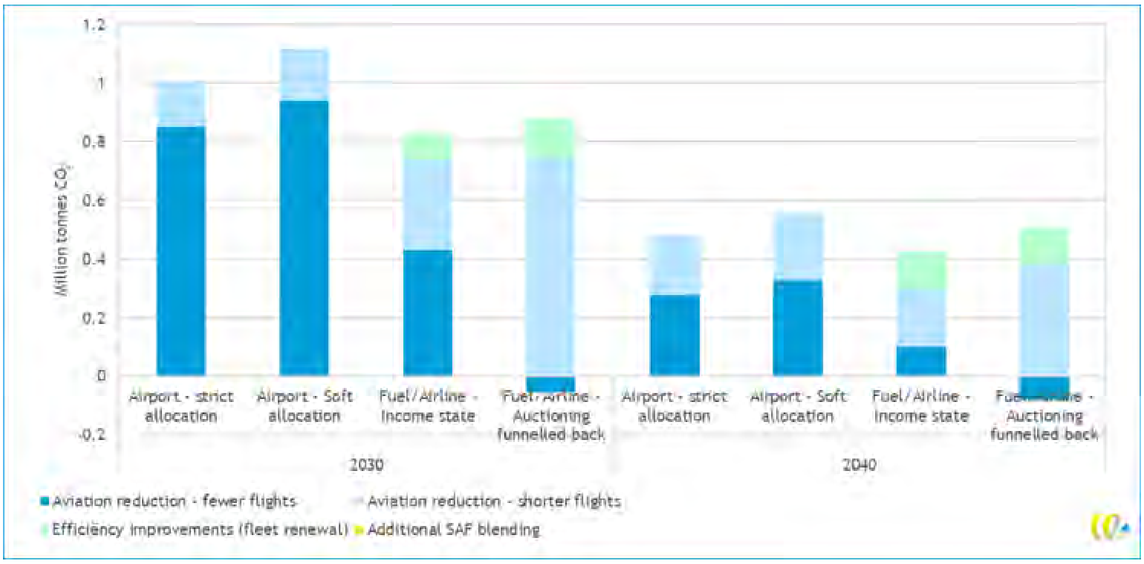
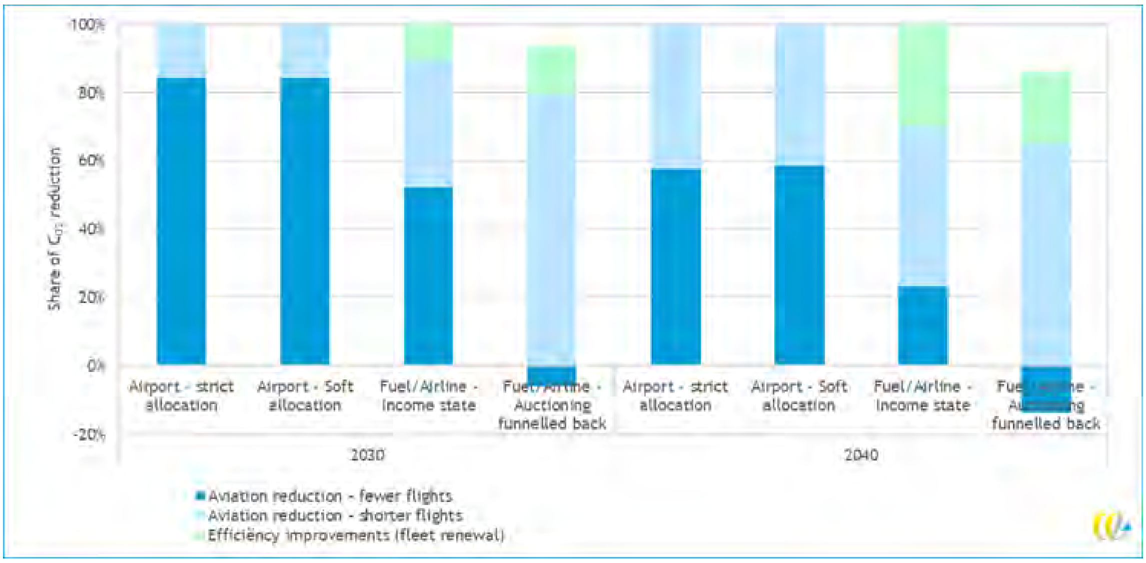


Figure 22 - Relative CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the reference scenario



3.2.1 Results in other baseline scenarios

In most scenarios, CO_2 emissions remain below the ceiling, so the implementation of the ceiling would not cause behavioural responses from the airlines (see Section 2.3).

The share of the absolute and relative CO_2 reduction per option which the airlines have to reduce emissions are shown in Figure 23 and Figure 24. Compared to the reference scenario (see Figure 21 and Figure 22) it can be seen that the CO_2 reductions are much higher in the extreme scenario. This results in higher CO_2 costs, which make additional SAF blending cost-effective in 2040. Because of the additional SAF blending and efficiency improvements, the effects on the network quality are relatively small compared to the airline option.

Figure 23 - Absolute CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the extreme scenario

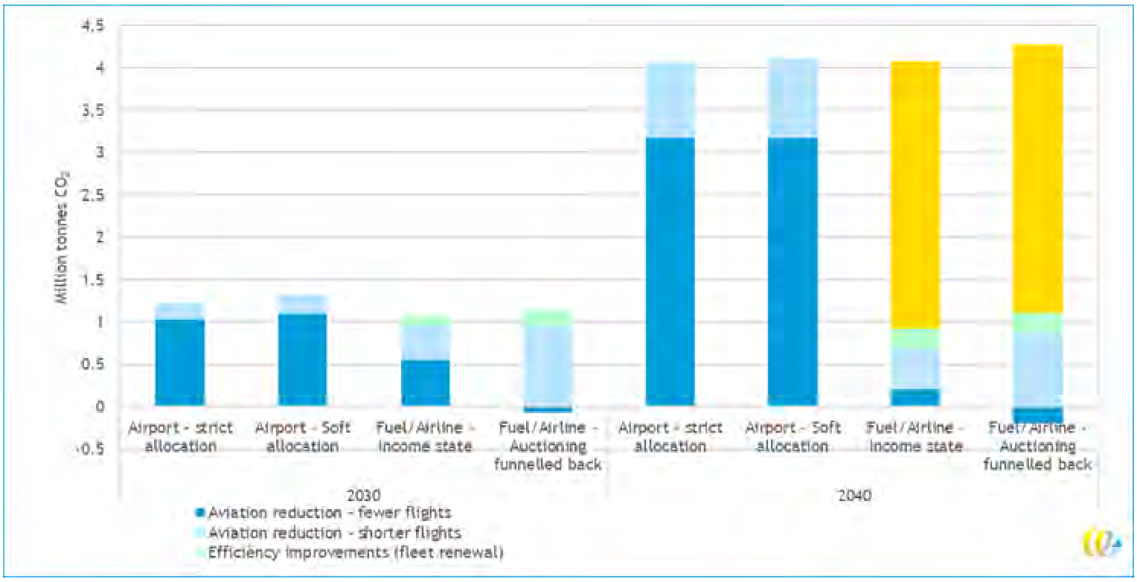
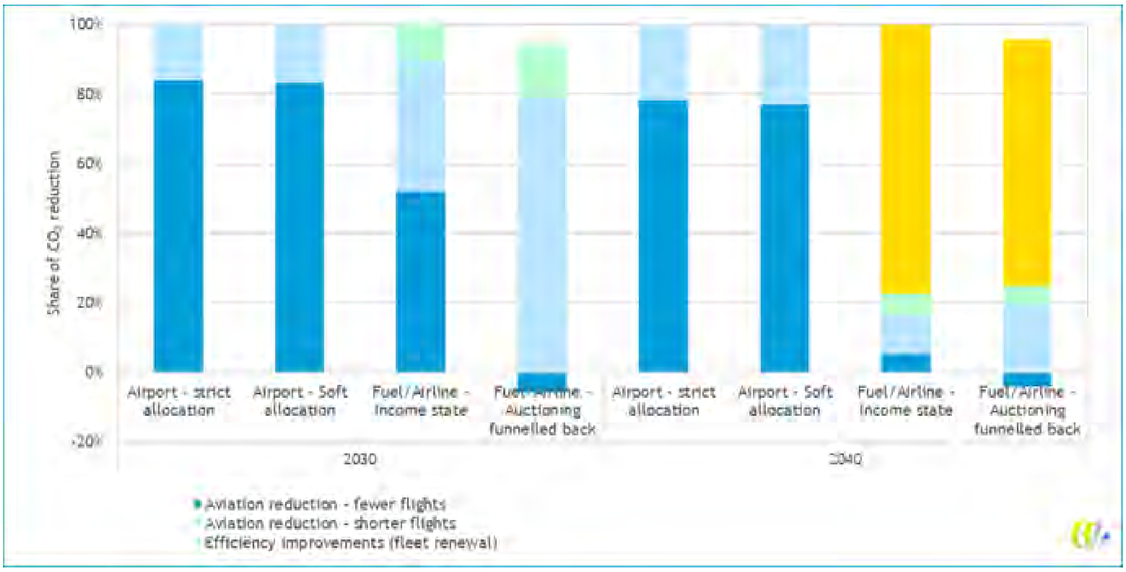


Figure 24 - Relative CO_2 emission reduction of reduced aviation volumes, efficiency improvements and additional SAF blending in the extreme scenario



In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in Annex B.

3.3 Impacts on number of passengers at Dutch airports

3.3.1 Introduction

The number of flights at Dutch airports is already restricted due to capacity limits and noise limits in the airport permits. Therefore, in this reference scenario (nr. 23), aviation growth is restricted in the baseline at Schiphol between 2031 and 2050. During restrictive periods the most cost-sensitive segments with good alternative travel options lose market share. These are usually transfer passengers and Full freighters. At all other airports and at Schiphol before 2031, the capacity is sufficient to accommodate the demand. For Schiphol this is mainly caused by a reduction in demand due to the COVID pandemic.[11] The assumptions for capacity and noise limits at different airports are discussed in Annex B.

In this section we discuss the impact of the different options of the CO_2 ceiling on the number of passengers. The number of passengers flying from different Dutch airports in the reference baseline scenario is shown in Table 6. We can see that the number of passengers at all Dutch airport are growing rapidly. Lelystad airport is assumed to open in 2024. What we do not see clearly in this table is that all airports have to cope with a COVID dip. This dip starts around 2020 and full recovery is expected around 2030, the growth in passengers is however so strong that 2030 already shows strong growth compared to pre-COVID. Note that Schiphol's capacity of 500,000 flights is already reached before 2030 (see the number of flights in the reference scenario baseline in Subsection 3.4.1). Therefore the growth in passengers at Schiphol is mostly due to the use of increasingly larger aircrafts, more efficient seating and higher occupation rates.

Table 6 - Development of the number of passengers (x 1,000) at Dutch airports without CO_2 ceiling (reference scenario baseline)

Airport	2017	2030	2040	2050
Total	76,197	99,144	116,967	128,420
Amsterdam	68,393	88,044	99,033	103,812
Lelystad	0	2,884	5,384	7,472
Eindhoven	5,701	6,033	8,893	12,559
Rotterdam	1,733	1,790	2,982	3,717
Maastricht	168	173	267	318
Groningen	202	219	408	543

Baseline forecasts for other aviation aspects (in the reference scenario) can be found in: Subsection 3.3.1 for ticket prices, Section 3.4 for number of flights, Subsection 3.5.1 for cargo, Section 3.6 for fleet renewal and Subsection for fuel consumption.

3.3.2 Methodology

The impacts of the ceiling on the number of passengers are based on the AEOLUS model runs. AEOLUS is the national Dutch aviation model, which is owned by the ministry of Infrastructure and Water management. The latest version of the model is AEOLUS-2018 with base year 2017.

[11] Note that the demand growth is reduced compared to pre-Corona levels, due to an assumed reduction of business air travel demand and increased ticket prices caused by 1) higher ticket prices to pay-back state loans, 2) an increased Dutch ticket tax, 3) the Fit for 55 proposals (different in the individual baseline scenarios) and 4) a Dutch SAF blending obligation (not relevant in this scenario).

AEOLUS is a simulation model that forecasts the number of passengers and aircraft movements at Dutch airports for different future scenarios until 2050. The model takes into account restrictions on airports like year capacities, runway capacities and noise limits. In addition the model can calculate the impacts of several policy measures. The heart of the model is a passenger choice model (nested logit) with three levels: main mode choice, route choice (combination of airport, alliance and direct/indirect) and airport access choice to model the traveller choice. Travel alternatives are generated for all combinations of origins and destinations separately and all choices are simulated.

The main dimensions of AEOLUS are:
- 2 travel purposes (business/other);
- 2 x 2 types of passengers (Dutch/foreign and OD/transfer);
- 56 zones (27 in the Netherlands,[12] 17 in Europe,[13] 12 in the rest of the world);
- 5 groups of airlines / alliances (Star, OneWorld, SkyTeam, OtherFSC, LowCost);
- approx. 40 aircraft types;
- 4 periods of the day.

More information on AEOLUS can be found in the general AEOLUS documentation (Significance, 2020). More information on our assumptions as input for AEOLUS can be found in Annex D.

In most baseline scenarios a substantial growth of air traffic is predicted between 2022 and 2050. The resulting demand often exceeds the capacity on Dutch airports. In these cases an iterative procedure is started of adding scarcity costs that affects the choices of both passengers and airlines.

In our analysis for the impacts on the number of passengers for Dutch airports we distinguish the following passenger segments:
- OD passengers at (individual) Dutch airports and transfer passengers (Schiphol only);
- business and leisure passengers.

We compare the number of passengers in the reference baseline scenario (see Table 3) with the number of passengers for the different CO_2 ceiling options. We compare with the total number of passengers for all Dutch airports and also look specifically into the number of passengers per airport. We investigate the split of direct (OD) from all Dutch airports and transfer passengers for all Schiphol airport. For the OD passengers we show the split in EEA and intercontinental (ICA) passengers. We also investigate the split in business and non-business passengers.

We also investigate the effects of evasion - leakage of passengers to foreign airports. For this section we used the new recently actualised version of AEOLUS (updated in August 2022). In this version evasion behaviour is updated to also accurately include transfer evasion. The remainder of the report is based on the previous AEOLUS version, where transfer evasion could not be quantified. Since the new AEOLUS version came out during the end phase of the research for this report we only updated the evasion segments with the new AEOLUS runs. The upcoming addendum to this report regarding lower airport capacity for Schiphol will also be based on the actualised version of AEOLUS.
In Subsection 3.2.4 we look into evasion effects. We can distinguish two types of evasion:
1. Passengers who in the baseline would make a flight with origin or destination at a Dutch airport, but now shift to an airport in a surrounding country or to land transport;

[12] Including the airports of AMS, LEY, EIN, RTM, MST, GRQ.
[13] Including the airports of DUS, CDG, CGN, FRA, LUX, NRN, CRL and BRU.

2. Passengers who in the baseline would make a transfer stop at a Dutch airport, but now transfer at a foreign airport or fly directly.

For both OD- and transfer passengers an additional behavioural change is possible, namely not to travel anymore. However, this is no evasion.

3.3.3 Results

Figure 25 shows the number of passengers for all Dutch airports. First we see a drop in the number of passengers just after 2020. This is caused by the COVID pandemic which disrupted aviation by the imposed travel restrictions. Recovery in terms of number of passengers is predicted to take several years. We can see that in the reference baseline scenario the passenger demand surpasses the 2019 (pre-COVID) levels around 2027.[14] After which in both baseline as the CO_2 ceiling options strong growth is expected (30% baseline growth versus 26% CO_2 ceiling growth for 2020-2040).

If we now look at the effects of the different policy options, we can see that in the Airport options the growth of the passenger volume compared to the baseline is reduced most for the period of 2028 up to 2046,[15] after which the total number of passengers almost recovers to the baseline level. In the period of 2028 to 2046 the CO_2 ceiling limit is reached. In the Airport options this will directly result in a decrease in the number of flights.[16] In the Fuel supplier and Airline options the restrictive effect on the number of passengers is much smaller. There are three main reasons for this different behaviour between the Airport and Fuel supplier/Airline options:

1. In the Fuel supplier and Airline options there is a shift from passengers with an intercontinental destination to inter-EEA destinations. Passengers on Inter-EEA flights have way lower CO_2 emissions, therefore more passengers are allowed to fly using the same CO_2 budget. In the Airport options we do not see this shift.[17] (See further on in this section the results on EEA OD and intercontinental OD passengers; or Subsection 3.4.3 for the results on EEA/intercontinental flights).
2. Due to the allocation mechanism in the Airport options the CO_2 ceiling for the regional airports is not reached at least until 2040. This means there is unused CO_2 capacity, which does not occur in the Fuel and Airline options. As a consequence, in practice the Airport options are more restrictive than the Fuel and Airline options.[18] (For further explanation see Subsection 3.4.3 concerning capacity following from the CO_2 ceiling Airport options).
3. In the Fuel supplier and Airline options it is assumed that airlines will use the possibility to blend extra SAF in order to make more flights when this is economically viable. This effect is significant from 2040 onwards. (See Section 3.6 for results on SAF blending).

14 For a precise description of the modelling assumptions, see the AEOLUS documentation for these model runs (Significance, 2022).

15 The 'bend' we see in the results of the Airport options around 2045 follows from the ReFuelEU Aviation proposal's blending requirements in combination with the decreasing CO_2 ceiling. Up to 2040 the SAF blending requirements increase steadily to 32%, while in 2045 there is a relatively smaller increase up to 38%, after which the requirement jumps to 63% in 2050.

16 If in the Airport options the CO_2 ceiling is reached scarcity is created, airlines will increase their ticket prices such that demand will drop to match the level of the capacity

17 In the Airport options scarcity costs are added to all passenger tickets proportionally, resulting in a proportionate decrease of inter-EEA and intercontinental passengers. In the Fuel supplier and Airline options the ticket prices increase by the costs of the emission rights for the specific route, these costs are higher for passengers on longer intercontinental routes, causing a shift towards inter-EEA passengers.

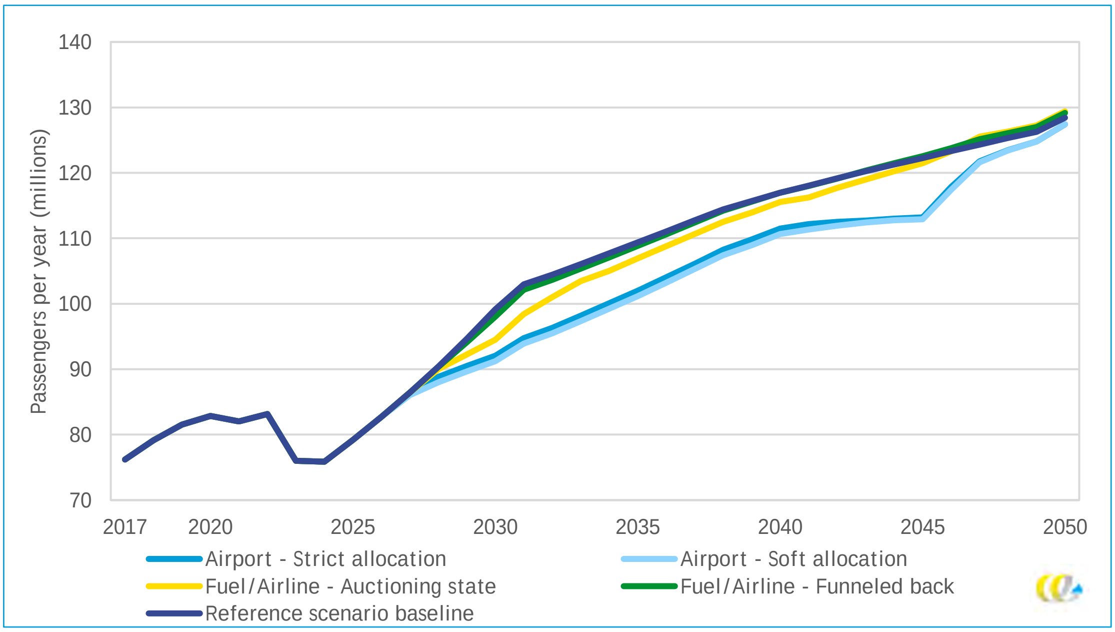
18 In 2030 the Airport - strict/soft allocation options are 22 to 35% more restrictive in terms of CO_2 emissions.

Discussion is still ongoing about this third point: the assumption that only in the Fuel supplier and Airline options the possibility of blending extra SAF is used. In principle airlines could choose to blend extra SAF as well in the Airport options. However, in the Airport options this does not give the airline a direct advantage: more slots will become available for all airlines to use. Individual airlines will be facing a 'prisoners dilemma'. If 'airline green' decides to blend extra SAF this should lead to increased ticket prices. If the competitor 'airline grey' decide not to blend more SAF to meet the CO_2 ceiling targets, they can offer lower ticket prices and would gain market share from 'airline green'. Since the slots which become available due to the CO_2 reduction of 'airline green' would be distributed over all airlines, 'airline green' and 'airline grey' would profit from this. Therefore the rational decision seems for all airlines to not blend extra SAF. However, there are two possible ways out of this prisoners dilemma:

1. If we have an airport where one airline has most of the market share (such as KLM has at Schiphol), it could be beneficial for this airline to blend more SAF since most of the extra slots that will become available are going to this airline.
2. The airlines could also choose to sign an agreement to collectively blend more SAF.

If due to these reasons more SAF is blended in the Airport options, the results of the Airport options would shift towards the results of the Fuel supplier and Airline options (since additional SAF blending would result in more possible passenger movements at the same CO_2 emission level). Note however that this SAF effect is only significant from 2040 onwards, the results shown up till 2040 will still remain largely the same.

Figure 25 - Total number of passengers at Dutch airports



Note: In these figures the suboptions with equivalent modelling outcomes are grouped together. Also, no upper and lower bound values are displayed, which makes the two different Airport - strict allocation suboptions indistinguishable.

The effect of all the different policy options of the CO_2 ceiling on the number of passengers compared to the baseline is shown in Table 7. In suboption Airport - Soft allocation the allocation of CO_2 budget is corrected for noise permits, allocating slightly more budget towards regional airports (and less towards Schiphol) compared to strict allocation. Another effect we see is that in the Airport options for most regional airports the number of passengers increases for the years 2030 and 2040.[19] As we will see in the section about flights (see Section 3.4,) there is more demand than capacity at Schiphol, also there is spare capacity at the regional airports, therefore a shift of passengers from Schiphol to regional airports occurs. In 2050 the CO_2 ceiling is not restrictive anymore, the small effects still visible in the results of 2050 are remnants from the restrictive period.

For three suboptions (Airport - strict allocation 3-year cycle, Airport - strict allocation 1-year cycle and Fuel supplier - no stability mechanism) we see ranges in the results of the tables. The main outcome is based on the corresponding model run, and can be seen as the 'mean value'. The ranges indicate deviations from the mean value, caused by inflexibility in the system due to either: the shorter compliance cycle (3-year or 1-year for the Airport - strict option) or having no stability mechanism (for the Fuel supplier option). The ranges are determined with an additional analysis of historic fluctuations in aviation demand (see Annex F). Due to these fluctuations, the total number of flights in the period 2024-2050 is expected to be lower for the three suboptions:
1. In the Airport - strict allocation option with a 3-year compliance cycle, the total number of this flights in this period can be expected to be 0.8% lower compared to a situation with infinite flexibility.
2. In the Airport - strict allocation option with a 1-year compliance cycle, the total number of this flights in this period can be expected to be 1.0% lower compared to a situation with infinite flexibility.
3. In the Airport - soft allocation option with a 3-year compliance cycle, the total number of this flights in this period can be expected to be 0.8% lower compared to a situation with infinite flexibility.
4. In the Fuel supplier - no stability mechanism option, the total number of this flights in this period can be expected to be 0.2% lower compared to a situation with infinite flexibility.

[19] The effects for regional airports are relatively small. For some years the effects are such small that they are rounded off to 0.

Table 7 - Impacts on passenger demands (millions per year)

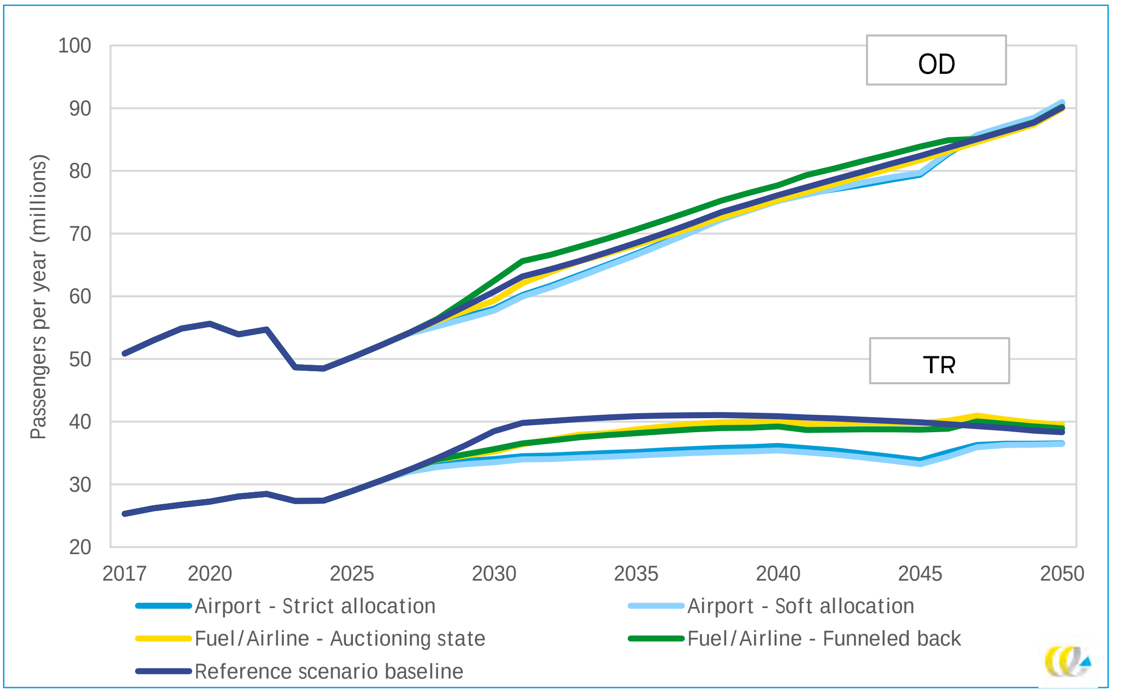
Airport	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-7.07 (-9.71 to -7.07)	-7.07 (-10.08 to -7.07)	-7.9 (-10.52 to -7.9)	-4.63	-1.09	-4.63 (-4.91 to -4.36)	-4.63	-1.09
	2040	-5.47 (-10.95 to -5.47)	-5.47 (-11.44 to -5.47)	-6.33 (-11.76 to -6.33)	-1.41	0.00	-1.41 (-1.72 to -1.11)	-1.41	0.00
	2050	-1 (-11.68 to 0.39)	-1 (-10.77 to 0.29)	-1 (-11.67 to 0.4)	0.98	0.73	0.98 (-4 to 1.98)	0.98	0.73
Amsterdam	2030	-7.21 (-9.52 to -7.21)	-7.21 (-9.85 to -7.21)	-7.98 (-10.28 to -7.98)	-4.44	-1.61	-4.44 (-4.44 to -4.44)	-4.44	-1.61
	2040	-6.02 (-10.59 to -6.02)	-6.02 (-11 to -6.02)	-6.89 (-11.42 to -6.89)	-0.51	-0.48	-0.51 (-0.51 to -0.51)	-0.51	-0.48
	2050	-0.61 (-9.26 to -0.61)	-0.61 (-8.52 to -0.61)	-0.7 (-9.34 to -0.7)	0.88	0.72	0.88 (-3.15 to 0.88)	0.88	0.72
Lelystad	2030	-0.27 (-0.35 to -0.27)	-0.27 (-0.36 to -0.27)	-0.3 (-0.37 to -0.3)	-0.06	0.12	-0.06 (-0.13 to 0.01)	-0.06	0.12
	2040	-0.31 (-0.56 to -0.31)	-0.31 (-0.58 to -0.31)	-0.36 (-0.61 to -0.36)	-0.38	0.14	-0.38 (-0.46 to -0.29)	-0.38	0.14
	2050	-0.12 (-0.73 to 0.5)	-0.12 (-0.68 to 0.45)	-0.13 (-0.74 to 0.49)	0.02	-0.01	0.02 (-0.27 to 0.31)	0.02	-0.01
Eindhoven	2030	-0.15 (-0.32 to -0.15)	-0.15 (-0.34 to -0.15)	-0.19 (-0.36 to -0.19)	-0.10	0.28	-0.1 (-0.25 to 0.04)	-0.10	0.28
	2040	0.85 (0.37 to 0.85)	0.85 (0.33 to 0.85)	0.9 (0.42 to 0.9)	-0.51	0.19	-0.51 (-0.65 to -0.36)	-0.51	0.19
	2050	-0.22 (-1.25 to 0)	-0.22 (-1.16 to 0)	-0.1 (-1.15 to 0.12)	0.06	0.02	0.06 (-0.43 to 0.54)	0.06	0.02
Rotterdam	2030	0.45 (0.39 to 0.45)	0.45 (0.38 to 0.45)	0.47 (0.4 to 0.47)	-0.03	0.10	-0.03 (-0.07 to 0.02)	-0.03	0.10
	2040	0.01 (-0.13 to 0.01)	0.01 (-0.15 to 0.01)	0.02 (-0.13 to 0.02)	-0.02	0.12	-0.02 (-0.07 to 0.03)	-0.02	0.12
	2050	-0.05	-0.05	-0.06	0.02	0.00	0.02	0.02	0.00

Airport	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
		(-0.36 to 0.25)	(-0.33 to 0.23)	(-0.36 to 0.25)			(-0.13 to 0.16)		
Maastricht	2030	0.04 (0.04 to 0.04)	0.04 (0.03 to 0.04)	0.04 (0.04 to 0.04)	0.00	0.01	0 (-0.01 to 0)	0.00	0.01
	2040	0 (-0.01 to 0)	0 (-0.01 to 0)	0 (-0.01 to 0)	0.00	0.01	0 (0 to 0)	0.00	0.01
	2050	0 (-0.03 to 0.02)	0 (-0.03 to 0.02)	0 (-0.03 to 0.02)	0.00	0.00	0 (-0.01 to 0.01)	0.00	0.00
Groningen	2030	0.06 (0.05 to 0.06)	0.06 (0.05 to 0.06)	0.06 (0.05 to 0.06)	0.00	0.02	0 (-0.01 to 0)	0.00	0.02
	2040	0 (-0.02 to 0)	0 (-0.02 to 0)	0 (-0.02 to 0)	0.00	0.02	0 (-0.01 to 0.01)	0.00	0.02
	2050	-0.01 (-0.05 to 0.04)	-0.01 (-0.05 to 0.04)	-0.01 (-0.05 to 0.04)	0.00	0.00	0 (-0.02 to 0.02)	0.00	0.00

Note: For the suboptions Airport - Strict allocation (3-year cycle), Airport - Strict allocation (1-year cycle), Airport - Strict allocation (3-year cycle) and Fuel Supplier - no stability mechanism, additional analysis were made based on the underlying AEOLUS runs to reflect the potential effects of fluctuations in aviation demand (see Annex F).

Figure 26 distinguishes origin-destination passengers[20] (OD) and transfer passengers (TR). The drop in transfer passengers is much larger (-15% compared to baseline in 2035) than the decrease in OD-passengers (-2% in 2035). This is due to the fact that the price elasticity of transfer passengers is way higher. If the price of a transfer stop is only slightly smaller at a competing hub, passengers are very likely to choose the cheaper transfer stop. It is also possible that passengers alternatively choose a direct flight to their final destination. This clearly shows that the CO_2 ceiling has a much smaller effect on passengers travelling to or from the Netherlands compared to passengers using Schiphol as a hub.

Figure 26 - Development of the number of OD and transfer passengers (TR) at Dutch airports



OD-passengers at Dutch airports are further segmented by their destination. Figure 27 shows the effect for OD-passengers with a destination within the EEA. The reduction of passengers with destinations within the EEA is only significant in the Airport options, while the Fuel/Airline options show almost no decrease or even an increase. The reason for this difference is a shift of passengers with intercontinental destinations to inter-EEA destinations in the Fuel supplier and Airline options. In these policy options either fuel suppliers or airlines have to buy an amount of CO_2 permits corresponding to their CO_2 emissions. In the model the costs of these CO_2 permits are passed through to the ticket prices of the passengers proportionally to the amount of CO_2 emitted on their flight. Therefore passengers on longer intercontinental flights will pay a higher CO_2 premium on their ticket than passengers on shorter inter-EEA flights. This will shift the passenger demand from intercontinental to inter-EEA flights. In the Airport options we do not see this shift[21].

[20] Origin-destination passengers are passengers who have their origin or destination at a specific airport, in this case at a Dutch airport. The other category are transfer passengers who, in this case, only make a transfer at a Dutch airport.

[21] In the Airport options scarcity costs are added to all passenger tickets proportionally, resulting in a proportionate decrease of inter-EEA and intercontinental passengers.

We can see that in the Fuel/Airline - Funnelled back option there even is an increase in the number of passengers. The reason for this is that the previously mentioned shift from intercontinental to inter-EEA is even stronger in this policy option. In the Fuel Supplier/Airline - Auctioning funnelled back option the income raised by the auctioning of CO_2 permits is funnelled back to the sector. In the model we assume a 100% cost pass through, such that all ticket prices are decreased by a fixed amount. This fixed cost reduction will be relatively larger for short inter-EEA routes with low ticket prices, and can be even thus large that ticket prices become cheaper than in baseline for intra-EEA routes.[22] This results in an increased demand for inter-EEA passengers.

Figure 27 - Development of the number of EEA OD passengers at Dutch airports

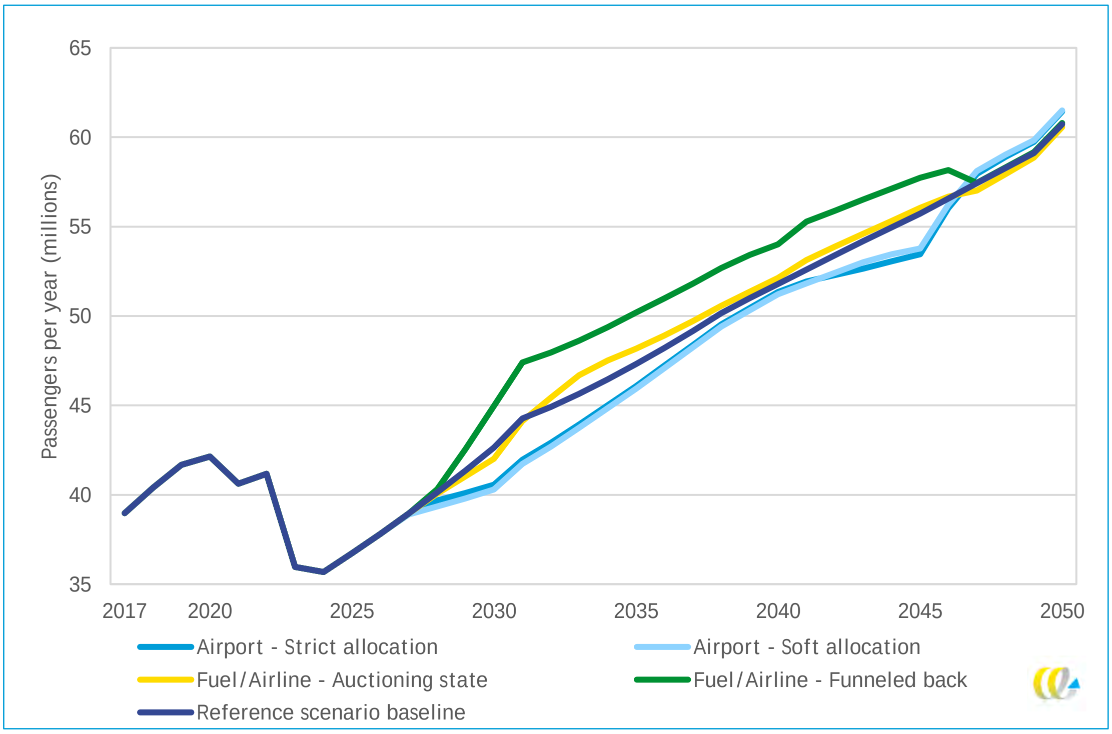
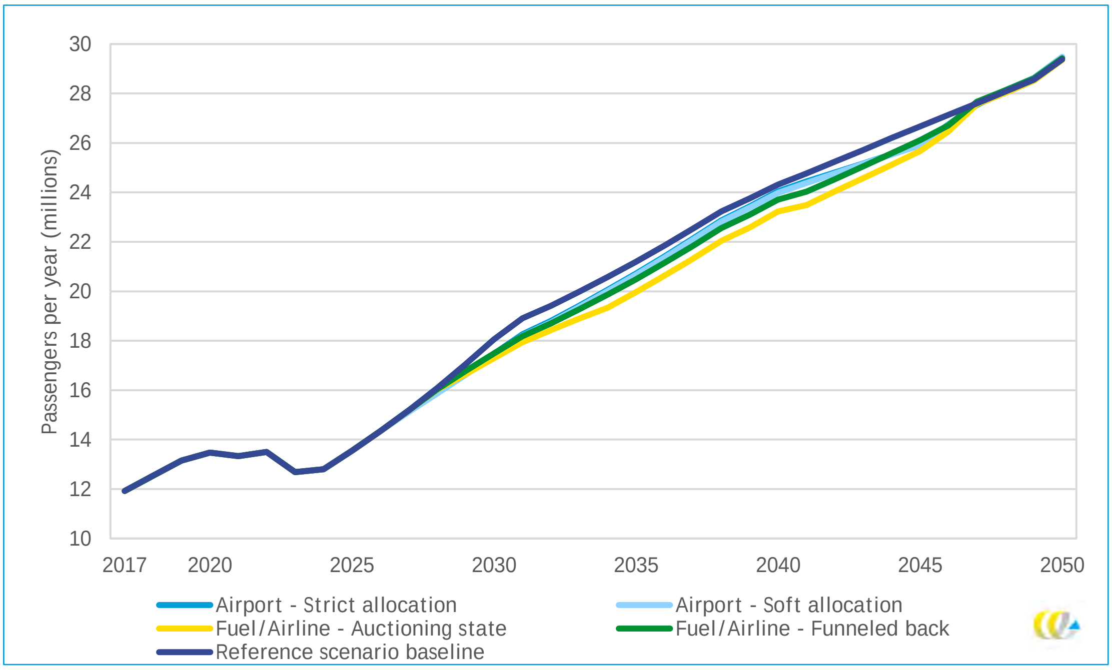


Figure 28 shows the impacts on intercontinental OD-passengers. We can see the effects of the CO_2 ceiling policy options are rather small and overall quite similar. The Fuel supplier and Airline options have a slightly larger decrease in passengers. The reason for this is explained in the previous paragraph, in short longer intercontinental flights have higher CO_2 costs in these suboptions.

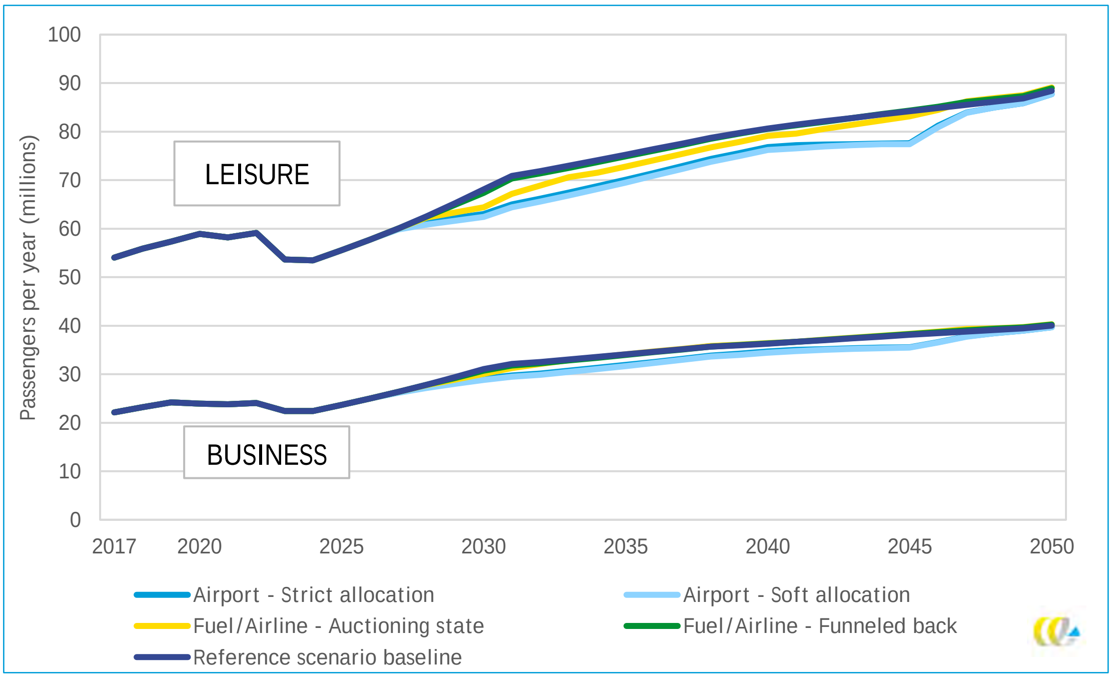
[22] Note that there is a relatively large uncertainty in how the funneling back of auctioning incomes will be done in practice. Also, the assumption that this will lead to a reduction in ticket prices is relatively uncertain. In practice, different responses are imaginable, which would also result in different modelling results.

Figure 28 - Development of the number of intercontinental OD passengers at Dutch airports



The total number of passengers can also be split by travel purpose into business and non-business passengers (mostly leisure). This is shown in Figure 29. The relative decrease for both business as other passengers is approximately equal at 7% in the Airport options. However, since the non-business passenger category is larger, it contributes more to the decrease of the total passenger demand under the CO_2 ceiling. In the Fuel supplier and Airline options, the reductions are small.

Figure 29 - Development of the number of business and leisure passengers at Dutch airports



3.3.4 Evasion

The presented impacts here are results from runs of the new actualized AEOLUS version (Update August 2022). The upcoming addendum to this report regarding lower airport capacity for Schiphol will also be based on this new actualised version of AEOLUS. These results - especially the changes in number of passengers on Dutch airports - may differ slightly from the impacts in other sections of the report, for which the previous version of AEOLUS has been used. We therefore also show the results from the 'old runs', such that they can be compared.

In this section we look into evasion effects. We can distinguish two types of evasion:

1. Passengers who in the baseline would make a flight with origin or destination at a Dutch airport, but now shift to an airport in a surrounding country or to land transport.[23]
2. Passengers who in the baseline would make a transfer stop at a Dutch airport (Schiphol), but now transfer at a foreign airport or fly directly.

For the first type of evasion we compared the decrease of OD passengers using Dutch airports to the change of OD passengers using foreign airports (adjusted route choice). We also calculated the change in land transport to see how many OD passengers now choose to go by car or train (adjusted mode choice). Passenger travelling to destinations within Europe have the possibility to travel by air and by land transport. For intercontinental destinations air travel is the only feasible option for the majority of passengers[24]. Therefore we discuss evasion separately for EEA and ICA passengers.

We show the 2030 results for EEA OD passengers in Figure 30. We can see that for the Airport options a large share (63%) of the passengers that would have used Dutch airports now switch to a foreign airport. A small share switches to land transport (10%) and the other 27% chooses to not travel anymore. For the Fuel supplier and Airline options the behaviour is quite different. In the auctioning state suboptions, we see for the new AEOLUS run an increase in the number of EEA OD passengers at Dutch airports. This is due to a shift of long flights to short flights, which is a bit stronger in the new AEOLUS runs than with the previous version of the model. These extra EEA OD passengers would have travelled by car or train in the baseline. In the suboptions where auctioning income is funnelled back, there is a strong increase in the number of OD passenger using Dutch airports. This is caused by the funnelling back of the auctioning revenues, leading to cheaper ticket prices for short flights compared to the baseline, see Subsection 3.3.3. We can see that this increase in passengers comes mostly from passengers who would have used foreign airports in the baseline (42%), but also quite a share from people who would have used land transport and people who would not have travelled. Note that the percentages mentioned here are shares of the decrease in EEA OD passengers using Dutch airports. If we look at the share of the total number of EEA OD passengers in baseline, we are talking about 0.2 to 3.0% evasion to foreign airports.

23 The AEOLUS model does not take into account capacity restrictions at foreign airports. Therefore we calculated the maximum of potential evasion. Capacity restrictions at other airports could mean in practice that not all demand for evasion can be realized.

24 In AEOLUS land transport is only considered for destinations within Europe.

Figure 30 - Impacts on EEA OD passengers on Dutch airports and foreign airports; impacts on land transport and non-travellers in 2030

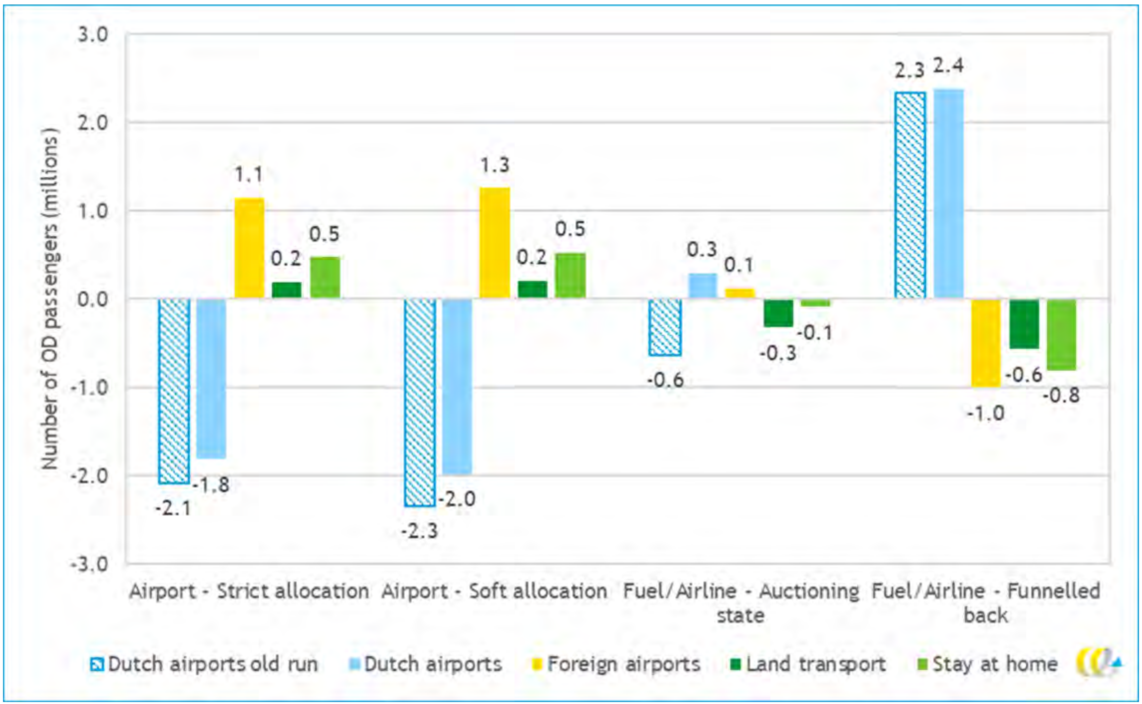


Figure 31 shows the 2030 results for intercontinental OD passengers. Here we see similar behaviour for all options. There is a decrease in intercontinental OD passengers via Dutch airports: these passengers mostly chose to go through a foreign airport (about 60%) or do not travel at all anymore. Land transport is not an option for intercontinental travel. If we look at the share of the total number of intercontinental OD passengers in baseline, we are talking about 1.7 to 2.8% evasion to foreign airports.

Figure 32 now shows the aggregated impacts for all OD passengers. For the airport options we see similar behaviour to the EEA and intercontinental evasion; 65% of the decrease in OD passengers via Dutch airports go to a foreign airport, 8% travel over land and the remaining 27% stop travelling at all. For the fuel supplier and airline - auctioning state suboptions we find a different result. OD passengers using foreign airports increases slightly more than the decrease of Dutch OD passengers. Also land transport seems to decrease. This is a mixed effect of the EEA and intercontinental results. The increase in Dutch EEA OD passengers makes the decrease in total Dutch OD passengers smaller than the EEA OD passengers increase on foreign airports. Also land transport decrease because of the increase in EEA OD passengers. Therefore the result for all OD passengers makes sense if we look at the EEA and intercontinental segments separately. For the fuel supplier and airline - funnelled back suboptions we find that the EEA OD effects are larger than the intercontinental OD effects. Therefore there is a net increase in Dutch OD passengers who in the baseline would go through a foreign airport, by land or would not travel at all. If we look at the share of the total number of OD passengers in baseline, we are talking about 1.0% to 2.6% evasion to foreign airports.

Figure 31 - Impacts on intercontinental OD passengers on Dutch airports and foreign airports; impacts on land transport and non-travellers in 2030

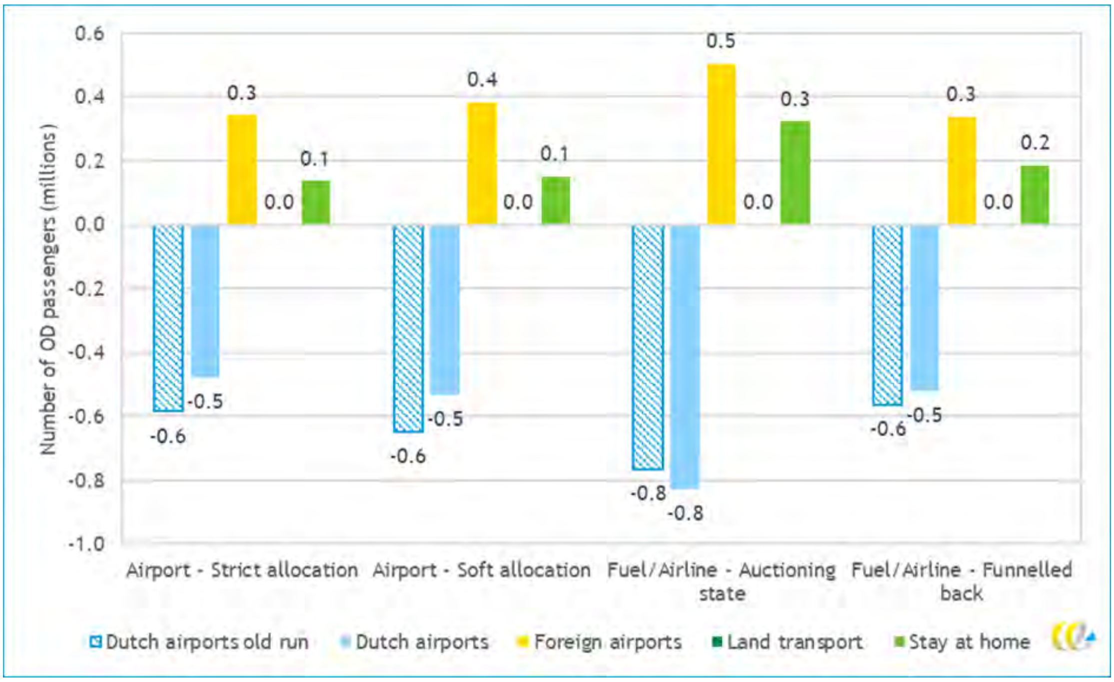
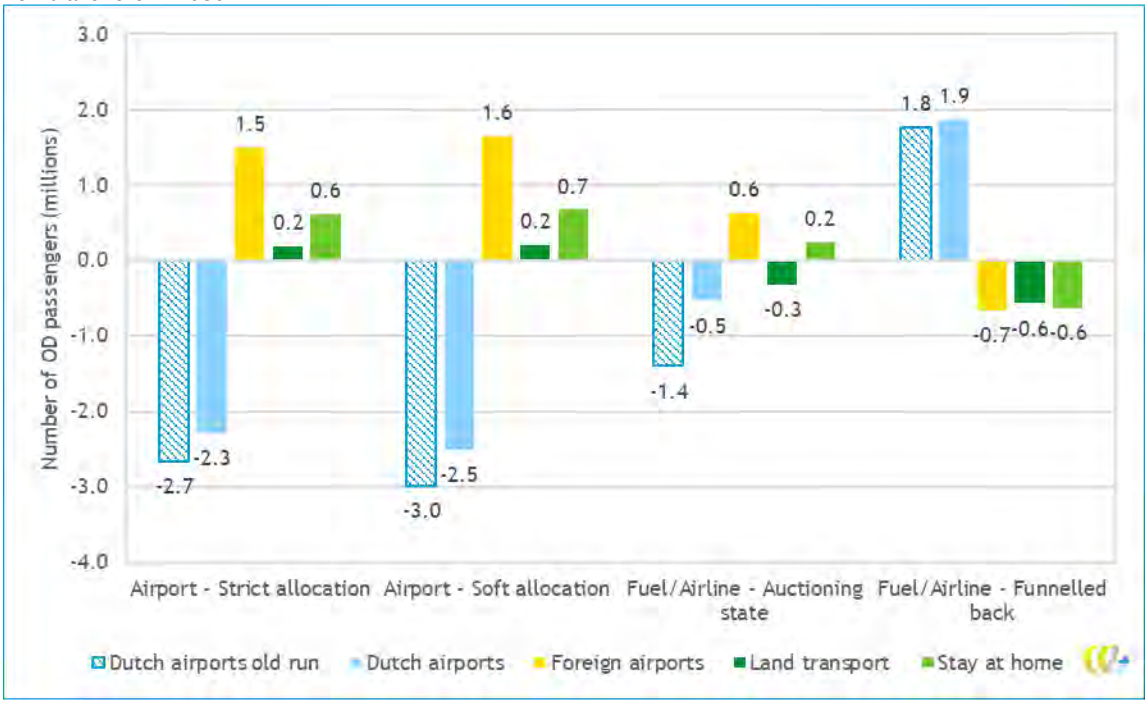


Figure 32 - Impacts on all OD passengers on Dutch airports and foreign airports; impacts on land transport and non-travellers in 2030



For transfer passengers there is a slightly different dynamic of evasion. The decrease of transfers at Schiphol could on the one hand result in a shift of the transfer stop to a foreign hub. However, the decrease of the Dutch transfer could also result in a direct flight, skipping the transfer stop completely. We used AEOLUS to calculate the decrease in transfer passengers at Schiphol and on foreign hubs, the increase in passengers flying directly from foreign airports and the increase in foreign non-travellers.

The results for 2030 are displayed in Figure 33. We can see that the number of transfer passengers decreases in all suboptions and that there is a similar distribution for all suboptions. About 60-70% of the transfer passengers use a foreign hub for their transfer stop and 25-35% take a direct flight to their destination if the CO_2 ceiling is restrictive. The remaining 5-15% of the passengers do not travel anymore. Therefore almost all passengers (85-95%) who do not make a transfer stop at Schiphol anymore either evades to foreign hubs or chooses to fly direct. If we look at the share of the total number of transfer passengers in baseline, we are talking about 7.8 to 10.4% evasion to foreign hubs or direct flights.

Figure 33 - Impacts on transfer passengers through Dutch hubs and foreign hubs; impacts on direct flights and non-travellers in 2030

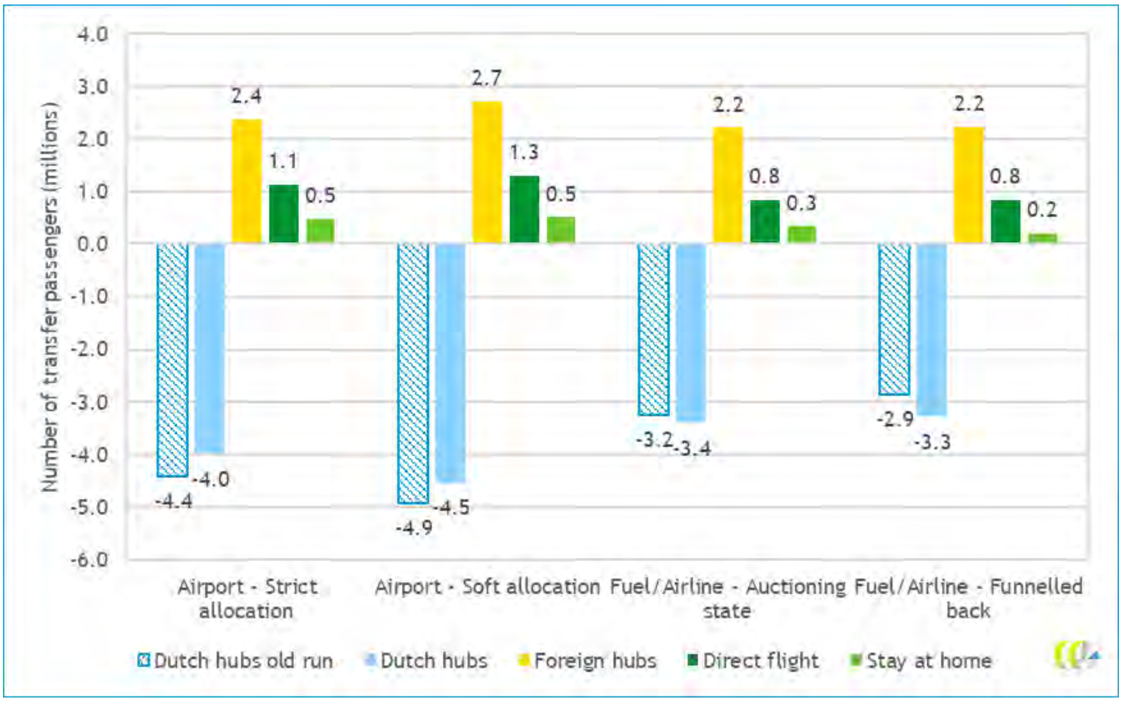


Table 8 and Table 9 show the impacts for the years 2030, 2040 and 2050. We can see the effects are significantly smaller in 2040 and 2050. This is because the CO_2 ceiling in the new AEOLUS runs is only slightly restrictive in 2040. In 2050 the ceiling is not restrictive anymore, the effects we still see are remnant from the restrictive period effecting the supply in r=this year.

Table 8 - Impacts on OD passengers on Dutch airports, foreign airports, land transport and non-travellers (millions per year)

CO_2 ceiling option	Year	Dutch airports	Foreign airports	Land transport	Non-travellers
Airport - Strict allocation (3-year cycle)	2030	-2.29 (-4.07 to -2.29)	1.49	0.19	0.61
	2040	-0.51 (-4.65 to -0.51)	0.19	0.28	0.04
	2050	0.58 (-8.06 to 1.81)	-0.71	0.61	-0.49
Airport - Strict allocation (1-year cycle)	2030	-2.29 (-4.33 to -2.29)	1.49	0.19	0.61
	2040	-0.51 (-5.02 to -0.51)	0.19	0.28	0.04
	2050	0.58 (-7.33 to 1.71)	-0.71	0.61	-0.49
Airport - Soft allocation (3-year cycle)	2030	-2.51 (-4.29 to -2.51)	1.64	0.21	0.67
	2040	-0.22 (-4.37 to -0.22)	0.16	-0.03	0.08
	2050	0.67 (-7.98 to 1.91)	-0.67	0.29	-0.28
Fuel - Auctioning state	2030	64.89	0.63	-0.32	0.23
	2040	86.22	-0.70	-0.14	-0.53
	2050	103.76	-0.56	0.05	-0.66
Fuel - Auctioning funnelled back	2030	67.29	-0.66	-0.57	-0.62
	2040	86.13	-0.82	-0.16	-0.29
	2050	103.57	-0.65	-0.04	-0.30
Fuel - No stability	2030	-0.54 (-0.72 to -0.35)	0.63	-0.32	0.23
	2040	1.36 (1.13 to 1.59)	-0.70	-0.14	-0.53
	2050	1.18 (-2.81 to 1.99)	-0.56	0.05	-0.66
Airline - Auctioning State	2030	64.89	0.63	-0.32	0.23
	2040	86.22	-0.70	-0.14	-0.53
	2050	103.76	-0.56	0.05	-0.66
Airline - Funnelled back	2030	67.29	-0.66	-0.57	-0.62
	2040	86.13	-0.82	-0.16	-0.29
	2050	103.57	-0.65	-0.04	-0.30

Table 9 - Impacts on transfer passengers on Dutch airports, foreign airports, direct flights and non-travellers (millions per year)

CO_2 ceiling option	Year	Dutch hubs	Foreign hubs	Fly direct	Non-travellers
Airport - Strict allocation (3-year cycle)	2030	-4.14 (-5.1 to -4.14)	2.37	1.14	0.47
	2040	-2.14 (-3.82 to -2.14)	1.68	0.82	-0.27
	2050	-0.86 (-3.33 to -0.5)	0.88	0.41	-0.37
	2030	-4.14	2.37	1.14	0.47

CO_2 ceiling option	Year	Dutch hubs	Foreign hubs	Fly direct	Non-travellers
Airport - Strict allocation (1-year cycle)		(-5.24 to -4.14)			
	2040	-2.14 (-3.97 to -2.14)	1.68	0.82	-0.27
	2050	-0.86 (-3.12 to -0.53)	0.88	0.41	-0.37
Airport - Soft allocation (3-year cycle)	2030	-4.7 (-5.64 to -4.7)	2.71	1.30	0.52
	2040	-2.76 (-4.41 to -2.76)	2.09	1.00	-0.26
	2050	-0.82 (-3.3 to -0.47)	0.88	0.42	-0.40
Fuel - Auctioning state	2030	-3.60	2.22	0.84	0.34
	2040	-1.99	1.40	0.71	-0.08
	2050	-0.87	0.66	0.36	-0.11
Fuel - Auctioning funnelled back	2030	-3.38	2.22	0.85	0.21
	2040	-1.92	1.46	0.75	-0.22
	2050	-0.68	0.65	0.36	-0.28
Fuel - No stability	2030	-3.6 (-3.7 to -3.5)	2.22	0.84	0.34
	2040	-1.99 (-2.08 to -1.9)	1.40	0.71	-0.08
	2050	-0.87 (-2.01 to -0.64)	0.66	0.36	-0.11
Airline - Auctioning State	2030	-3.60	2.22	0.84	0.34
	2040	-1.99	1.40	0.71	-0.08
	2050	-0.87	0.66	0.36	-0.11
Airline - Funnelled back	2030	-3.38	2.22	0.85	0.21
	2040	-1.92	1.46	0.75	-0.22
	2050	-0.68	0.65	0.36	-0.28

Note: impacts on transfer in this figure shows transfers including to the Hinterland and therefore can differ slightly with the figure above.

3.3.5 Results in other baseline scenarios

In most scenarios, CO_2 emissions remain below the ceiling, so the implementation of the ceiling would not affect the number of passengers at Dutch airports (see Section 2.3).

In scenarios in which emissions remain below the ceiling, we expect no impact on passenger demand. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the impacts in 2030 are 25 to 32% higher compared to the reference scenario for the airport and fuel supplier/airline - auctioning state options, respectively. The number of flight from Dutch airports in the fuel supplier/airline - auctioning funnelled back policy options is not very different compared to the baseline. However, this does not imply that there are no effects: there for example is a significant shift from intercontinental flights to more European flights. In the long run the impacts for the airport options increases even more, with in 2050 a drop of more than 55 million passengers per year. The impacts of the fuel supplier and airline options restore to baseline because of more SAF blending.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in Annex B.

3.4 Impacts on ticket prices and freight rates

3.4.1 Introduction

Passengers

If the CO_2 ceiling is restrictive, it will cause extra CO_2 costs which will increase ticket prices. There are already CO_2 costs present in the baseline scenarios, due to current measures aiming at reducing CO_2 emissions, such as the EU ETS, CORSIA, SAF blending obligations (RED III) and a fuel tax (ETD). The CO_2 ceiling will cause additional CO_2 costs, at the moment when the ceiling is restrictive. The mechanism depends on the specific policy option. In the 'Airport options' an extra limit on the airport capacity is introduced, causing scarcity which increases ticket prices. In the Fuel supplier and Airline options extra CO_2 costs are introduced by the allowances that fuel suppliers or airlines have to buy for their CO_2 emissions. It is assumed that the additional costs of the CO_2 ceiling will be passed through by 100% to the ticket prices.[25]

Air Cargo

In order to be able to quantify a difference in cargo rates, it is foremost important to understand the market dynamics of intercontinental cargo transport and air cargo in particular.

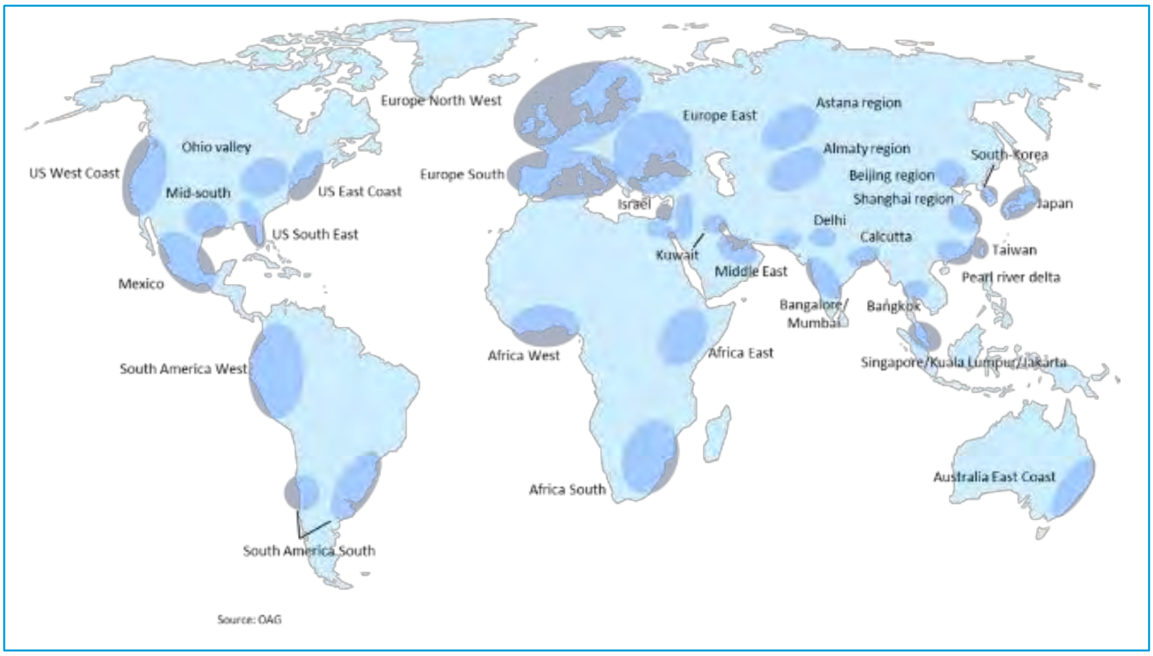
In order to obtain access to air cargo capacity, freight forwarding companies have established themselves in a role as intermediary (Chu, 2014), like travel agents have in passenger air travel. Freight forwarding companies therefor have an important role in the choice of mode and consequently the choice of capacity provider and its routing. The larger freight forwarding companies have global coverage, meaning contracts with multiple shippers and airlines that provide air cargo capacity and are represented at most larger European cargo airports. Driven by the Service Level Agreements (SLA) that freight forwarders have with their customers, the shippers, they choose mode and routing.

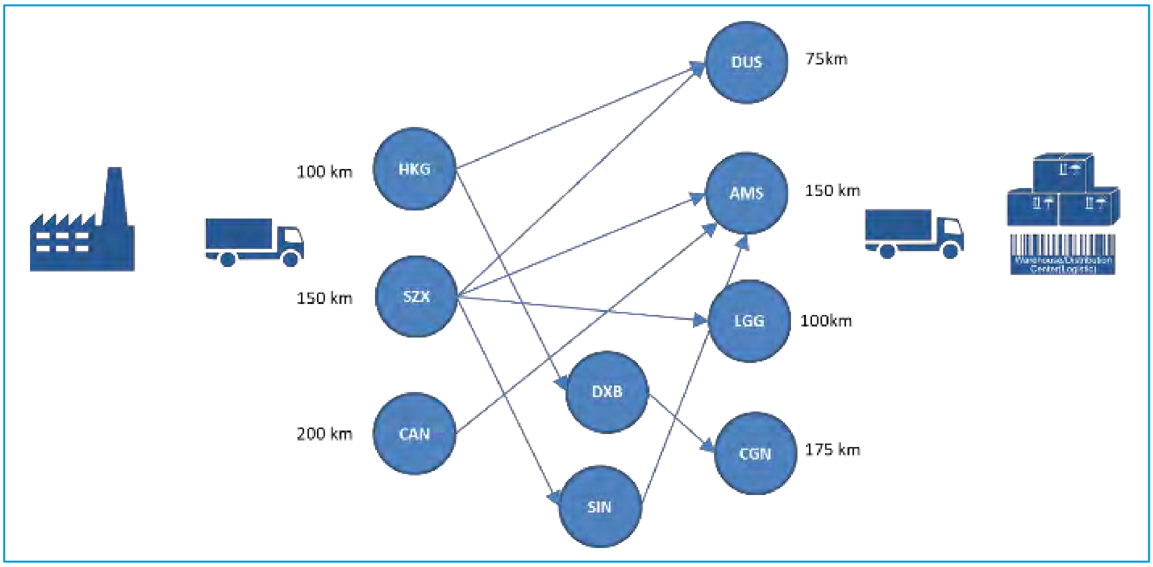
Since the cost of road transportation, as compared to air cargo transport, is limited, additional surface transport by truck is usually insignificant with regard to the total cost of transport. This will lead to the use of other airports, provided that capacity is available at those airports for a competitive price. Air cargo should be considered at a regional level, rather than on city-to-city level.

In order to be able to quantify the effect on cargo rates at Dutch airports, a comprehensive view is required on the total air cargo capacity available in the market in north-western Europe, both for Full Freighter aircraft as well as available belly space in passenger aircraft.

[25] In practice airlines could choose to not fully pass through the additional CO_2 costs, but partly take up the additional costs in the margins. For modelling purposes the costs are passed through (see Annex D for exact modelling), in practice airlines could choose to allocate the costs differently (taking into consideration competition and margins on specific routes).

Figure 34 - Regional economies connected through multiple connections





Source: (Source: Erasmus UPT).

Unfortunately, AEOLUS does not provide any output with regard to changes in transportation cost for the shippers when using other air cargo hubs, bridging longer trucking distances. Given the interrelationships of available air cargo capacity at airports within the larger region and the potential leakage of cargo demand to other cargo airports, the effect on freight rates is complex to calculate. However, during previous capacity limitations, as a result of slot scarcity at Amsterdam Airport Schiphol in the period 2017 to 2019, crowding out of the full freighter flights has been observed. This effect was mainly caused by the lower on time performance of full freighter airlines (as compared to passenger airlines) and a consequent loss of grandfather rights for slots. At the same time the utilisation of belly capacity has increased. As a result, the remaining capacity at Schiphol has seen price increase which can be identified as scarcity rents. To what extent these effects will be seen under a CO_2 ceiling is unknown at this stage and therefore does not provide a quantified effect on the transportation cost that importing and exporting companies are confronted with, being serviced through other air cargo hubs in north-western Europe. Note that we do have AEOLUS results on cargo, these can be found in Section 3.5.

3.4.2 Methodology

The ticket-prices are input for the AEOLUS model. They are based on the OAG database and the future projections are defined in the Dutch WLO scenarios by CPB Netherlands Bureau for Economic Policy Analysis and PBL Netherlands Environmental Assessment Agency.
In AEOLUS, the ticket price consists of the following components:
1. Base price (including assumed price increase due to COVID pandemic).
2. Airport fees.
3. Flight tax.
4. CO_2 costs excluding national CO_2 ceiling.[26]
5. Costs due to the CO_2 ceiling emissions trading.
6. Cost increase due to limited airport capacity.

The 'Costs due to the CO_2 ceiling emissions trading' are costs due to the purchase of CO_2 permits and are only present in the Fuel supplier and Airline options. In the Airport option, the costs are expressed as scarcity costs[27] which are visible in the 'Cost increase due to limited airport capacity'.
In this report we present the results for five distinct example routes:
1. Direct flights from Amsterdam to Spain (direct flight within the EEA).
2. Direct flights from Amsterdam to the North-Eastern USA (intercontinental direct flight).
3. Transfer flights from Eastern Europe to Central America with Amsterdam as transfer hub (transfer connection with one intercontinental and one EEA leg).
4. Transfer flights from Scandinavia to Italy with Amsterdam as transfer hub (transfer connection with two EEA legs).
5. Transfer flights from North-Eastern USA to South-Eastern Asia with Amsterdam as transfer hub (transfer connection with two intercontinental legs).

3.4.3 Results

Figure 35 shows (for Scenario 23) the baseline ticket prices[28] for the three different routes in different years. It can be seen that the base prices drop over time especially on intercontinental routes and that 'CO_2 costs' become increasingly more important. Also, these are relatively higher in intra-EEA flights (due to the Fit for 55 measures). The scarcity costs due to limited airport capacity are present in this scenario as well, since Schiphol airport is at the peak capacity after 2040. In all cases, the additional costs due to the CO_2 ceiling are relatively low. There are several reasons for these low additional costs. First of all, substantial climate policy is already assumed in the reference baseline scenario. Therefore, the additional effort to stay under the CO_2 ceiling is relatively small. This relatively small effort is mainly achieved by reducing the number of transfer flights, which

[26] These costs include the costs of all measures to reduce CO_2 emissions in the baseline scenario, such as emission pricing (EU ETS or CORSIA), blending obligations (RED III) and the fuel tax (RED recast). For a full description of the assumptions see Annex E.

[27] This is because there is no explicit emission trading in this scenario. However, the reduced airport capacity will likely lead to increased ticket prices. These are expressed in the scarcity costs.

[28] The displayed ticket prices are one-way prices, calculated as half of the return price. Prices are averaged over all booking classes and airline types.

are highly price-sensitive. Also, for intra-EEA flights, the marginal costs of blending extra SAF are about equal to the marginal climate costs of using fossil kerosene.

Figure 35 - Ticket prices in the reference baseline scenario for different destinations

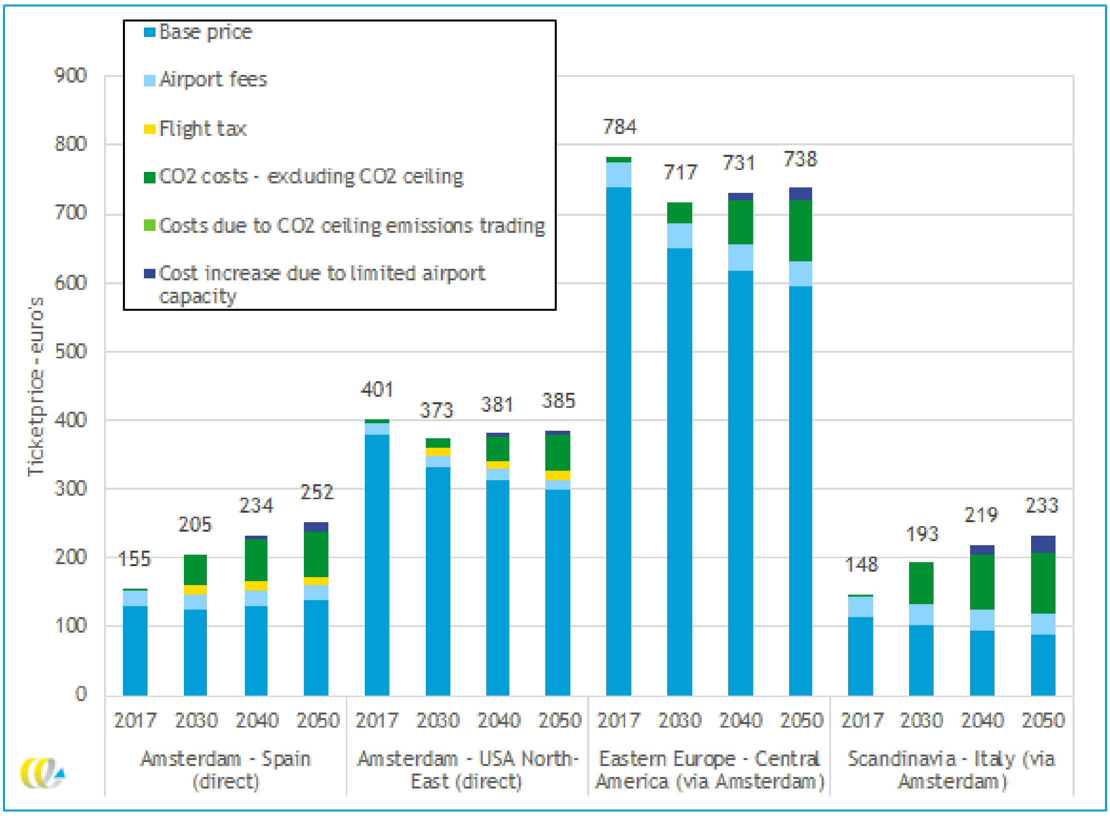


Figure 36 shows the ticket prices in the different CO_2 ceiling scenario's for the route Amsterdam to Spain. Ticket prices increase most in the Airport options and relatively little in the Fuel/Airline - Auctioning state options. This corresponds to the effects we saw earlier, where intra-EEA flights decreased significantly in the 'Airport options', while for the Fuel/Airline options there only is a small intra-EEA decrease. This is caused by the relatively small amount of CO_2 emitted from this short flight, which therefore gives small costs for the CO_2 permits in the Fuel/Airline options.

The ticket price for 'Fuel - Auctioning funnelled back' is less expensive compared to the ticket price in the baseline for this route. This is due to the auctioning income which is funnelled back to the sector in this policy option. We assumed that the sector passes this through in the ticket prices with a fixed cost reduction per passenger. This causes a relative advantage for short flights (short flights have lower ticket prices, therefore relatively they get a larger cost reduction), which even makes ticket prices cheaper here. This results in additional passenger demand for intra-EEA flights and a decrease for intercontinental flights (see Figure 37 and Figure 38).

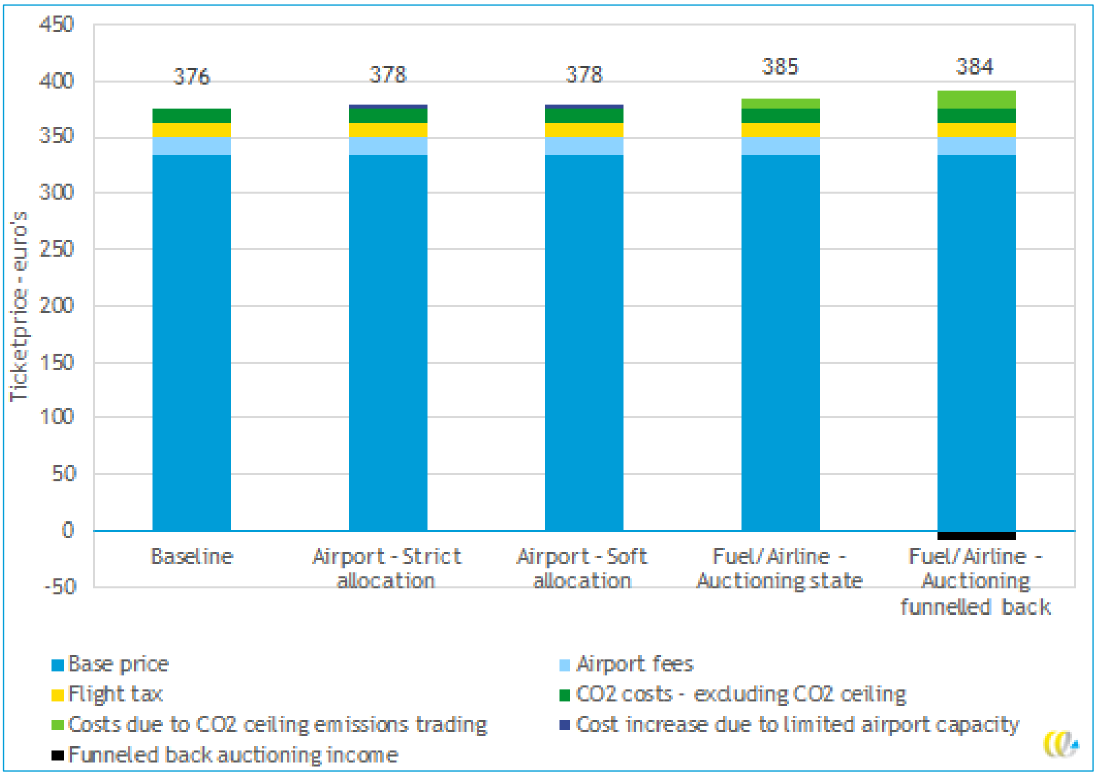
Please note that the reference baseline scenario already includes a rise in ticket price by ca. 45 Euro resulting from the Fit for 55 policy measures. The add on resulting from ceiling costs varies between the policies from 2 to 6 Euros and in one case, the Fuel/ETS auction funnelled back, it decreases the ticket price by 5 Euro. This makes obvious that the big demand effects will result from Fit for 55 and just a minor part from the additional Dutch ceiling costs. In consequence the national Dutch policy measure has a limited negative competitive effect on the national aviation system.

Figure 36 - Ticket prices for direct flights from Amsterdam to Spain in the different suboptions in 2030

The direct intercontinental route of Amsterdam to USA North-East (Figure 37) shows the highest ticket price increase for 'Fuel - Auctioning state'. Since this is a relatively long flight, the costs for CO_2 permits are high in the Fuel/Airline options. This corresponds to what we saw earlier, with a relatively strong decrease in intercontinental OD passengers for Fuel - Auctioning state.

Note that the CO_2 costs are relatively small here. Since this is an intercontinental flights, CORSIA applies, which has significantly lower CO_2 costs than the Fit for 55 package. If we compare the prices of the policy options in 2030 to the 2017 price in baseline, we see that the tickets have actually become cheaper. This is caused by the steep decrease in base price, which represents fleet renewal with more efficient aircrafts.

Figure 37 - Ticket prices for direct flights from Amsterdam to the USA North-East in the different suboptions in 2030



For transfers flights we investigated three routes here. One intercontinental to intra-EEA transfer from Central America to Eastern Europe via Amsterdam (Figure 38), one intra-EEA to intra-EEA route from Scandinavia to Italy via Amsterdam (Figure 39) and one intercontinental to intercontinental transfer from North-Eastern USA to South-Eastern Asia via Amsterdam (Figure 40).[29] We see that in the intercontinental-EEA transfer the Fuel supplier and Airline options have the highest ticket price increase. This makes sense since the intercontinental part of the flight emits a lot of CO_2 increasing the CO_2 costs for the emission rights. It also matches with what we saw earlier with the shift of intercontinental flights to intra-EEA flights in the Fuel supplier and Airline options.

For the EEA-EEA transfer we see the opposite effect, the 'Airport options' having the highest ticket price increase. In the 'Airport options' scarcity costs are created because of the reduced airport capacity. These scarcity costs are passed through to all flights proportionally,[30] resulting in a relatively larger effect on intra-EEA flights (having a lower base ticket price). For the intercontinental-intercontinental transfer we see similar effects as in the intercontinental-EEA transfer. High ticket price increases for the Fuel supplier and Airline options, and relatively small effects for the Airline options.

29 Note that the ticket price depends on the direction of the route. For example Eastern Europe - AMS - Central America has lower ticket prices than Central America - AMS - Eastern Europe. The effects from the policy options are however very similar.

30 Also longer flights usually have more passengers per plane, therefore the costs are lower per passenger on longer flights.

Figure 38 - Ticket prices for transfer flights from Central America to Eastern Europe via Amsterdam in the different suboptions in 2030

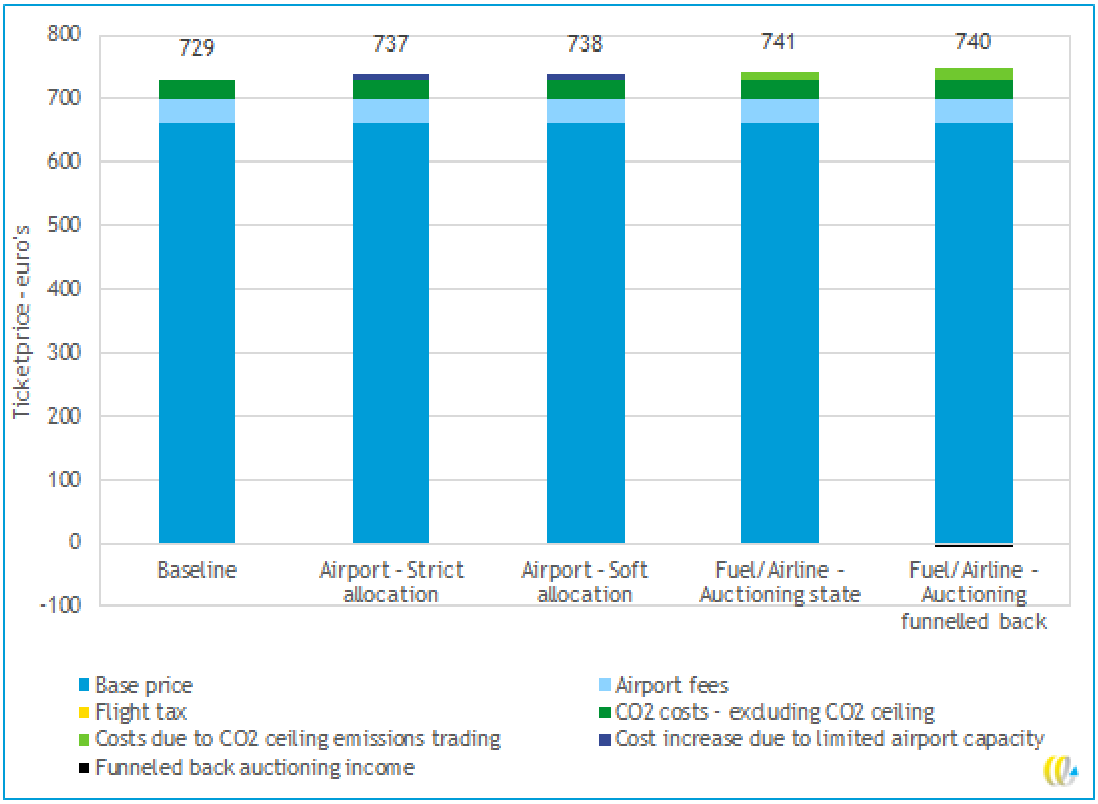


Figure 39 - Ticket prices for transfer flights from Scandinavia to Italy via Amsterdam in the different suboptions in 2030

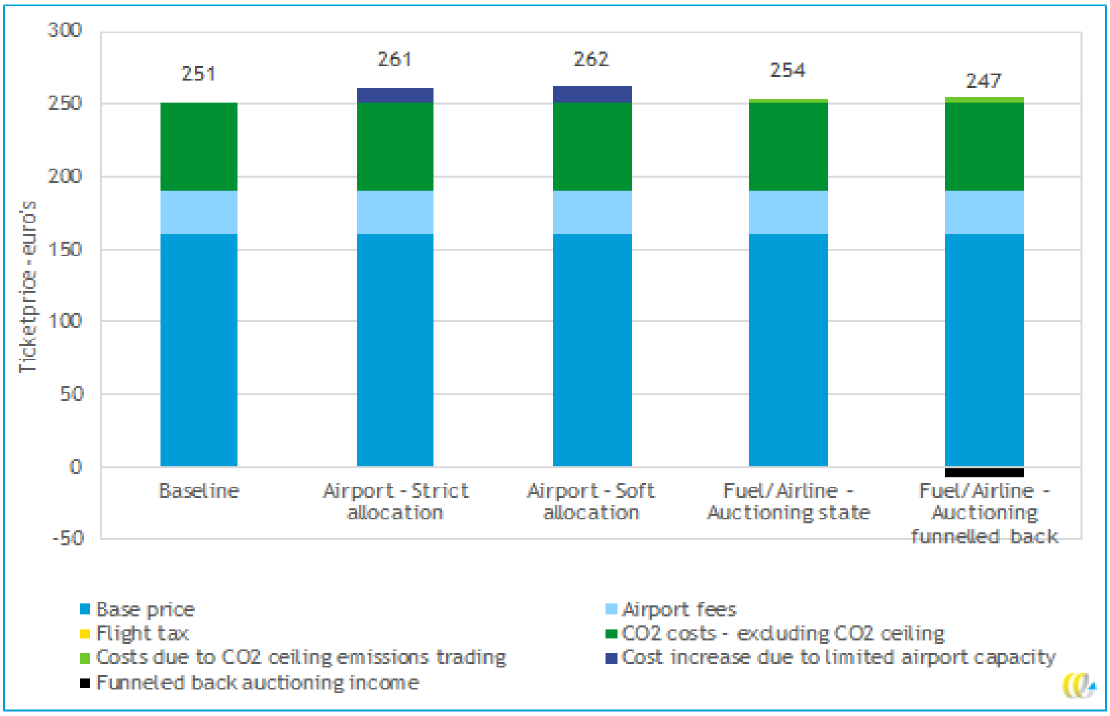
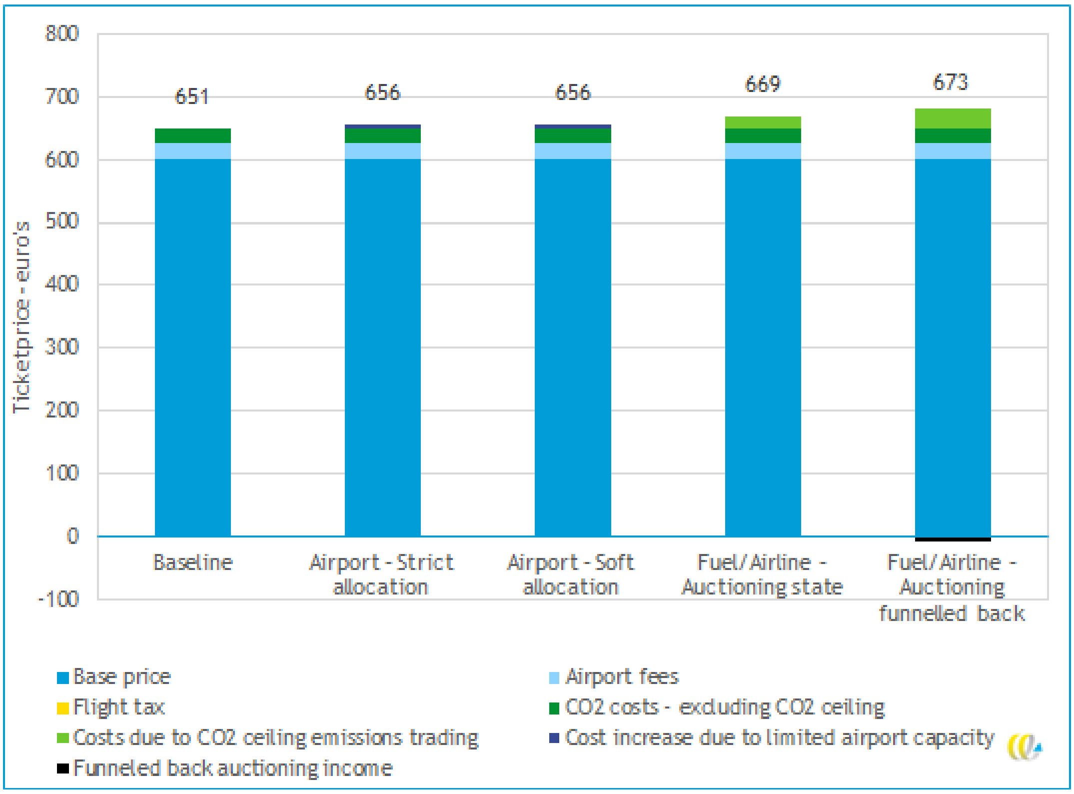


Figure 40 - Ticket prices for transfer flights from North-Eastern USA to South-Eastern Asia via Amsterdam in the different suboptions in 2030



In all cases, the additional costs due to the CO_2 ceiling are relatively low. There are several reasons for these low additional costs. First of all, substantial climate policy is already assumed in the reference baseline scenario. For a family going on holiday from Amsterdam to Spain the total increase in ticket price is therefore significant in comparison to 2017. However, the additional effort (and costs) to stay under the CO_2 ceiling is relatively small. This relatively small effort is mainly achieved by reducing the number of transfer flights, which are highly price-sensitive. Also, for intra-EEA flights, the marginal costs of blending extra SAF are about equal to the marginal climate costs of using fossil kerosene.

3.4.4 Results in other baseline scenarios

In most scenarios, CO_2 emissions remain below the ceiling, so the implementation of the ceiling would not affect ticket prices (see Section 2.3).

In scenarios in which emissions remain below the ceiling, we expect no impact on the ticket prices from the CO_2 ceiling. Nevertheless ticket prices can still increase depending on the other climate policies (Fit for 55). In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the ticket prices in the baseline are lower due to lower CO_2 costs from the weakened Fit for 55 package. The ticket price increases from the CO_2 ceiling policy options are in 2030 about 30% higher, this is due to higher CO_2 costs (scarcity costs and emission rights price) from a more restrictive CO_2 ceiling. This, in combination with the weakened Fit for 55 package, makes the CO_2 ceiling's impacts on ticket price in this scenario relatively more significant. However, the lower CO_2 costs from the weakened Fit for 55 package makes the total increase in ticket prices lower than in the

reference scenario (for example for the route AMS-Spain the maximum price is € 193 compared to € 210 in the reference scenario).
In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes. The impacts of Scenario 6 are shown in Annex H , the impacts for the other modelled scenarios are displayed in the Excel Results Spreadsheets.

In this section we discuss the impact of the different options of the CO_2 ceiling on the number of passengers. The number of passengers flying from different Dutch airports in the reference baseline scenario is shown in Table 10. When comparing the number of passengers in Table 10 to the amount of passenger flights in Figure 41, it is clear that the average number of passengers per flight increases over time. This is due to the following assumed developments in AEOLUS: use of increasingly larger aircrafts, more efficient seating and higher occupation degrees.

3.5 Impacts on flights, destinations and network quality

3.5.1 Introduction

Table 10 shows the number of flights per airport in the reference baseline scenario. In the regional airports, the number of flight grows over time. At Schiphol Airport, the number of flights is currently already close to the capacity limit of 500 thousand flights per year. In the reference baseline scenario, the maximum of 500 thousand will be reached again in 2031. At regional airports, the limits are not reached except for Eindhoven, where the limit of 55.000 flights per year is reached in 2050.

Table 10 - Development of the number of flights at Dutch airports in the reference scenario baseline (without **CO_2** ceiling, thousands of flights per year)

Airport	2017	2030	2040	2050
Total	556	560	596	626
Amsterdam	497	495	500	500
Lelystad	0	14	24	33
Eindhoven	35	29	40	55
Rotterdam	16	13	21	25
Maastricht	4	5	6	7
Groningen	3	3	5	7

3.5.2 Methodology

The impacts on flights are based on the AEOLUS model runs.

In our analysis we distinguish the following categories within the total number of flights:
- within the EEA and intercontinental flights;
- passenger flights and full-freight flights;
- flights departing from different Dutch airports.

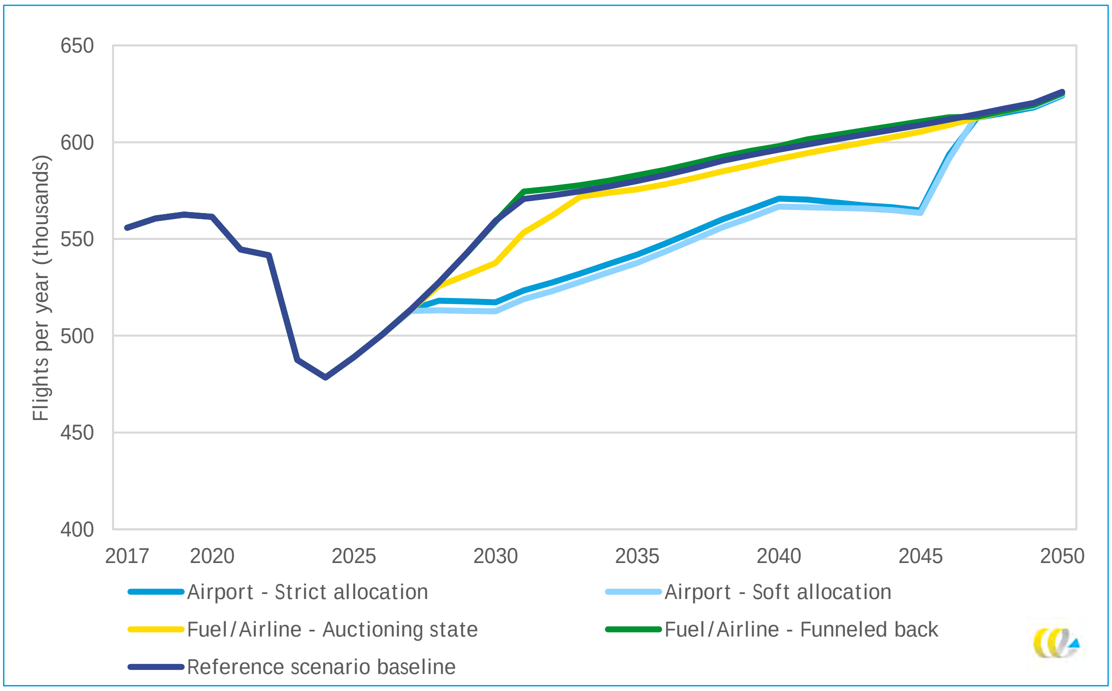
3.5.3 Results

Figure 34 displays the total number of flights at Dutch airports for the baseline and different CO_2 ceiling options (in the reference scenario). First we see a big drop in the number of flights from 2020 onwards. This is caused by the COVID pandemic, recovery in terms of number of flights is predicted to take several years. If we now look at the effects of the different policy options, we can see that the Airport options of the CO_2 ceiling lead to a systematically lower number of flights compared to baseline for the period when the CO_2 ceiling is restrictive - from around 2028 lasting until 2046.[31] After this period the number of flights almost recovers to baseline. The Fuel Supplier/Airline - Auctioning state options also show a decrease in flights in the same period, but this effect is significantly smaller. These trends are very similar to the development of the number of passengers. For a discussion of the difference we therefore refer to Section 3.2.

In contrast to the other options, the Fuel Supplier/Airline - Auctioning funnelled back option shows a slight increase in the number of flights. This is caused by the shift from intercontinental flights to inter-EEA flights. Inter-EEA flights emit way less CO_2, therefore airlines are able to make more flights with the same CO_2 budget. This shift is larger for the Fuel Supplier/Airline - Auctioning funnelled back option due to the funnelled back auctioning income to the sector, such that there even is an increase in number of flights.[32]

Overall we still see growth in the number of flights until 2050. However, if we compare to the number of passengers we can see that the growth is stronger there. This can be explained by the assumption that there will be on average more passengers per flight in the future, driven by technological innovation and fleet renewal.

Figure 41 - Total number of flights at Dutch airports



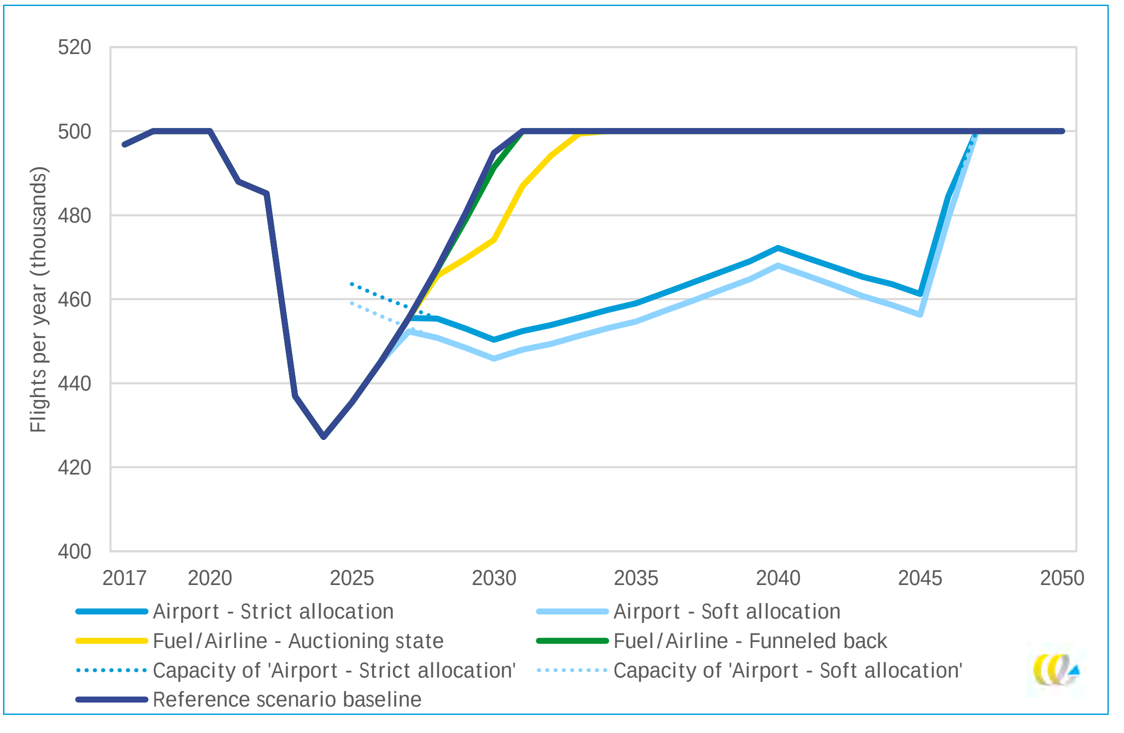
31 The 'bend' we see in the results of the Airport options around 2045 follows from the ReFuelEU Aviation proposal's blending requirements in combination with the decreasing CO_2 ceiling. Up to 2040 the SAF blending requirements increase steadily to 32%, while in 2045 there is a relatively smaller increase up to 38%, after which the requirement jumps to 63% in 2050.

32 In the Fuel Supplier/Airline - Auctioning funnelled back option the income raised by the auctioning of CO_2 permits is funnelled back to the sector. In the model we assume a 100% cost pass through, such that all ticket prices are decreased by a fixed amount. This fixed cost reduction will be relatively larger for short inter-EEA routes with low ticket prices, resulting in an increased demand for inter-EEA passengers.

Figure 41 shows that the number of flights in the fuel supplier and airline options in which the auctioning revenues are retained by the State are lower than in the option in which they are funnelled back to the sector, especially in the period until 2032. After that, the number of flights is quite close, despite the outflow of money. The reason why the total number of flights in these two options is close, is that in both options, airport capacity constrains further growth. The scarcity rents associated with unmet demand are at least equal to the auctioning revenue. This means that the scarcity rents are captured by the State when the auctioning revenues are added to the general budget, and to the airlines when the revenues are funnelled back to the sector.

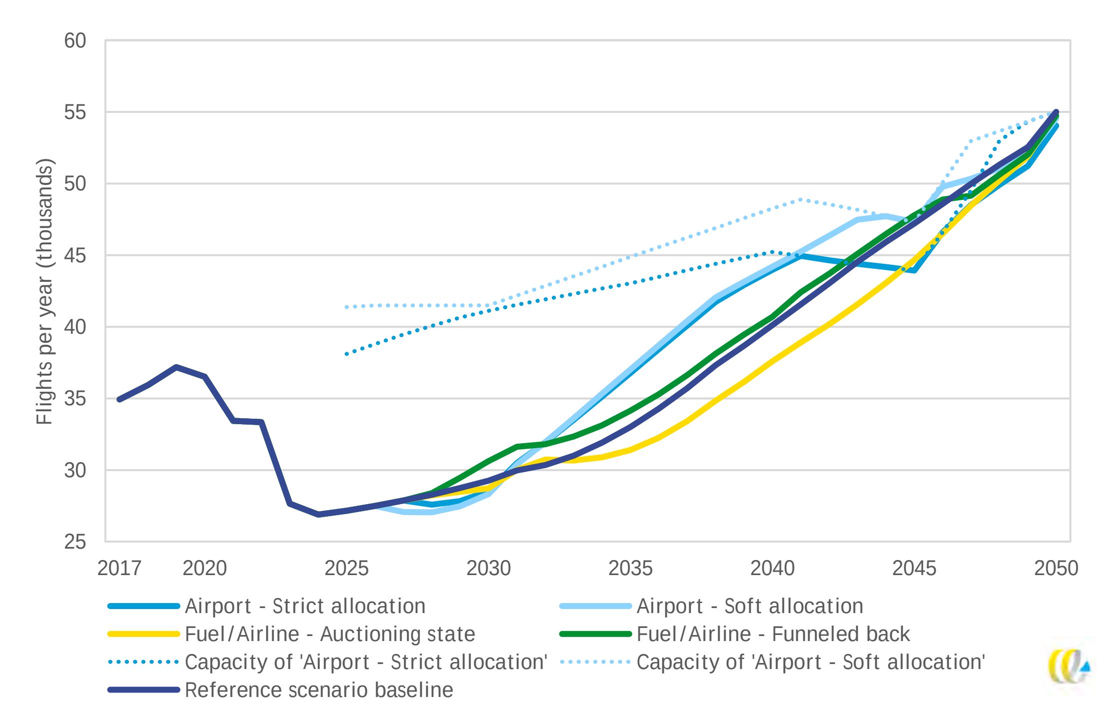
In Figure 42 the number of flights at Schiphol airport is displayed for the different options. Also the capacity for Schiphol following from the CO_2 ceiling Airport - strict/soft options is plotted with dotted lines.[33] We can see that around 2028, when the number of flights from the Airport - strict/soft options (blue lines) start to vary from the other options, the Airport - strict/soft capacity of Schiphol is instantly reached (the solid blue lines hit the light blue dotted lines). For the regional airports, see Figure 43 for Eindhoven airport as an example, it takes longer (until at least 2040) before the Airport - strict/soft capacity is reached. This unused capacity for the regional airports make the Airport - strict/soft options more restrictive in practice (in 2030 for example 22 to 35% more CO_2 is saved than in the other options).

Figure 42 - Total number of flights on Schiphol airport with capacity of Airport Strict and Soft options



[33] We assume an introduction of the CO_2 ceiling in 2025, therefore the CO_2 ceiling capacity lines start at 2025.

Figure 43 - Total number of flights on Eindhoven airport with capacity of Airport Strict and Soft options



The effect from all the different suboptions of the CO_2 ceiling on the number of flights compared to the baseline is shown in Table 11. The impacts on passengers are very similar to the impacts on passengers. Since for the suboption Airport - Soft allocation the allocation of CO_2 budget is corrected for noise permits, we see slightly more flights in regional airports compared to strict allocation here. Another effect we see is that in the Airport options for most regional airports the number of flights increases for the years 2030 and 2040. As we saw in Figure 42 there is more demand than capacity at Schiphol, we also see there is spare capacity at the regional airports, therefore a shift of flights from Schiphol to regional airports occurs. In 2050 the CO_2 ceiling is not restrictive anymore, the small effects still visible in the results of 2050 are remnants from the restrictive period.

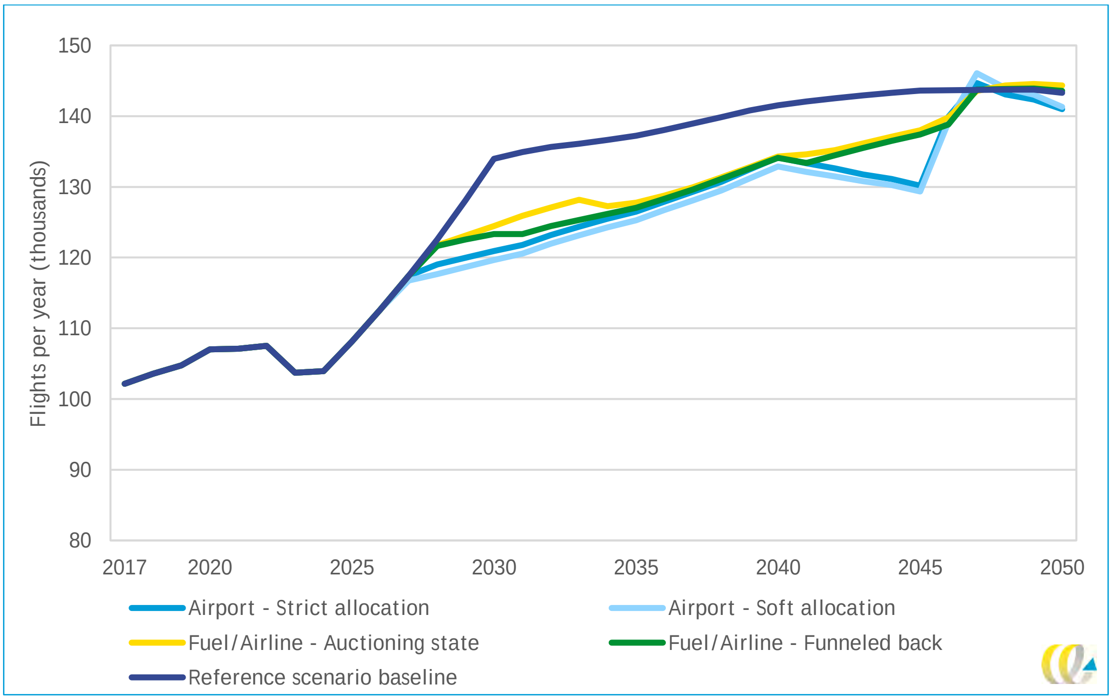
Table 11 - Development of the number of flights at Dutch airports compared to the baseline (thousands per year). The ranges in brackets indicate the expected fluctuations of travel demand, which are not modelled in AEOLUS

Airport	Year	Airport - Strict allocation (3-year cycle)[a]	Airport - Strict allocation (1-year cycle)[a]	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability[a]	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-42.2 (-57 to -42.2)	-42.2 (-59.1 to -42.2)	-46.9 (-61.6 to -46.9)	-21.9	-0.6	-21.9 (-23.4 to -20.3)	-21.9	-0.6
	2040	-25.2 (-53.2 to -25.2)	-25.2 (-55.7 to -25.2)	-29.3 (-57.2 to -29.3)	-4.8	1.9	-4.8 (-6.3 to -3.2)	-4.8	1.9
	2050	-1.9 (-54.2 to 4.9)	-1.9 (-49.7 to 4.4)	-1.5 (-53.8 to 4.8)	-0.2	-0.7	-0.2 (-24.3 4.6)	-0.2	-0.7
Amsterdam	2030	-44.5 (-57.4 to -44.5)	-44.5 (-59.3 to -44.5)	-49 (-61.8 to -49)	-20.7	-3.5	-20.7 (-20.7 to -20.7)	-20.7	-3.5
	2040	-27.8 (-51 to -27.8)	-27.8 (-53.1 to -27.8)	-32 (-55 to -32)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2050	0 (-41.9 to 0)	0 (-38.3 to 0)	0 (-41.9 to 0)	0.0	0.0	0 (-19.2 to 0)	0.0	0.0
Lelystad	2030	-1.3 (-1.7 to -1.3)	-1.3 (-1.7 to -1.3)	-1.5 (-1.8 to -1.5)	-0.3	0.6	-0.3 (-0.6 to 0)	-0.3	0.6
	2040	-1.4 (-2.5 to -1.4)	-1.4 (-2.6 to -1.4)	-1.6 (-2.7 to -1.6)	-1.9	0.4	-1.9 (-2.2 to -1.5)	-1.9	0.4
	2050	-0.5 (-3.2 to 2.2)	-0.5 (-3 to 2)	-0.6 (-3.3 to 2.1)	-0.1	-0.2	-0.1 (-1.3 to 1.2)	-0.1	-0.2
Eindhoven	2030	-0.7 (-1.5 to -0.7)	-0.7 (-1.7 to -0.7)	-0.9 (-1.7 to -0.9)	-0.5	1.4	-0.5 (-1.2 to 0.2)	-0.5	1.4
	2040	3.9 (1.7 to 3.9)	3.9 (1.5 to 3.9)	4.1 (1.9 to 4.1)	-2.5	0.6	-2.5 (-3.2 to -1.9)	-2.5	0.6
	2050	-1 (-5.5 to 0)	-1 (-5.1 to 0)	-0.5 (-5 to 0)	-0.1	-0.3	-0.1 (-2.2 to 0)	-0.1	-0.3
Rotterdam	2030	3.4 (2.9 to 3.4)	3.4 (2.8 to 3.4)	3.5 (3 to 3.5)	-0.2	0.7	-0.2 (-0.5 to 0.1)	-0.2	0.7
	2040	0.1 (-0.9 to 0.1)	0.1 (-1 to 0.1)	0.1 (-0.9 to 0.1)	-0.3	0.7	-0.3 (-0.6 to 0.1)	-0.3	0.7

Airport	Year	Airport - Strict allocation (3-year cycle)[a]	Airport - Strict allocation (1-year cycle)[a]	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability[a]	Airline - Auctioning state	Airline - Funnelled back
	2050	-0.4 (-2.4 to 1.7)	-0.4 (-2.2 to 1.5)	-0.4 (-2.4 to 1.7)	0.0	-0.2	0 (-1 to 0.9)	0.0	-0.2
Maastricht	2030	0.2 (0 to 0.2)	0.2 (0 to 0.2)	0.2 (0 to 0.2)	-0.1	0.0	-0.1 (-0.2 to 0)	-0.1	0.0
	2040	0 (-0.3 to 0)	0 (-0.3 to 0)	0 (-0.3 to 0)	-0.1	0.0	-0.1 (-0.2 to 0)	-0.1	0.0
	2050	0 (-0.6 to 0.5)	0 (-0.5 to 0.5)	0 (-0.6 to 0.5)	0.0	0.0	0 (-0.3 to 0.3)	0.0	0.0
Groningen	2030	0.8 (0.7 to 0.8)	0.8 (0.7 to 0.8)	0.8 (0.7 to 0.8)	0.0	0.2	0 (-0.1 to 0.1)	0.0	0.2
	2040	0 (-0.2 to 0)	0 (-0.2 to 0)	0 (-0.2 to 0)	0.0	0.2	0 (-0.1 to 0)	0.0	0.2
	2050	-0.1 (-0.6 to 0.5)	-0.1 (-0.6 to 0.4)	-0.1 (-0.6 to 0.5)	0.0	0.0	0 (-0.3 to 0.3)	0.0	0.0

Figure 44 shows the total number of intercontinental flights, these are long distance flights with high CO_2 emissions per passenger. Between 2025 and 2040 the impact of all options is very similar. The CO_2 ceiling leads to a reduction of 10 to 15 thousand flights per year. In the five years afterwards the Airport option is more restrictive than the other two. This is due to the fact that after 2040 it becomes economically viable for airlines to blend more SAF in the Fuel supplier and Airline options. They will then use this possibility to allow for more flights. After 2046 the ceiling is not restrictive anymore.

Figure 44 - Development of the number of intercontinental flights at Dutch airports



For the relatively short flights within the EEA the situation is very different. Figure 45 shows the total number of EEA flights at Dutch airports. When comparing the suboptions, it becomes clear that the reduction of flights within the EEA is only significant in the Airport options. The reason for this difference is two-fold. For the period of up to 2040 the Airport options are in practice more restrictive. This is due to the fact that the ceiling at Schiphol is quickly reached, while there is unused CO_2 capacity for the regional airports. After 2040, in the Fuel supplier and Airline options, airlines will use the possibility to blend more SAF. For flights within the EEA this often is viable, because of the high CO_2 prices due to the different Fit for 55 measures and the additional CO_2 ceiling permits.[34] In the Airport option, it is assumed that airlines will not blend additional SAF.[35] For flights to destinations outside the EEA, the CO_2 costs (CORSIA) are much lower, which means that it is not economically beneficial to blend extra SAF, even with additional costs caused by the CO_2 ceiling.

34 The SAF price keeps decreasing over time, while the CO_2 costs keep increasing. In 2040 the CO_2 costs for EEA flights are high enough to make SAF economically viable. (Price of SAF < price of kerosene + CO_2 costs)

35 See the discussion on page 29 for a more elaborate explanation of this assumption.

Comparing the impact of the Airport option, we find that the number of intercontinental flights decrease relatively more (9% in 2035), compared to 7% for EEA flights. However, note that intercontinental flight have significantly more passengers than EEA flights. Therefore, as we saw in Subsection 3.2.3, the Airport options reduce the passenger volume on shorter distance flights more than on intercontinental flights.

Figure 45 - Development of the number of EEA flights at Dutch airports

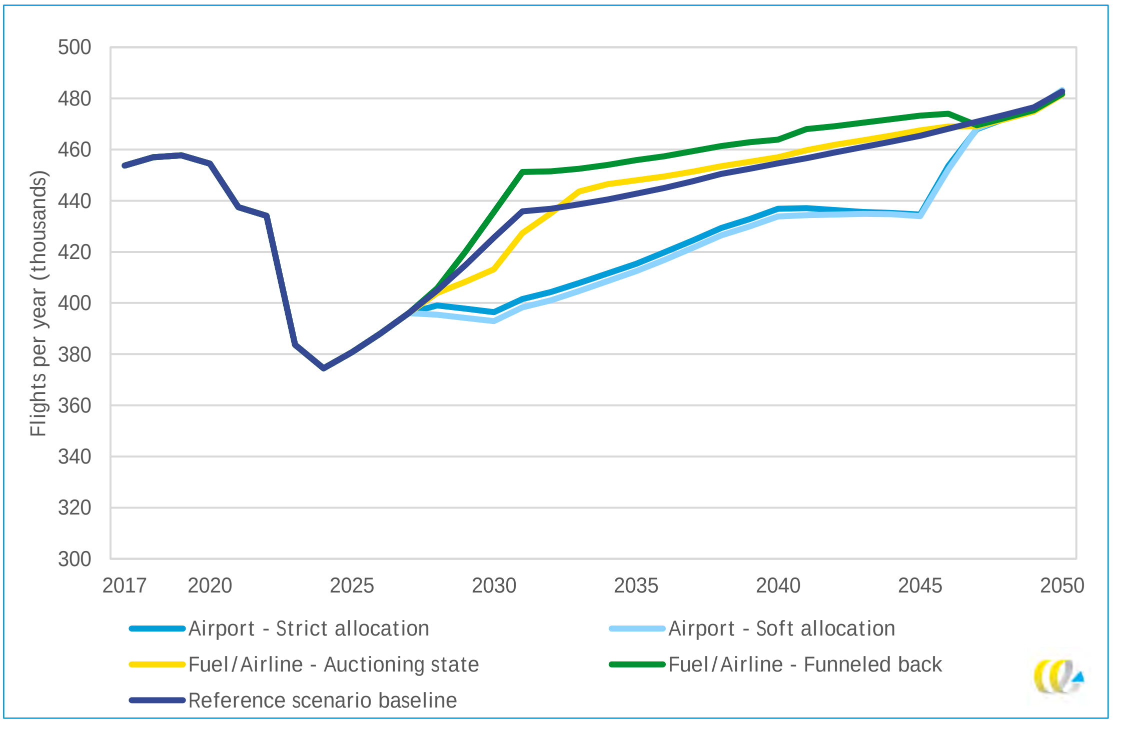


Figure 46 shows the development of passenger flights and Figure 47 shows the development of full-freight flights. Since the vast majority of flights are passenger flights (96% in 2019), the results of the passenger flights is almost identical to the development of the total number of flights. The modelled results show that the number of full-freight flights is barely affected by the CO_2 ceiling. In the period between 2027 and 2035 the 'Airport' options lead to a decrease of approximately 5,000 movements per year.[36] Note that the AEOLUS modelling results for freight are not very precise as the effects of price changes due to the Fit for 55 proposals and the CO_2 ceiling cannot be modelled in detail. This limits the conclusions that can be made based on these quantitative results.

[36] The spike after 2045 in the full-freight data is an artefact of the modelling, and should not be expected in reality. This is due to inaccuracy in AEOLUS for modelling freight.

Figure 46 - Development of the number of passenger flights at Dutch airports

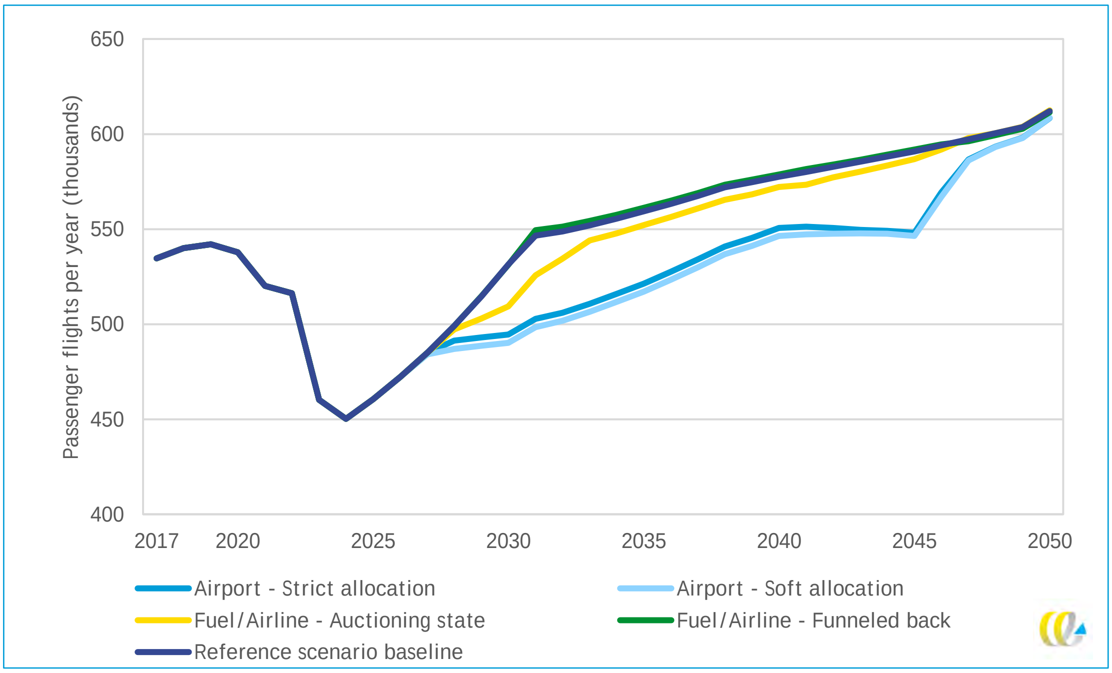
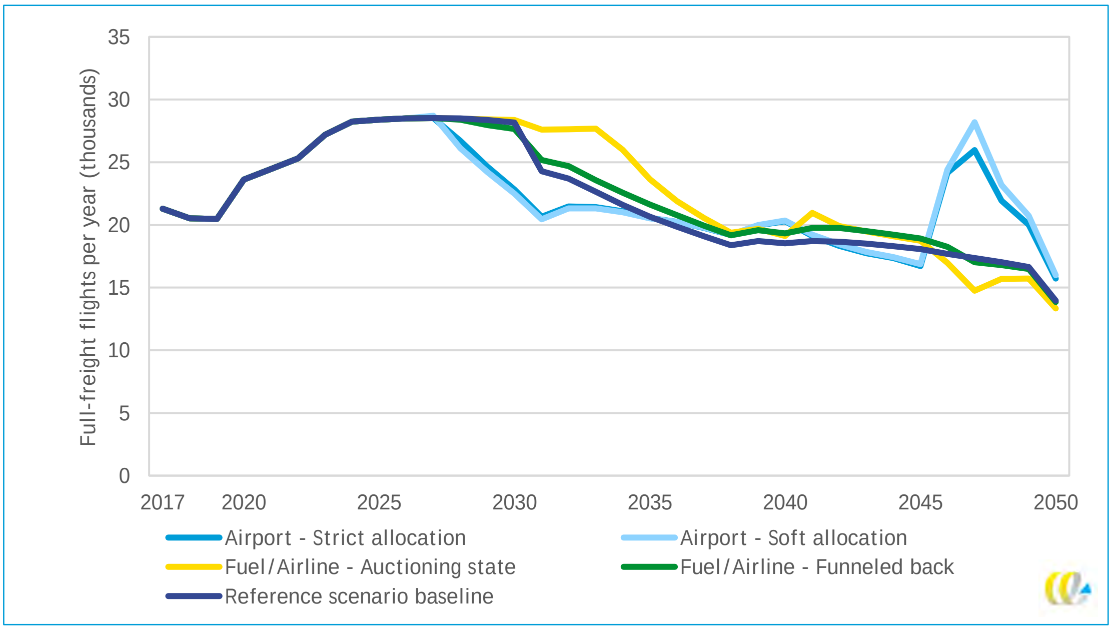


Figure 47 - Development of the number of full freighter flights at Dutch airports



3.5.4 Impacts on the network and connectivity

Connectivity describes how the Netherlands is connected by passenger flights with the rest of the world. Two important aspects related to connectivity are the number of destinations and the frequency with which these destinations are visited. In line with (SEO, 2021) we distinguish three types of connectivity:

1. Direct connectivity is the direct number of flights to a certain destination per time interval.

2. Indirect connectivity describes the indirect connections to a certain destination with a layover at another hub per time interval.
3. Hub connectivity describes all indirect connections from other destinations with a layover at Schiphol Airport to a certain destination per time interval.

Indirect flights (indirect- and hub connectivity) are less attractive compared to a direct flight (or other indirect flights). How much more unattractive they are depends on the delays from layovers and detour factors. Therefore, it is common to express the different types of connectivity in connectivity units (CNUs) which range from 0 to 1 depending on the amount of delay.

In our analysis we were limited due to the available data. Therefore, we included the textbox below which clarifies what could and could not be quantified.

Limitations in the discussion of impacts on connectivity

There are several limitations in the AEOLUS model which limit our possibilities to calculate the different types of connectivity:

1. AEOLUS consists of a limited number of destination zone (seventeen within Europe and twelve intercontinental). Individual airports within these zones are not specified. Therefore, the AEOLUS model is not suitable to calculate changes in the number of destinations that can be reached and the frequency with which individual airports are visited.
2. AEOLUS does not model the profitability of individual routes for specific airlines. Therefore, it is impossible to model the strategic reactions from the airlines which affect the connectivity.
3. It was not possible to determine CNUs for indirect- and hub connectivity, since this requires detailed information about the detour factors and layover times that is not modelled with sufficient detail in AEOLUS.

With these limitations in mind we were able to quantify only a limited part of the effects on connectivity: the direct connectivity aggregated per geographical zone. With this aggregation still meaningful insight about the effects on direct connectivity can be obtained. For the impacts on indirect connectivity and hub connectivity, that are not quantified, we did include a qualitative discussion based on the available information.

Direct connectivity

Since individual airports are not modelled in AEOLUS, it was not possible to determine the impacts of the CO_2 ceiling on the connectivity of Dutch airports with particular foreign airports. However, the effects on the total number of flights per year per geographical zone is modelled. This can be seen as an aggregated indicator of the effects on direct connectivity.

The effects of the different options for the CO_2 ceiling in 2030 and 2050 are shown in Table 12. It can be seen that the decrease in direct connectivity in 2030 is largest in the ceiling per airport suboptions and lowest in the fuel supplier/airline suboptions where the revenues are funnelled back. An explanation of these differences is provided in Section 3.2. The extra information that can be seen from this table is that there are significant differences between geographical regions. On average, the decrease in intercontinental aviation is larger compared to EU aviation. In the fuel supplier/airline suboptions with funnelling back of income, an increase in direct connectivity to EU destinations is even observed. In 2050 there are no significant effects, since the CO_2 ceiling is not restrictive anymore. However, we can see some small lasting effects on the network, such as a lower number of flights going to intercontinental destinations in the airport suboptions.

We also analysed the effects on the different alliances (see Table 13). It is clear that for the airline options the reduction of the number of flights from sky team is larger compared to the other full service carriers and the low cost carriers. This reduction persists until 2050, indicating that according to the modelling a persisting loss of market share is caused.

Table 12 - Change on the number of flights due to the **CO_2** ceiling per geographical zone

	2030				2050			
	Airport - strict allocation	Airport - soft allocation soft	Fuel/airline - auctioning state	Fuel/Airline - funnelled back	Airport - strict allocation	Airport - soft allocation soft	Fuel/airline - auctioning state	Fuel/Airline - funnelled back
Germany	-9,7%	-11,0%	-3,9%	0,3%	0,2%	0,5%	-0,7%	-0,2%
France	-7,1%	-7,8%	-3,7%	0,9%	-0,6%	-0,4%	-0,1%	-0,2%
UK	-5,8%	-6,5%	-2,2%	4,1%	0,0%	0,1%	-0,6%	-0,4%
Belgium/Luxemburg	-2,4%	-2,6%	-6,8%	-5,0%	0,9%	1,0%	-0,9%	-0,7%
Scandinavia	-8,3%	-9,3%	-3,4%	1,2%	-0,9%	-0,9%	0,0%	0,0%
Switzerland/Austria	-9,0%	-10,0%	-2,8%	3,7%	0,9%	1,2%	-0,6%	-0,3%
Spain	-3,4%	-4,0%	-2,6%	2,9%	0,3%	0,3%	0,0%	-0,2%
Portugal	-4,9%	-5,6%	-2,5%	2,5%	0,9%	0,8%	-0,3%	-0,2%
Italy	-6,8%	-7,5%	-3,3%	1,5%	-1,2%	-1,3%	0,4%	0,1%
Greece	-5,7%	-6,2%	-2,6%	3,0%	1,4%	1,4%	-0,5%	-0,3%
South-East Europe	-8,1%	-9,0%	-2,8%	3,1%	1,6%	1,2%	-0,2%	-0,1%
Eastern Europe	-8,2%	-9,0%	-3,1%	2,4%	-0,4%	-0,8%	0,7%	0,2%
Central America	-6,8%	-7,5%	-7,9%	-8,6%	-2,1%	-2,2%	0,9%	0,2%
South America	-7,5%	-8,3%	-9,0%	-9,9%	-2,2%	-2,2%	0,9%	0,2%
Africa	-8,2%	-9,4%	-7,7%	-6,9%	-3,8%	-3,3%	1,2%	0,2%
South-East Asia	-7,4%	-8,3%	-9,1%	-10,0%	-2,5%	-2,5%	1,2%	0,3%
Asia	-11,1%	-12,7%	-11,9%	-13,5%	-3,8%	-3,9%	1,4%	0,6%
Middle East	-5,8%	-6,3%	-6,5%	-5,5%	-0,5%	-0,2%	-0,2%	-0,3%
USA	-7,9%	-8,8%	-7,6%	-7,6%	-3,9%	-4,1%	1,8%	0,5%
Canada	-8,4%	-9,3%	-8,8%	-8,9%	-2,8%	-3,0%	1,2%	0,2%
EU total	*-6,7%*	*-7,5%*	*-3,0%*	*2,4%*	*0,0%*	*0,0%*	*-0,2%*	*-0,2%*
Intercontinental total	*-7,6%*	*-8,5%*	*-8,2%*	*-8,4%*	*-2,8%*	*-2,7%*	*1,1%*	*0,2%*
Total	-6,9%	-7,8%	-4,2%	0,0%	-0,6%	-0,6%	0,1%	-0,1%

Table 13 - Change in number of flights for the different alliances

	Alliance	Airport - strict allocation	Airport - soft allocation soft	Fuel/airline - auctioning state	Fuel/Airline - funnelled back
2030	SkyTeam	-9,4%	-10,5%	-5,9%	-3,2%
	OtherFSC	-4,1%	-4,7%	-1,4%	4,3%
	LowCost	-3,1%	-3,6%	-1,8%	4,5%
2040	SkyTeam	-11,2%	-12,7%	0,8%	-1,5%
	OtherFSC	2,5%	2,6%	-2,2%	1,9%
	LowCost	2,6%	2,8%	-3,3%	2,2%
2050	SkyTeam	-4,8%	-5,1%	2,6%	0,9%
	OtherFSC	4,5%	4,7%	-2,8%	-1,1%
	LowCost	1,6%	1,9%	-1,4%	-0,8%

Number of destinations and frequency

It was not possible to model changes in the number of destinations or the changes in frequency to these destinations from Schiphol with the AEOLUS model. Therefore, a quantitative analysis is included.

Routes with high frequencies are often characterized by high competition and low margins. In case of a restricting ceiling on the number of aircraft movements, it is likely that airlines adjust marginally profitable routes first. This will probably be achieved by decreasing the frequencies to destinations (maybe partly compensated by the utilization of larger aircrafts). If this is not enough, marginally profitable routes might be closed resulting in a decrease of non-stop destinations from the Netherlands.

A recent study quantified the effects of a reduction of the yearly number of flights at Schiphol to 460 thousand (PWC Strategy&, Adecs airinfra, Moving dot, 2022). This reduction is roughly comparable to the reduction which can be seen in the ceiling per airport option (Figure 33). They estimated the reduction of the destinations with more than ten flights per year to be in the range of 0 to 11%, depending on the market reaction.

In the fuel supplier and airline options the decrease in direct connectivity is much smaller compared to the ceiling per airport option (see Table 11). Therefore, we do not expect a significant drop in the number of destinations. However, especially in the suboptions where the incomes are funnelled back, we do observe a significant difference in the effects on intercontinental and EU aviation: the number of flights to EU airports is affected much less or even grows compared to the baseline, whereas the number of intercontinental flights decreases significantly. Therefore, it is likely that the EU network is not much affected whereas the number of international destinations might decline.

Indirect connectivity

We were not able to quantify the effects on indirect connectivity, since this not only depends on the changes in direct connectivity but also on the developments at other airports. However, in general a decrease in the number of direct connections to hub airports results in less indirect connections via these hubs. Therefore, we can conclude that the indirect connectivity will be lower in 2030 compared to the baseline in all suboptions (with the largest reductions in connectivity for the ceiling per airport suboptions).

Hub connectivity

Hub connectivity is a measure for the quality of transfers the transfer network at Schiphol. Therefore, the hub connectivity does not directly affect the Dutch traveller.[37] However, indirectly the hub function of Schiphol does allow for an extensive network which the people flying from the Netherlands benefit from.

We were not able to quantify the effects on hub connectivity because specific information about the flight schedules are required. However, based on the changes in the direct connectivity some conclusions can be made. First of all, the hub connectivity between zones is related to the direct connectivity of Schiphol airport and these two zones.

[37] This is because travellers with a layover in the Netherlands are typically not Dutch.

Therefore, we can conclude that in 2030 the hub connectivity also is lower compared to the baseline[38].

3.5.5 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on the number of flights and also no impact on the network quality. This is the case for almost all scenarios in which low economic growths has been assumed (WLO low) and in those scenarios with high economic growth (WLO high) in combination with ambitious climate policies (Fit for 55 ambitious and national Dutch SAF blending obligation) and moderate no capacity growth at Dutch airports (see Figure 17).

In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20: WLO high, Fit for 55 reduced, increased airport capacity and no Dutch SAF blending) the impacts on the number of flights in 2030 are about 24 to 32% higher in 2030 in the airport and fuel supplier/airline - auctioning state options, respectively. Only very small effects are visible for the fuel supplier/airline - auctioning funnelled back policy options. In the long run the effects for the airport options increase even more, with in 2050 a drop of over 275 thousand flights per year compared to the baseline. This is the opposite of what happens in the reference scenario, where we see that in 2050 the CO_2 ceiling is not restrictive anymore. This is caused by the difference in Fit for 55 ambitions and airport capacity. In Scenario 6 the Fit for 55 ambitions are reduced and airport capacity is high, while for the reference scenario the Fit for 55 ambitions are as proposed and airport capacity is middle. The blending requirements in the proposed Fit for 55 package increases quickly from 2045 to 2050 while there is no more growth than 500,000 flights on Schiphol possible, such that emissions will drop below the CO_2 ceiling around 2046 in the reference scenario.

The high airport capacity makes strong growth for Schiphol possible, while the reduced Fit for 55 ambition is by far not enough to stay under the CO_2 ceiling in 2050, leading to an increasing difference in number of flights between baseline and the policy options for Scenario 6. This consequently would mean that the network quality is lower compared to the baseline. For the fuel supplier and airline options the number of flights restores to baseline level by blending a significantly higher share of SAF in Scenario 6. Due to the high airport capacity there is a strong growth of number of flights in baseline, creating a large difference with what is allowed within the CO_2 ceiling. This increases the costs of the CO_2 rights by so much that blending more SAF becomes economically viable.

In all other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes. The results for Scenario 6 are presented in Annex H, the results for the four other modelled scenarios are presented in the Excel Results Spreadsheets.

[38] As an example, consider flights between Spain and Schiphol and flights between Schiphol and Scandinavia. If the direct connectivity between both connections and Schiphol decreases, it can be concluded that the hub connectivity also decreases. However, the exact decrease is dependent on for example the time of day of the specific flights that are removed from the schedule.

3.6 Impacts on cargo

3.6.1 Introduction

For air cargo only the airports Schiphol and Maastricht are considered, since at the other regional airports no cargo is transported. Schiphol facilitates both full freighter airlines and passenger airlines that belly carry cargo of their passenger aircraft, whereas Maastricht focusses only on the full freighter segment.

Table 14 shows the volume of cargo transported in the reference baseline scenario. We see a significant increase of the cargo volumes both at Schiphol and at Maastricht airport which is comparable to the development of passenger aviation.

Table 14 - Development of the cargo volume per year at Dutch airports without **CO_2** ceiling (reference scenario baseline)

Airport	Year	Cargo volume (thousand tonnes)
Total	2017	1,839
	2030	2,786
	2040	2,602
	2050	2,403
Amsterdam	2017	1,787
	2030	2,708
	2040	2,508
	2050	2,290
Maastricht	2017	52
	2030	78
	2040	94
	2050	113

3.6.2 Methodology

The impact on air cargo is also estimated in the AEOLUS model, however the AEOLUS model provides less detailed output for air cargo, since the AEOLUS model is initially based on passenger nested logit, which models flight movements. Air cargo is estimated in an additional module.

First, import and export of air cargo between the different regions is estimated. The observed 2017 air cargo flows between the regional freight zone of the Netherlands and the rest of the world[39] are taken as base scenario. The asymmetry found in 2017 is kept throughout the years. The total import and export are divided between the four cargo airports of the regional freight zone of the Netherlands: Schiphol, Maastricht, Frankfurt & Paris. The market-share of the base year 2017 is considered as base, the market share can change over time depending on capacity of an airport. For the development of air cargo over time the AEOLUS model uses two types of elasticity, namely price elastic and trade elasticity.

Once the total cargo is estimated per airport, air cargo is allocated to type of flight. First the cargo is allocated to belly of passenger flights and the remaining cargo is allocated to full freighters. It is assumed that low-cost carriers do not carry cargo and that full-service carriers do carry cargo on each flight. The load factors of bellies and full freighters are

[39] In AEOLUS cargo transport is modelled for seven freight zones: two for Europe and five for intercontinental.

based on the number of flights per airport to world regions. For the change of load factors over time it is assumed that there will be an increase in load factor over the period 2020 to 2050 in the low and high scenario for full freighters (+3%, +10%) and for belly flights (+10%, +20%).

In the AEOLUS model, the grandfathering rule of Schiphol is taken into account. According to the grandfathering rule, the number of full freighter slots is constant to 2020 at 95% and will then decrease with 2% each year. It is assumed that this rule applies to all continents equally. For Schiphol the assumption is made that in 2030, 75% of the freighter slots in 2017 are maintained, while in 2050 35% of the 2017 freighter slots are still in place. For the other three airports in the model (Maastricht, Paris & Frankfurt) there is no decrease in the number of guaranteed full freighter slots assumed.

Airports may reach their capacity level. The AEOLUS model will then iterate with higher prices for passengers and less cargo until a new balance has been reached.
It should be noted that the AEOLUS model has some serious limitations when analysing air cargo. On the passenger side, AEOLUS considers different modalities (car, train or plain) for the trip choice, however the trade-offs between these modalities are not considered when estimating air cargo. Additionally, transhipment goods are also not considered by AEOLUS. Because of these limitations, we do not fully base our conclusions on the AEOLUS output.

3.6.3 Results

Figure 48 shows the total volume of cargo transported at Dutch airports in the reference baseline scenario and in the CO_2 ceiling scenarios. For the Fuel supplier suboptions, no large deviations from the baseline are seen. For the Airport suboptions, a large spike is seen between 2045 and 2050. This spike is an artefact of the modelling. Results therefore can only be interpreted up to 2045. The decrease from 2027 to 2030 in the Airport suboptions is caused by the CO_2 ceiling which becomes restrictive. The mechanism in the airport options using scarcity costs has a relatively higher impact on freight than the mechanism with CO_2 costs for the fuel supplier and airline options.

Figure 48 - Total volume of cargo at Dutch airports

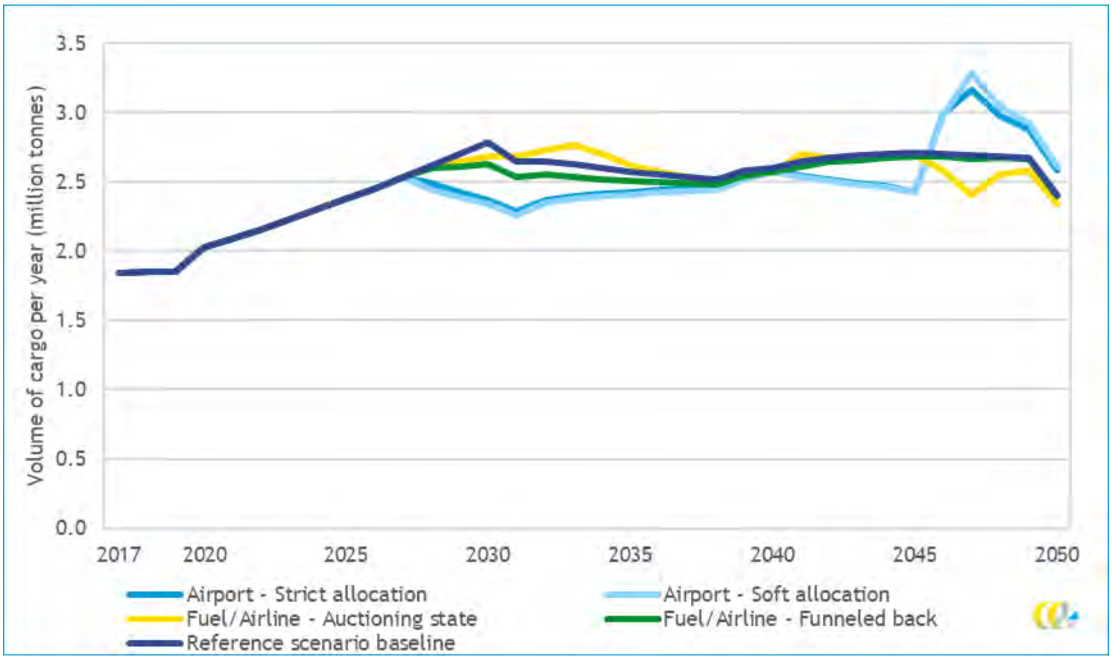


Table 15 - Impacts on the cargo volume at Dutch airports (thousand tonnes per year)

Airport	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-416 (-484 to -416)	-416 (-494 to -416)	-448 (-515 to -448)	-109	-158	-109 (-117 to -101)	-109	-158
	2040	-12 (-139 to -12)	-12 (-151 to -12)	-29 (-155 to -29)	-42	-31	-42 (-49 to -35)	-42	-31
	2050	178 (-38 to 207)	178 (-20 to 204)	209 (-10 to 238)	-68	-10	-68 (-157 to -49)	-68	-10
Amsterdam	2030	-416 (-482 to -416)	-416 (-491 to -416)	-448 (-513 to -448)	-107	-157	-107 (-107 to -107)	-107	-157
	2040	-12 (-135 to -12)	-12 (-146 to -12)	-29 (-151 to -29)	-40	-31	-40 (-40 to -40)	-40	-31
	2050	178 (-29 to 205)	178 (-11 to 203)	209 (0 to 237)	-68	-10	-68 (-153 to -68)	-68	-10
Maastricht	2030	0 (-2 to 0)	0 (-3 to 0)	0 (-2 to 0)	-2	-1	-2 (-4 to 0)	-2	-1
	2040	0 (-5 to 0)	0 (-5 to 0)	0 (-5 to 0)	-2	-1	-2 (-3 to 0)	-2	-1
	2050	0 (-9 to 1)	0 (-9 to 1)	0 (-9 to 1)	0	0	0 (-4 to 4)	0	0

Analysing the development of full freighter flights as depicted in Figure 47 of Section 3.4 a similar spike is seen after 2045, this spike is however an artefact of the model and therefore irrelevant. In the period between 2030 and 2045 total transported cargo volume is more or less stable (Figure 49), while the full freighter flights (Figure 51) show a gradual decrease during that same period. Compared to the reference baseline scenario, outcomes for other ceiling variants are somewhat similar. However, it should be noted that the 2017-2019 figures are above actual figures for Schiphol (full freighter flights 2017: 17.796, full freighter flights 2019: 14.156, source Royal Schiphol Group).[40]

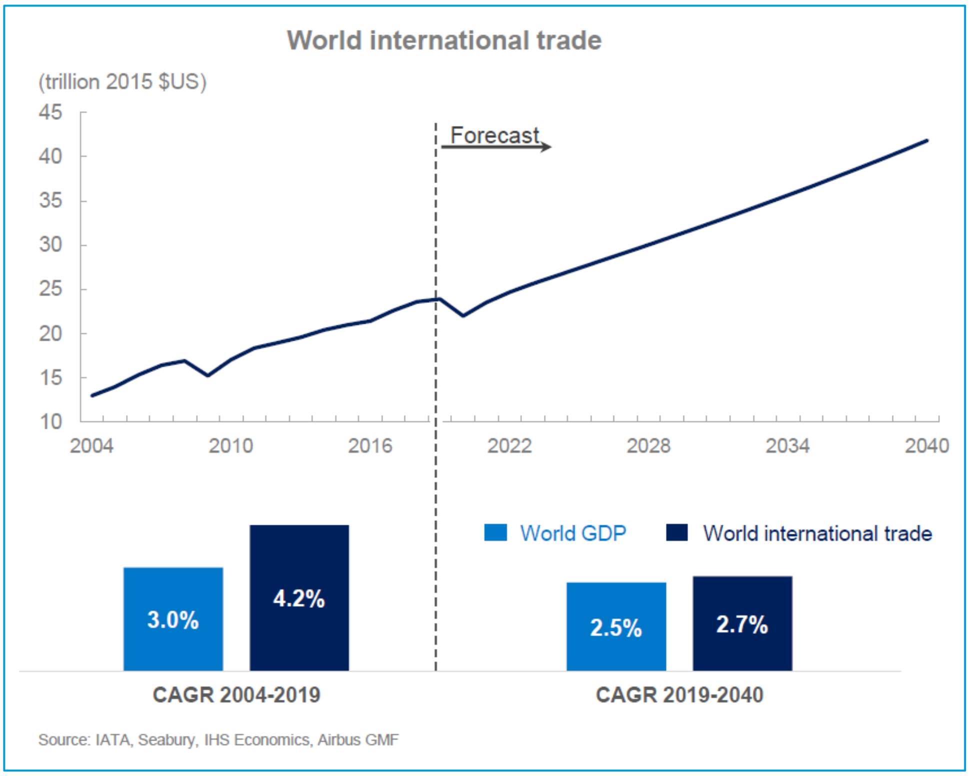
The relatively strong increase in number of full freighter flights in the period between 2020 and 2030 can be clarified by the high demand for air cargo transport capacity, which can be accommodated by full freighter capacity as long as passenger capacity is not up to pre-COVID levels. During previous capacity constraint periods (2017-2019) crowding out of full freighter flights was observed as a result of lower on time performance of full freighter aircraft and consequent loss of grandfather rights. A capacity surplus available at Schiphol and Maastricht airport resulting from COVID recovery, may allow for increased numbers of full freighter flights, however, this is highly uncertain.

Logistics Service providers prefer airports that facilitate both main deck capacity on board full freighter aircraft as well as belly capacity on board of passenger aircraft. This enables them to provide a competitive proposition to their customers, the shippers. Previous airport slot scarcity and consequent decrease in air cargo capacity, has led to a shift in transportation towards other airports that facilitate air cargo capacity. Should such slot scarcity situation arise again, this may lead to lower investments from logistics service providers in the long term. Conclusion: a decrease in full freighter capacity will have an effect on total cargo volumes transported at an airport.

Comparing the reference baseline scenario to long term air cargo predictions as forecasted by Boeing and Airbus (see Figure 49 and Figure 50), both manufacturers expect growth in a range between 2,5 and 4,0% annually. In the reference baseline scenario AEOLUS expects an accumulated average growth rate of 1.25% per annum globally, which is significantly lower than the before mentioned industry forecasts do expect. At the same time, it should be noted that the Boeing and Airbus figures are global figures, not corrected for regional differences.

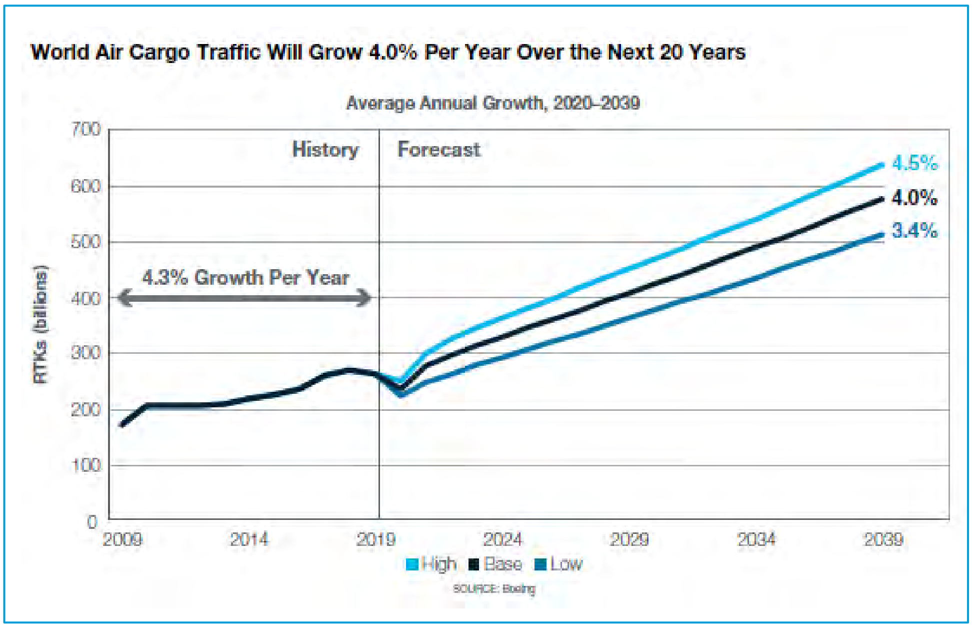
40 https://www.schiphol.nl/nl/schiphol-group/pagina/verkeer-en-vervoer-cijfers/

Figure 49 - Airbus Global Market Forecast 2021-2040



Source: Airbus.

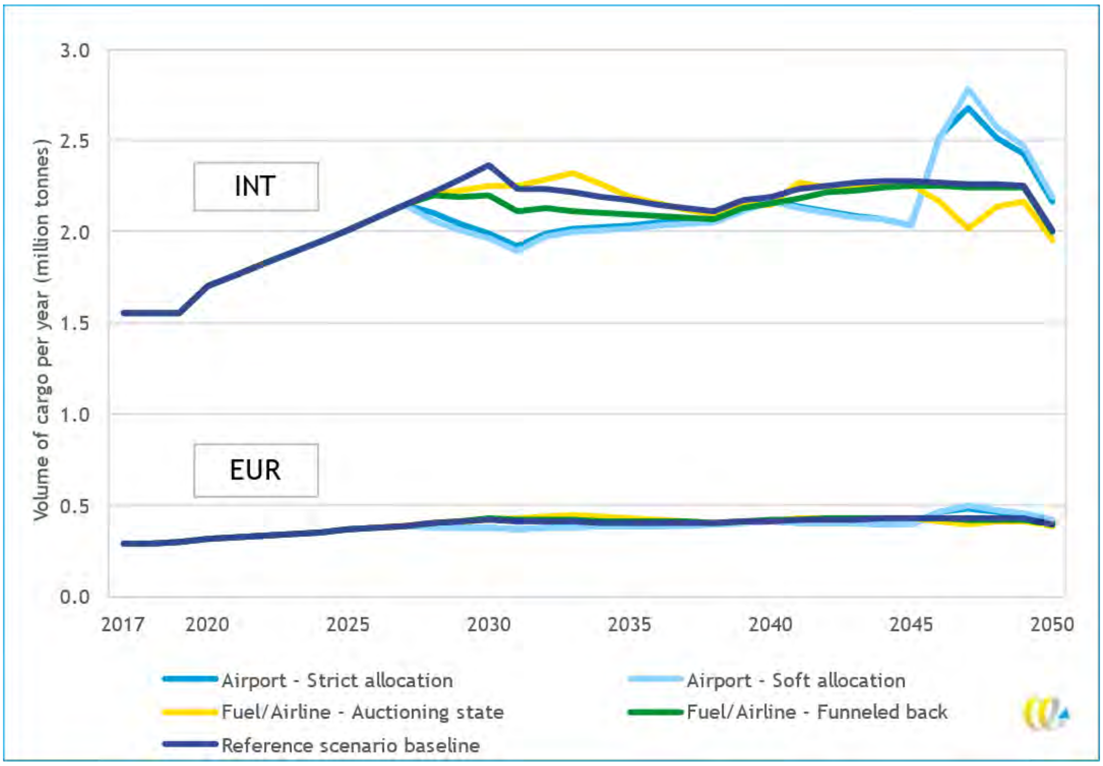
Figure 50 - Boeing World Air Cargo Forecast 2020-2039



Source: Boeing.

The effect of the CO_2 ceiling is mainly seen at intercontinental Air Cargo transported tonnes and to a lesser extend affects European air cargo. Since air cargo is mainly used as mode of transport for intercontinental cargo demand, whereas continental cargo demand mainly uses trucking by road, which is not part of the AEOLUS model.

Figure 51 - Development of EU and intercontinental cargo volume transported at Dutch airports



3.6.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on cargo demand. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the decrease in cargo volume are 14 to 30% higher in 2030 for the airport and Fuel Supplier/Airline - auctioning state options respectively. There are almost no impacts from the Fuel Supplier/Airline - auctioning funnelled back policy options. In the long run the impacts increase even more for the Airport options, with in 2050 a drop of more than 1,600 kilo tonnes cargo volume per year. If the ceiling become more restrictive both passenger as full-freight flights will decrease in the Airport options, resulting in both lower belly as lower full-freight cargo transport. The impacts of the Fuel Supplier and Airline options restore to baseline because of more SAF blending.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are always smaller or equal to the impacts in baseline scenario 6 (of which the results are shown in Annex H).

3.7 Fleet renewal

3.7.1 Introduction

The Fit for 55 package will imply higher costs for airlines for their fuel use (for example from the fuel taxation or SAF blending mandate) or higher costs for airlines for CO_2 (for example from the EU ETS or CORSIA). Also, the CO_2 ceiling options will imply higher costs for CO_2. From an airline perspective higher cost for CO_2 has the same implication as an increase in fuel cost. This because of the direct relation between fuel use and CO_2 emissions: 1 ton of aircraft fuel burn leads to 3.15 ton of CO_2 emissions. Therefore, all cost impacts of the Fit for 55 proposals and the CO_2 ceiling options can be translated and summed up into an overall increase of the costs for CO_2.

One of the potential impacts of higher CO_2 costs is an additional shift by airlines to more fuel-efficient aircraft (see Figure 52), which will imply a reduction of fuel use and hence CO_2 emissions. This is referred to as the fleet renewal related fuel and CO_2 reduction. This reduction is additional to the demand side fuel and CO_2 reduction, which is related to lower levels of demand and a reduction in the number of flights.

Traditionally the AEOLUS model does compute the demand side fuel and CO_2 reduction but not the fleet renewal related fuel and CO_2 reduction. As part of this project a method was developed to also compute the fleet renewal related fuel and CO_2 reduction in AEOLUS using computational results from the AERO-MS model (Aviation Emissions and evaluation of Reduction Options Modelling System).[41]

3.7.2 Methodology

The methodology to assess the fleet renewal related fuel and CO_2 reduction consists of the following steps:
1. Assess functions with relation between CO_2 costs and fleet renewal related fuel and CO_2 reduction using the AERO-MS.
2. Implement these functions in AEOLUS as correction factor.
3. Assess the increase of costs for CO_2 for Fit for 55 and CO_2 ceiling options.
4. Assess the fleet renewal related fuel use and CO_2 reduction for any case with Fit for 55 and a CO_2 ceiling option with AEOLUS.

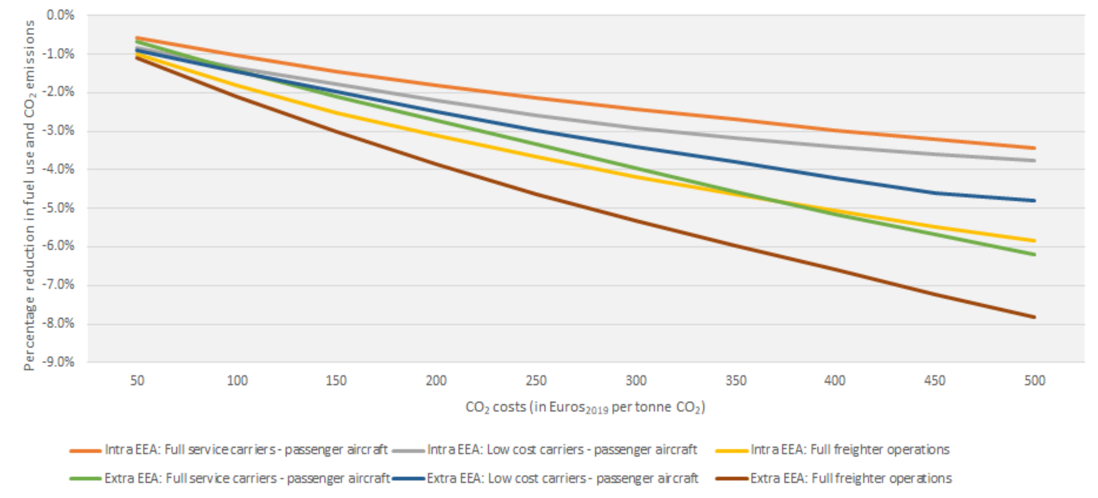
The functions in Step 1 have been assessed for:
1. Three flight types: i) full service carriers – passenger aircraft; ii) low cost carriers - passenger aircraft; and iii) full freighter operations.
2. Two route groups: i) Intra EEA; and ii) extra EEA.
3. Two years: 2030 and 2050.

The functions for 2050, as derived from the AERO-MS and implemented in AEOLUS, are presented below in Figure 52.

The figure shows that generally the fleet renewal related impact for freighter operations is larger compared to passenger aircraft. Because freighters aircraft are generally relatively old compared to passenger aircraft in the baseline (i.e. situation without Fit for 55 and CO_2 ceiling option), there is more potential for fuel efficiency improvement of this part of the aircraft fleet in case the costs for CO_2 increase.

41 See here for further information of the AERO-MS model.

Figure 52 - Functions with relation between **CO_2** costs and fleet renewal related fuel and **CO_2** reduction



In Step 3 the increase in costs for CO_2 is computed for any of the Fit for 55 and CO_2 ceiling options. These costs reflect the additional costs relative to the baseline, whereby additional costs for fuel and CO_2 are summed up.

AEOLUS not only assesses the fleet renewal related fuel use and CO_2 reduction but also the demand side fuel and CO_2 reduction. Moreover, there is a CO_2 reduction related to the use of SAF. In the results we have therefore not only presented the fleet renewal related CO_2 but reduction but also the overall CO_2 reduction in order to put the former in perspective.

3.7.3 Results

The fleet renewal related CO_2 reduction on flights departing from the Netherlands are computed by AEOLUS and shown in Table 16. In these calculations the fleet renewal functions presented in Figure 52 have been applied.

Table 8 first presents the fleet renewal related CO_2 reduction for the Fit for 55 package relative to the situation without Fit for 55. These results are for the reference scenario (23). The Fit for 55 related fleet renewal CO_2 reduction increases over time from 0.08 Mt in 2030 to 0.19 Mt in 2050. This increase over time follows from the increase in the Fit for 55 related costs. For the AEOLUS computations all the Fit for 55 related higher costs are expressed in terms of an increase in the CO_2 costs. Increased CO_2 costs for airlines imply a larger incentive for fleet renewal and an increase in the resulting CO_2 reduction. The fleet renewal related CO_2 reduction is fairly limited compared to the overall CO_2 reduction in case of Fit for 55 (see Section 5.2).

The second part of Table 16 provides the fleet renewal related CO_2 reduction of the CO_2 ceiling relative to the situation with Fit for 55. In the Airport option no additional incentive for fleet renewal related CO_2 reduction is assumed because there is no impact on the CO_2 costs in this option. The small increases in the Airport options are a consequence of the reduction in the number of flights relative to the baseline. Due to this reduction less new and more efficient aircrafts are purchased by the airlines.

Similar to the fleet renewal related impacts for Fit for 55, the Fossil Fuel and Airline options show a fleet renewal related reduction. However, the contribution is limited compared to the overall CO_2 reduction. For 2050 no or a negligible fleet renewal related CO_2 reduction is computed for the Fuel Supplier and Airline options simply because the CO_2 ceiling is not restrictive anymore.

Table 16 - Fleet renewal related **CO_2** reduction on flights departing from the Netherlands (in million tonnes)

CO_2 ceiling option	2030	2040	2050
Impact of Fit for 55 as proposed (relative to situation without Fit for 55)			
Fit for 55 under WLO high with middle airport capacity, no NL SAF	0.08	0.17	0.19
Impact of **CO_2** ceiling options (relative to situation with Fit for 55)			
Airport - Strict allocation (3-year cycle)	-0.01	-0.01	0.00
Airport - Strict allocation (1-year cycle)	-0.01	-0.01	0.00
Airport - Soft allocation (3-year cycle)	-0.01	-0.01	0.00
Fuel Supplier - Auctioning state	0.07	0.09	0.00
Fuel Supplier - Auctioning funnelled back	0.11	0.09	0.00
Fuel Supplier - No stability mechanism	0.07	0.09	0.00
Airline - Auctioning State	0.07	0.09	0.00
Airline - Funnelled back	0.11	0.09	0.00

Source: AEOLUS.

3.7.4 Results in other baseline scenarios

In most scenarios, CO_2 emissions remain below the ceiling, so the implementation of the ceiling would not affect fleet renewal rates (see Section 2.3).

Apart from the reference scenario (Scenario 23), the fleet renewal related impacts have also been assessed for the five other baseline scenarios:
1. Fit for 55 reduced, no NL SAF, WLO low, middle airport capacity (Scenario 2).
2. Fit for 55 reduced, no NL SAF, WLO high, middle airport capacity (Scenario 5).
3. Fit for 55 reduced, no NL SAF, WLO high, high airport capacity (Scenario 6).
4. Fit for 55 reduced, with NL SAF, WLO high, high airport capacity (Scenario 12).
5. Fit for 55 as proposed, no NL SAF, WLO high, high airport capacity (Scenario 24).

The fleet renewal related impact for these scenarios have been computed with and without (i.e. impacts of Fit for 55 only) the eight ceiling options. Results are presented in Annex D.

For the other baseline scenario with Fit for 55 reduced without additional Dutch SAF blending obligation (first three scenarios in the above list) the fleet renewal related impacts are smaller compared to the central baseline scenario. Where for the reference baseline scenario the fleet renewal related CO_2 reduction is 0.19 Mt in 2050, for these three scenarios the reduction in 2050 varies between 0.11 and 0.15 Mt. For baseline Scenario 12 (also Fit for 55 reduced, but with Dutch SAF blending obligation), there is a higher cost incentive and the fleet renewal related CO_2 reduction is estimated to 0.27 Mt in 2050. For the last scenario (Fit for 55 as proposed with high airport capacity) in comparison to the reference baseline scenario also a higher fleet renewal related CO_2 reduction is computed (i.e. 0.24 Mt in 2050).

The impacts of the ceiling options relative to the other baseline scenarios are generally in the same order compared to the impacts relative to the reference baseline scenario. In scenarios in which emissions remain below the ceiling, there is no fleet renewal related CO_2

reduction (similar to the impacts of the ceiling options for 2050 relative to the reference baseline scenario as presented in Table 16).

3.8 Impacts on fuel consumption

3.8.1 Introduction

In this section we discuss the impact of the CO_2 ceiling on fuel consumption. Table 17 shows the consumption by type of aviation fuel in the reference baseline scenario per year. Whereas the market share of fossil kerosene was 100% in 2017, it is expected that 63% of fuel will be Sustainable Aviation Fuel (SAF) in 2050. This is mainly due to the blending requirements defined in the ReFuelEU Aviation and the Renewable Energy Directive III proposals.[42] The shares of SAF are deduced from the ReFuelEU Aviation proposal (European Commission, 2021).

Table 17 - Fuel consumption in reference scenario (million tonnes per year)

Year	Total	Kerosene	HEFA	Gas. + FT	ATJ	RFNBO
2017	3.81	3.81	0.00	0.00	0.00	0.00
2030	4.15	3.77	0.16	0.00	0.18	0.03
2040	4.07	2.77	0.19	0.40	0.39	0.33
2050	3.63	1.34	0.18	0.61	0.48	1.02

3.8.2 Methodology

The CO_2 ceiling affects the fuel consumption in two distinct ways:

1. If the CO_2 ceiling causes the number of flights to decrease, the total fuel consumption is decreased.
2. If the airlines choose to blend extra SAF rather than reduce the number of flights, the share of SAF in the total fuel mix is increased.

In the Fuel Supplier and Airline options, we assume that airlines choose to blend additional SAF if the marginal costs of doing so are lower than the marginal climate costs of using fossil kerosene (including all costs related to CO_2 emissions).

In the estimations of this study, we assume that all extra SAF blending caused by the CO_2 ceiling will be non-synthetic fuels (and therefore use SAF prices of non-synthetic fuels), since they are cheaper and there is no incentive in the CO_2 ceiling to blend additional synthetic fuels.

The AEOLUS model internally does not calculate the fuel consumption. However, the output of CO_2 emissions with and without blending is converted into the amount of fuel with the emission factor of kerosene (3.15 $kgCO_2/kg$). To determine the consumption in specific types of non-synthetic SAF we use the assumptions from the RefuelEU Aviation impact assessment.

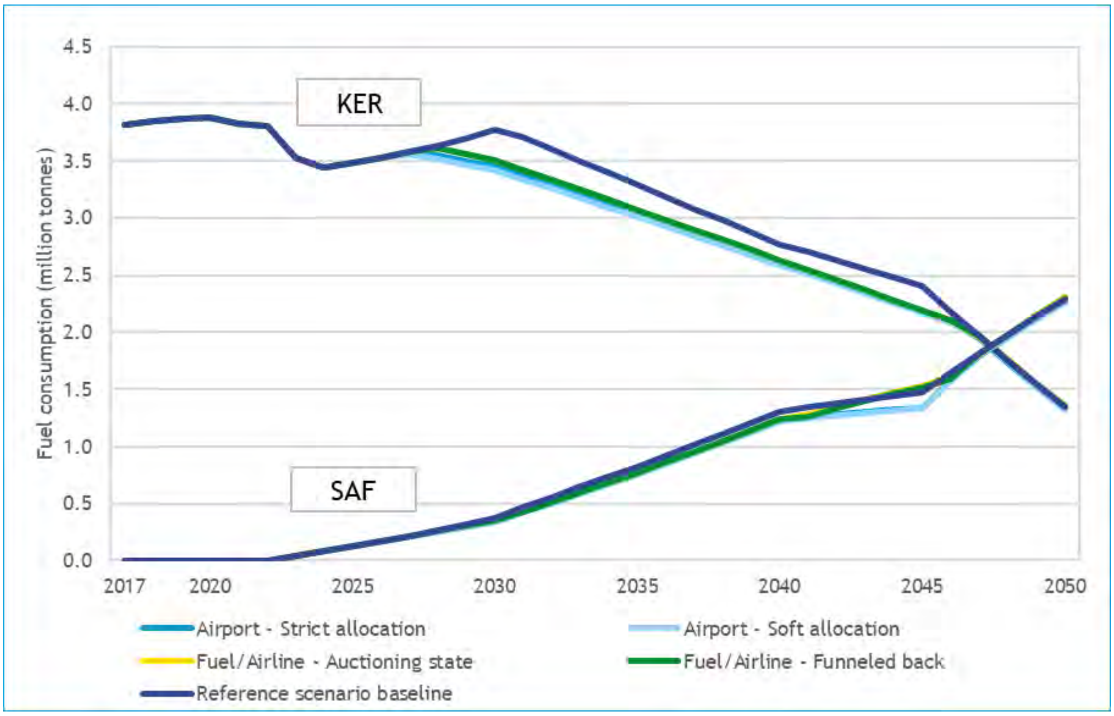
For the specific SAF mix and the cost trajectories per type of fuel, we chose to align with the assumptions from the ReFuelEU Aviation impact assessment (EC, 2021e).

42 2021 version of proposals.

3.8.3 Results

Figure 53 shows the consumption of fossil fuel and SAF (total of all types) per year for the different CO_2 ceiling options. A more detailed overview where the different types of SAF. The exact aviation fuel consumption figures in the suboptions is shown in Annex G. The consumption for fossil kerosene has a similar curve in all suboptions. This is to be expected, since the fossil kerosene is directly linked to the CO_2 emissions (which in all cases must remain under the ceiling). However, we can also see that the Airport options use slightly less fossil kerosene, especially in the beginning of the restrictive period. This is due to the allocation of the CO_2 budget in the Airport options, where regional airports have unused budget in the starting period. The consumption for SAF is slightly higher in the Fuel supplier and Airline options from 2040 onwards, since here airlines make use of additional SAF blending to stay below the CO_2 ceiling.

Figure 53 - Development of the consumption in fossil kerosene and SAF at Dutch airports in the reference scenario



3.8.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on fuel consumption. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) there is a 18% stronger decrease in total fuel consumption in the Airport options, and 30% stronger decrease in the Fuel Supplier/Airline – auctioning state options in 2030. There are almost no impacts from the Fuel supplier/Airline – auctioning funnelled back policy options. In the long run the impacts increase even more for the Airport options, with in 2050 a drop of more than 2 mega tonnes of total fuel consumption per year. This is caused by a lower number of possible flights (by the lower SAF blending mandate from the weakened Fit for 55 proposal) versus the increased consumption in baseline due to increased airport capacity. The levels of total fuel consumption from the Fuel Supplier and Airline options restore to baseline because of more SAF blending.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes. For Scenario 6 the results are shown in Annex H for the other modelled scenarios the results are displayed in the Excel Results Spreadsheets.

3.9 International relations

3.9.1 Introduction

The introduction of a Dutch CO_2 ceiling for aviation could result in unintended international effects. If the CO_2 ceiling establishes a precedent that is perceived as undesirable by third countries or creates uncertainty, additional administrative or financial burden for foreign parties, this can create political resistance and possibly provoke countermeasures. It is important to compare the different options of the CO_2 ceiling on this theme; which options are most likely to generate undesirable international resistance? In this paragraph we consider which risks may arise in the international context when each option is rolled out and which objections international parties could raise. A more detailed account of the potential international effects and the methodology used for the analysis can be found in a preliminary study by CE Delft (2021a). Impact on the EU ETS and CORSIA are treated separately in Paragraph 5.4

Diplomatic resistance resulting from the introduction of a climate instrument in aviation is not just a hypothetical possibility. Extensive experience with such resistance has been in the past within the context of the EU ETS. At the time aviation was introduced to the EU ETS (2012), the EU ETS still held its full scope. This meant that all flights to or from a European airport were subject to the obligations of the EU ETS - including intercontinental flights. However, this full-scope was met with strong resistance from virtually all major non-European countries. These countries announced different countermeasures and even went as far as to prohibited their airlines to comply with the European legislation. In view such countermeasures, the (non)enforceability of the aviation ETS, and of the ongoing ICAO negotiations on a global CO_2 system (CORSIA), the European Commission limited the scope of the EU ETS to intra-European flights.

If a decision is made to introduce a national CO_2 ceiling for aviation, including for intercontinental flights, the Dutch government could encounter similar resistance. This could lead to diplomatic tensions and measures against the Netherlands or Dutch airlines. Such a situation could also worsen the negotiating position of the Netherlands within ICAO, for example in the context of CORSIA and the ICAO long-term goal for CO_2 reduction. However, the extent to which such undesirable consequences appear to be probable differs between the three options of the CO_2 ceiling.

First of all, it should be noted that undesired diplomatic effects are highly dependent on whether the CO_2 ceiling will become restrictive (baselines emissions are higher than the CO_2 ceiling). If the CO_2 ceiling is not restrictive, there will be no cost increases or additional capacity shortages, which means that the risk of repercussions will be significantly reduced. Any resistance must then arise from the uncertainty about the future impact of the ceiling (including potential policy changes to the ceiling's height), the risk of precedent setting and/or increased administrative burdens. The extent to which the Dutch CO_2 ceiling would be restrictive differs across the multiple baseline runs and WLO-scenarios.

3.9.2 Important international players

A national CO_2 ceiling for aviation could be objectionable to various parties. In this paragraph we explore the behavioral responses of three groups of players: 1) the European Commission; 2) non-EU countries with a major interest in international aviation; and 3) umbrella organizations such as ICAO and ECAC.

The European Union

The European Union — in this section mainly understood as the European Commission — advocates an ambitious climate policy, based on the European Green Deal and the European Climate Law adopted in 2021. The Commission emphasizes that all sectors must contribute to the energy transition in Europe, including international sectors, including aviation, which is only implicitly covered by the Paris Agreement.

The general attitude of the European Commission towards an ambitious climate policy in aviation is therefore positive. In principle, the Commission will also have no major objections to national measures that complement EU policy, unless they are incompatible with EU law, impede the functioning of European policy measures or are not legally compatible with them. Finally, the Commission (and incidentally also the third countries discussed below) would probably follow closely the introduction of a CO_2 ceiling in the Netherlands because of its link with the scope of the EU ETS. Should the Netherlands successfully introduce a CO_2 ceiling that also affects international flights from the Netherlands, this again raises the question whether the EU ETS should and could not also apply to extra-European flights.

Third countries

Countries that can be expected to resist ambitious national aviation reduction measures are mainly countries with a major interest in international aviation. A first category of countries meeting this condition are countries with a strong geopolitical position, for example because they have a sizeable economy, large airspace and/or a pivotal position in international trade flows. Important members of this category include Russia, the United States and China, Brazil and India. A second category of countries consists of countries that play a key role in international aviation, for example because they have airports that fulfill an important hub function. This category includes Turkey (Istanbul), the United Kingdom (London), the United Arab Emirates (Dubai) and Qatar (Doha).

In general, countries in both categories will try to block measures that impose restrictions on international aviation as much as possible. The CO_2 ceiling in the Netherlands will probably not be seen as a threat (especially as the costs of the ceiling is relative small in opposite to the Fit for 55 program) when considered in isolation- some foreign airports may even see opportunities to take over market share from Schiphol, should the CO_2 ceiling lead to a reduction in aviation volume. However, these countries may well have concerns about the precedent setting of such unilateral steps. They are in general in favor of adopting emission reduction measures exclusively in a multilateral context, such as in ICAO (CE Delft, 2021). An important nuance here is that the climate ambition of these countries can influence their position on this point. Within the US government, for example, the desire to impose as few restrictions as possible on national and international aviation could clash with the ambition to pursue a strong global climate policy. Turkey, the UAE and Qatar are not known for being ambitious within the UNFCCC and are likely to give priority to the interests of their aviation sector. The UK, on the other hand, has itself set ambitious

climate targets and would therefore run into credibility problems if it strongly opposes national aviation emission reduction measures.
We expect that potential objections of third countries will focus mainly on the argument of extraterritoriality: the possibility that foreign airlines will face requirement related to emissions outside the Dutch airspace. Because the extent to which this applies depends strongly on the option of the CO_2 ceiling, we will deal with these types of objections later in this paragraph.

Associations and organizations

Finally, we briefly consider the role of the International Civil Aviation Organization (ICAO) and the European Civil Aviation Conference (ECAC). With CORSIA, ICAO introduced an important global instrument for reducing greenhouse gas emissions from aviation, although it stays far beyond the necessities to cope with the reduction of the greenhouse gas effect. It follows, from resolution A40-19 on the implementation of CORSIA (ICAO, 2019) that ICAO considers itself the appropriate forum to regulate international aviation emissions.
In addition, ICAO mostly opposes new national or regional market mechanisms besides CORSIA, for fear that this is not cost-effective and/or leads to taxing emissions twice. Whether the Dutch CO_2 ceiling becomes a market mechanism depends on the option in which it is elaborated, but it can be established that such initiatives do not fit in well with ICAO's working method.

Of course, ICAO's view, as an international organization, is the product of the positions of (the majority of) the member states, and it cannot be ruled out that this may change over time, for example through the efforts of the Netherlands and like-minded member states. At the moment, however, resistance to national or regional instruments seems strong, as the said resolution speaks of 'strong support from Member States for a global solution for the international aviation industry, rather than a possible patchwork of national and regional market mechanisms'.

The ECAC has a less important role than ICAO in negotiations on international aviation agreements. The ECAC member states, including the UK and Turkey, will not adopt a different position within this body than within ICAO, but precisely because ECAC negotiations take place in the background of ICAO, the ECAC can be a useful platform for disseminating the Dutch ideas and exchange views with other Member States.

3.9.3 Potential international effects per option of the CO_2 ceiling

The Airline option

Among the three options of the CO_2 ceiling, the Airline option seems most likely to provoke detrimental international effects. This is due to the nature of the instrument, as it directly regulates (foreign) airlines. Like in EU ETS full scope, airlines from other countries will be subject to obligations, even for emissions that take place outside the Dutch airspace. For governments of other countries, the argument of extra-territoriality will be central, as was the case in relation to the EU ETS. It was contested whether the EU was competent to regulate emissions that took place outside its own airspace and even to a significant extent in the airspace of other countries. Participation in a Dutch ETS could also set a precedent: the European Union could argue that when countries such as the US, Russia and China participate in a Dutch ETS, there are apparently no fundamental problems for returning to the full-scope within the EU ETS.

When third countries implement their threats and retaliate or forbid their airlines to comply with the requirements of the Dutch ETS the Netherlands faces a difficult dilemma. Strict enforcement is very challenging and would lead to more diplomatic tensions, countermeasures and the possible loss of some connections, especially at Schiphol. Failure to enforce the ceiling would imply that the CO_2 ceiling would not function as intended. Airlines that did adhere to the requirements of the national ETS in the first place would object to the incomplete enforcement vis-à-vis their competitors.

As mentioned in the previous chapter, there is a lot of resistance within ICAO to national or regional market mechanisms that would be placed on top of CORSIA, because this would disrupt the level playing field and lead to a patchwork of different policies. Because the Airline option of the CO_2 ceiling is a market mechanism and also has an extraterritorial effect (like the original full-scope EU ETS), ICAO's objections to this option will be stronger than with the other options. After all, a national ETS will induce an additional layer of regulation for intercontinental flights departing from the Netherlands (although of course, there are major differences between the requirements of CORSIA and those of a national ETS). Such objections within ICAO entail the risk that the negotiating position of the Netherlands (and any like-minded countries) within ICAO will deteriorate, which in turn may make it more difficult for the Netherlands to achieve its international policy goals in the field of aviation.

Finally, foreign countries could object to the fact that the revenues from the CO_2 ceiling (only) flow to the Dutch government (as if it were a tax), while these are generated by international airlines. In the Airline option, this only applies for rights that are auctioned.

The Fuel Supplier option

The concerns sketched above apply to a lesser extent to the Fuel Supplier option of the CO_2 ceiling. Foreign airlines may face cost increases due to increased fuel prices, but are not directly regulated (and therefore not regulated outside their territory). An important nuance is that in some cases airlines are also fuel sellers themselves. In that case, however, it can still be argued that the fuel sales take place within the Netherlands, and that the government is therefore authorized to impose restrictions.

The Fuel Supplier option could be interpreted as indirect kerosene excise duty, something that is currently not permitted under air services agreements in relation to airlines from third countries. The introduction of a fuel rights system also imposes additional administrative burdens on fuel sellers, and these parties. By linking up with the foreseen reporting obligation from ReFuelEU Aviation, the resistance from fuel sellers could decrease. However, monitoring and enforcement of foreign fuel sellers can remain complex, and may require the active involvement of fuel service providers and regional airports (CE Delft, 2021c).

The Fuel Supplier option can also lead to objections about the displacement of CO_2 emissions. Within the Fuel Supplier option airlines could avoid higher fuel prices in the Netherlands via inbound tankering (Planbureau voor de Leefomgeving, 2021). As Dutch fuel prices are currently relative low compared to prices in other European countries, this seems only likely for flights departing from extra-European countries where kerosene prices are especially low (like Eastern European countries). Inbound tankering would not only displace emissions, but even increase the total emissions somewhat, because the extra weight of the excess fuel increases the emissions per passenger when refueling. The proposal for the ReFuelEU Aviation Regulation (EC, 2021b) includes an anti-tankering measure, which means that in most baseline-scenarios tankering is unlikely to lead to large-scale displacement of emissions. The potential incompatibility of a fuel ceiling with ReFuelEU Aviation is an import legal question that remains outside the scope of this study.

Airport option

On the surface, the Airport option seems to provoke the fewest objections and risks in relation to the international policy context. In this option, there is no double regulation of emissions and no double financial taxation of airlines, because the airport option does not, in principle, lead to cost increases for airlines nor state revenues (CE Delft, 2021c). There is also little reason for the European Commission to be concerned about the compatibility of the airport option with the EU ETS or the ReFuelEU Aviation proposal.

When the airport option of the CO_2 forces Dutch airports to decrease their number of slots, this could however lead to countermeasures (just as other capacity restrictions caused by for example noise regulation could). This has already been shown several times in the past, for example when Russia threatened to close its airspace to Dutch airlines in 2017 because the Russian freight carrier AirBridgeCargo (ABC) was allocated fewer slots at Schiphol, while it wanted to expand there. Closing the airspace over Siberia would have had major consequences for the home carrier in particular, because flights to destinations in East Asia would then have to reroute, increasing flight durations by 3-5 hours. Other potential countermeasures could be aimed at the home carrier directly: for instance, an extra-European airline could force the Dutch home carrier to realize the required collective slot reduction on its own, threatening to take away its start and landing rights in their home country. This could result in the home carrier losing significant proportions of its market share.

3.9.4 Summary

Table 18 displays the likelihood of potential countermeasures as a response to the CO_2 ceiling for each option. Results are differentiated based on whether the CO_2 emissions in the given baseline scenario exceed the CO_2 ceiling. Outcomes for different suboptions of the main three options are expected to be comparable and are hence not displayed.

Table 18 - Likelihood of countermeasures by international players in the three options of the **CO_2** ceiling

Likelihood of countermeasures	Airport option	Fuel Supplier option	Airline option
In case CO_2 ceiling is not restrictive	Low	Low	High
In case CO_2 ceiling is restrictive	Medium	Medium	High

4 Economic impacts

4.1 Introduction

This chapter presents the economic impacts of the CO_2 ceiling for Dutch aviation. It starts with an assessment of the costs of compliance of the different options (Section 4.2). Like other sections, this section first presents the methodology followed by the detailed impacts of the CO_2 ceiling in the reference scenario (the reference scenario is defined in Section 2.2 and Annex B). The final subsection discusses how the impacts in other baseline scenarios differ from the impacts in the reference scenario.

Section 4.3 assesses the administrative costs; Section 4.4 auctioning revenue and use; Section 4.5 the fiscal impacts; Section 4.6 the costs of enforcement; Section 4.7 upstream and downstream effects and Section 4.8 the impacts of the CO_2 ceiling on innovation in the aviation sector.

4.2 Compliance costs

4.2.1 Introduction

The compliance costs are the costs of the changes which airlines need to make in order to meet the requirements of the CO_2 ceiling regulation. Administrative costs are excluded from the compliance costs, since they are assessed separately (see Section 4.3).

In the airport option, the regulated entity only has administrative costs because airports are not required to reduce their own emissions. In this option, the compliance costs of airlines are estimated, which stem from changes in fuel costs as a result of higher shares of SAFs (and lower use of fossil fuel); changes in fuel cost as a result of enhanced efficiency by fleet renewal; cost for additional fleet renewal; changes in ETS and CORSIA compliance costs; and cost for excise duty for aviation fuels as proposed in the ETD revision.

In the fuel supplier option, fuel suppliers are expected to meet the CO_2 ceiling by blending an increased share of SAFs and passing through additional costs to airlines. Hence, the compliance costs will comprise of the additional SAF purchase costs. In this option, airlines may respond to higher fuel prices by improving the efficiency of their fleet. Airlines will also see changes in ETS, CORSIA and excise duty costs.

In the airline option, airlines can comply by increasing the amount of SAF used, improving the fuel-efficiency of their aircraft, or by reducing the number of flights. The costs of the latter option are not estimated as it is assumed that the lower revenues are offset by lower operational costs. The costs of the two former options are included in the analysis, as these technical and operational changes involve changes in ETS, CORSIA and excise duty costs.

4.2.2 Methodology

Compliance costs are calculated as the difference in operational cost. We define these changes in operational cost as the compliance cost for the CO_2 ceiling regulatory scheme. Thus, the compliance cost is the difference on operational cost in the CO_2 ceiling options between the CO_2 ceiling options compared to the operational cost in the baseline. We do not incorporate administrative cost of adapting to different operations under compliance cost. The change in operational cost is the sum of delta fuel cost, delta fleet renewal cost, delta ETS and CORSIA cost, and delta fuel excise duty cost.

We assume the CO_2 ceiling policy is communicated in time, which gives the airlines sufficient time to adjust their fleet accordingly. Thus, if a reduction of flights will be required, airlines can end or shorten aircraft lease contracts, sell or lease a number of aircraft leading to no additional cost by lower utilization of their fleet.

Fuel cost

Using the fuel consumption of aviation in the Netherlands from the modelling results, and the projected fuel prices we obtain the total fuel cost in the baseline and each option (see Annex D.2.1). We understand airlines use hedging to ensure fuel prices for an extended period of time. Therefore, the fuel cost might differ for individual airlines. Due to a range of hedging strategies airlines decrease uncertainties of the actual fuel price in the future, we cannot account for these aspects.

Fleet renewal

The modelling results indicate the reduction of CO_2 emissions by supply effects. The supply effect is the reduction of CO_2 by the enhanced fleet renewal (implying improved efficiency in fuel combustion). The cost for enhanced fleet renewal can be perceived as the willingness to pay for fleet renewal by the airlines[43] (before considering other emission reduction techniques such as using SAF).

We define the fleet renewal cost as the cost made to reduce CO_2 emissions by improving energy efficiency of the fleet (aircraft flying to and from Dutch airports). By taking the difference in supply side emission reduction between the reduction in the options and the baseline, the *additional* supply side emission reduction due to the CO_2 ceiling is determined. Thus, the extra fleet renewal airlines perform over time in the CO_2 ceiling options compared to 'common' fleet renewal.

We calculate the additional fleet renewal cost by multiplying the amount of additional CO_2 emission reduction (supply side effect) and the total cost of fuel + additional CO_2 cost under the CO_2 ceiling (including ETS, ETD and CORSIA cost). This represents the maximum willingness to pay for fleet renewal, as with CO_2 prices higher than the SAF blending price, emission reduction by increasing SAF blending is more cost-effective.

ETS and CORSIA cost

For the calculation of the change in ETS and CORSIA cost, we sum the emissions of passenger and cargo flights for all intra-EEA destinations. Then, the total ETS cost is derived by multiplying the total CO_2 emissions in a year by the projected ETS price in the corresponding year. Subsequently, the differences between ETS cost in the options and the

[43] If some aircraft in the fleet are renewed earlier than their projected 20 year use period, this is reflected in the fleet renewal cost. An airline will not consider replacing an aircraft if there are more cost-effective emission reduction options (e.g. increasing SAF use). But, as fleet renewal is part of the operational cost, at some financial optimum it may be a more cost effective option to renew the aircraft (for example) 1-year earlier than planned at the start of the usage period. These depreciation cost are thus incorporated in the fleet renewal cost which the airlines perceive as a cost to establish (cost-effective) emission reduction.

baseline is derived. We perform this calculation similarly with emissions by extra-EEA flights and the CORSIA price to determine the difference between CORSIA cost in the options and the baseline. Similar calculations are performed to estimate changes in CORSIA compliance costs.

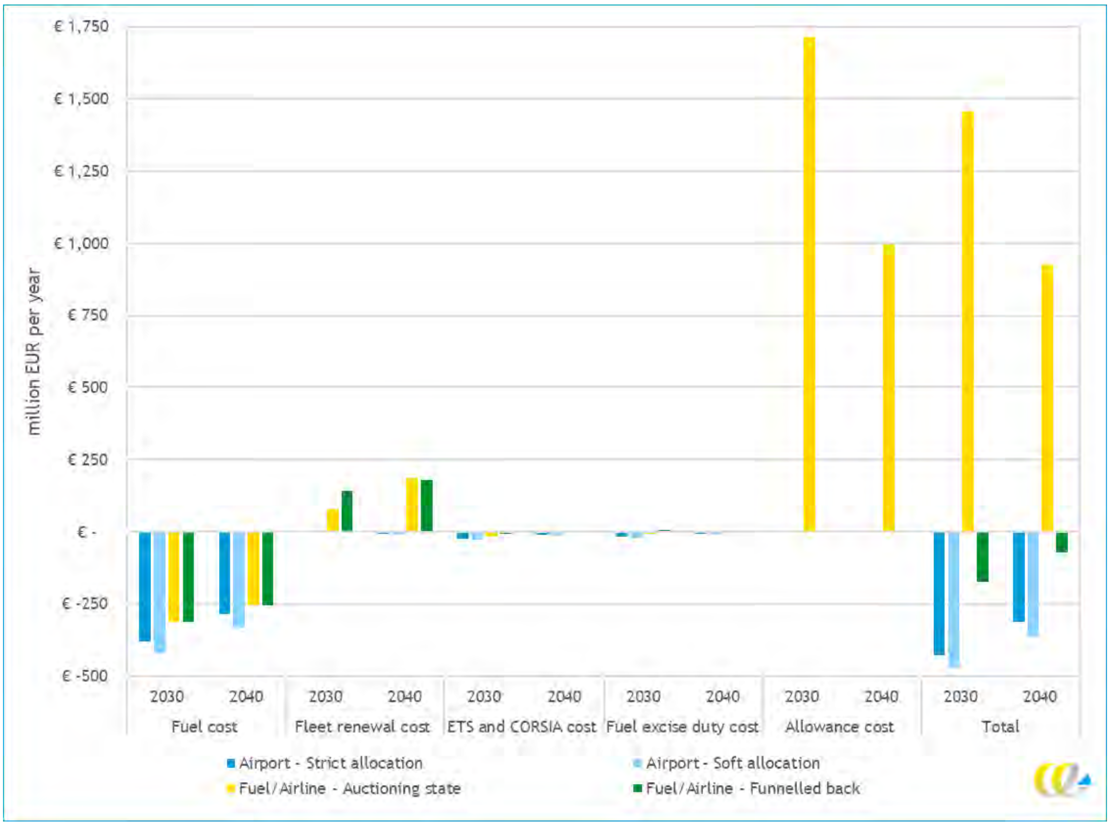
Fuel excise duty (ETD) cost

We multiply the fuel use by type with the fuel excise duty figures as listed in the proposed ETD revision to determine the total excise duty cost per year. By subtracting the fuel excise duty cost in a year in a option from the excise duty cost in the same year in the baseline, we obtain the difference in excise duty cost.

4.2.3 Results

In Figure 54 we present a graphic overview of the changes in operational cost under the CO_2 ceiling variants compared to baseline operational cost. The total change in yearly operational cost is thus the compliance cost per year. The exact figures of the compliance cost items are shown in Table 105 in Annex G.

Figure 54 - Changes in operational cost under the **CO_2** ceiling options, in million EUR per year



We observe a significant fall in fuel cost in the CO_2 ceiling options in the years 2030 and 2040 when the ceiling is restrictive. In 2050, cost figures show small variations which are due to different strategic choices operations in earlier years when measures were needed to comply to the maximum level of emissions. These effects may concern certain destinations which are not (yet) connected again, or fuel choices. Significant lower fuel cost compared to the baseline is mainly caused by the reduction in number of flights and a shift of long flights to shorter flights. In the airport options fuel costs decrease more significant than in the other policy options. This is primarily caused by the higher reduction in number of flights than in the other policy options. In the fuel supplier and airline options there mainly is a shift of intercontinental flights to inter-EEA flights, these flights are shorter and therefore consume less fuel.

Fleet renewal cost in the airport options are lower than in the baseline. We explain this outcome by the fact that a decrease in the number of flights result in slower depreciation of airplanes. Therefore, fewer emissions are reduced by improvement of energy efficiency in the fleet. We are aware some airlines are able to lease their aircraft to other (foreign) airlines, leading to a similar point in time when their aircraft needs to be renewed as in the baseline. However, we estimate this strategy may only impact the results to a limited degree.

As the aviation sector emits fewer emissions in the CO_2 ceiling options, the number of ETS and CORSIA allowances needed to comply to these regulations decreases. The difference in decline of ETS/CORSIA cost between the airport options and the Fuel supplier/airline options is due to the fact in the airport option there is unused CO_2 budget for the regional airports, which results in slightly higher emission reduction than strictly necessary for the compliance to the CO_2 ceiling.

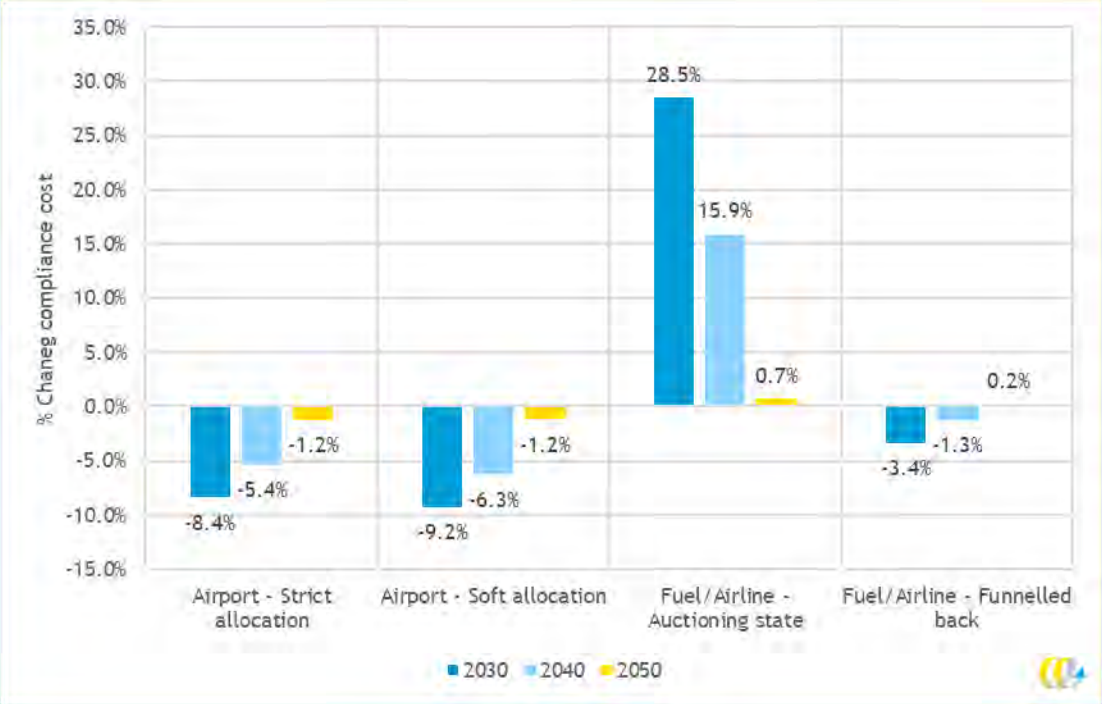
Less kerosene use and the exemption (and lower tariff) for SAF leads to lower expenses for fuel excise duty (which is proposed the ETD revision). In the year 2050, no changes in baseline fuel excise duty cost is expected, as there is no additional GHG emission reduction necessary. The lower tariff for SAF results in a decline in baseline excise duty cost (compared to 2030 and 2040) as blending obligations for bio-kerosene variants and RFNBO leads to a higher uptake of these fuel types.

In Table 19 we outline the total compliance cost under the CO_2 ceiling. In the first column, the baseline operational cost in million EUR per year is indicated (in grey), and in the subsequent columns, the difference in cost compared to the baseline cost is shown Figure 55 presents the change of operational cost per year in percentages.

Table 19 - Total compliance cost, in million EUR per year

Year	Reference scenario baseline cost	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ 5,117	€ -428 (€ -416 to € -428)	€ -428 (€ -428 to € -427)	€ -473 (€ -459 to € -473)	€ 1,456	€ -172	€ 1,456 (€ 1,436 to € 1,564)	€ 1,456	€ -172
2040	€ 5,816	€ -312 (€ -297 to € -312)	€ -312 (€ -312 to € -311)	€ -364 (€ -346 to € -364)	€ 924	€ -73	€ 924 (€ 870 to € 959)	€ 924	€ -73
2050	€ 6,058	€ -75 (€ -69 to € -76)	€ -75 (€ -76 to € -72)	€ -70 (€ -64 to € -71)	€ 44	€ 11	€ 44 (€ -179 to € 190)	€ 44	€ 11

Figure 55 - Relative change of total compliance cost in the **CO_2** ceiling options compared to the reference scenario baseline



The main factor for the large increase in operational cost in the Fuel/Airline auctioning state option is the additional cost for the allowances, which is revenue for the state. In the Fuel/Airline funnelled back options, the aviation receives this large sum back as a refund and does in the end not increase the total cost for the aviation sector.

4.2.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no significant effects to operational cost occur compared to the baseline.

In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the impacts are higher. Due to higher expected baseline growth of flights,[44] the compliance cost for adequate amount of reduction are higher as a higher number of flights must be reduced, aircraft need the be acquired or SAF blending has to take place. Therefore the total compliance cost are also higher in all options of the CO_2 ceiling.

See the exact impact figures on compliance cost in the other scenarios in Annex H.

44 The number of flights is compared to the abovementioned central baseline scenario.

4.3 Administrative costs

4.3.1 Introduction

The aim of the CO_2 ceiling is to ensure that the emissions of Dutch aviation remain below the ceiling. In order to be able to determine whether or not the aim has been achieved, emissions need to be monitored accurately and aggregated in annual totals which can be compared with the ceiling. This requires an administrative system which comes with additional cost.

The administrative costs are determined by the administrative set-up of the option, i.e. the monitoring, reporting and possibly verification obligations for regulated entities, as well as the monitoring obligations for regulators and the enforcement requirements. In all cases, the additional administrative requirements are identified. The baseline for the requirements result from the obligations which airports have to demonstrate that they operate within their permitted limits; the obligations for airlines under the EU ETS; and the current reporting practices.

The Fit for 55 package, if adopted, would also require regulated entities to carry out administrative tasks. These tasks would overlap partly with the tasks under the CO_2 ceiling. Specifically, fuel suppliers have obligations under the proposed revision of the Energy Taxation Directive; and the airports, fuel suppliers and airlines have obligations under ReFuelEU Aviation.

Because the adoption of the proposals of the Fit for 55 package is not certain, the study takes the following approach:

- All administrative tasks are identified;
- Tasks will be divided in three categories:
  1. Tasks which are currently carried out.
  2. Tasks which would in the future be carried out as a result of the adoption of proposals of the Fit for 55 package.
  3. Tasks which are exclusive to the CO_2 ceiling.
- We allocate costs to tasks following from the Fit for 55 package and/or the CO_2 ceiling (Category 2 and 3). Where possible, we show whether these costs are exclusive to the CO_2 ceiling, or already borne when the Fit for 55 package is accepted.

If the ReFuelEU Aviation proposal is adopted as proposed by the Commission, the following empirical data will be monitored and reported:

- For each aircraft operator:
  - the total amount of aviation fuel uplifted at each Union airport;
  - the yearly aviation fuel required, per Union airport;
  - the yearly non-tanked quantity, per Union airport;
  - the ratio of aviation fuel uplifted to aviation fuel required, such that at least 90% of the fuel required for each flight is tanked at the airport;
  - the total amount of sustainable aviation fuel purchased from aviation fuel suppliers, for the purpose of operating their flights departing from Union airports.
- For each fuel supplier:
  - the volume of aviation fuel supplied at each Union airport;
  - the volume of sustainable aviation fuel supplied at each Union airport;
  - for each type of SAF supplied at Union airports, the lifecycle emissions, origin of feedstock and conversion process.

On the basis of the reports, EASA will report annually, for each airport, the amount of sustainable aviation fuel purchased by aircraft operators, as well as the amount supplied by fuel suppliers.

Monitoring emissions can be expected to be a significant share of the administrative effort. There are basically two ways to monitor CO_2 emissions: by modelling emissions of international commercial flights departing from Dutch airports or by using empirical data. Modelling is probably cheaper; empirical data have the advantage that fuel suppliers can report the amounts of SAFs and other fuels separately, so that emissions can be calculated directly.

Modelling is possible for the airport option and for the airline option. In the former case, emissions of realised flights can be entered into existing inventory models like EUROCONTROLs aviation fuel use and emission inventory system (FEIS) in the latter case, the EU small emitters tool can be used or the model that will be used under FuelEU Maritime to monitor tankering provisions. Modelling fuel sales does not appear to be a viable option.

The administrative set-up of the different options is described in more detail below.

Airport option

The main features of the airport option are:
- the government allocates a CO_2 ceiling to the Dutch international airports based on historical emissions/permits;
- airports have to ensure that the emissions of departing flights stay within the limit;
- airports use their capacity declaration to stay below the ceiling;
- the regulator checks whether the emissions do not exceed the ceiling and enforces the ceiling, if necessary.

This implies that airports need to estimate the emissions ex-ante (in order to determine the available capacity). Ex-ante estimates can only be modelled. This will require an approved modelling method and possibly a CO_2 tool, comparable to the Lden tool for noise. The tool would ensure that all airports estimate their emissions in the same way and that the capacity is determined on the same basis across all airports.

Airports also need to monitor their emissions ex-post in order to estimate over- or undercompliance. In addition, the regulator needs to monitor emissions in order to check compliance. With regards to ex-post monitoring, there are two options: to model the emissions or to use empirical data, which would originate from either fuel suppliers or from airlines, but may be reported under future legislation. Because there are fewer fuel suppliers and because airports can require fuel suppliers contractually to report data as a condition of operating on the airport, we consider it more likely that they will use data from fuel suppliers.

One of the inputs for the modelling would be the share of SAF sold on Dutch airports.[45] Table 20 and Table 21 presents an overview of the administrative tasks when airports use empirical data for their emissions reports and when they model emissions, respectively.

[45] This information would be available after the implementation of ReFuelEU Aviation.

Table 20 - Administrative tasks in the airport option when airports use empirical data ex-post

Entity	Task
Airport ex-ante	Estimate emissions ex-ante on the basis of modelling and draft flight schedule
	Determine the maximum capacity within existing regulations and infrastructure (capacity declaration) for slot allocation by independent slot coordinator
	Declare capacity based on most stringent limit*
Slot coordinator	Allocate slots
Fuel supplier ex-post	Monitor and report SAFs and conventional fuels sold
Airport ex-post	Gather information about the amount of SAFs sold
	Gather information about the amount of conventional fuels sold
Regulator	Check annual emissions report or check whether emissions stay below the ceiling

* Part of existing procedures, albeit not for **CO_2**.

Table 21 - Administrative tasks in the airport option when airports model emissions ex-post

Entity	Task
Airport ex-ante	Estimate emissions ex-ante on the basis of modelling
	Determine the maximum capacity within existing regulations and infrastructure (capacity declaration) for slot allocation by independent slot coordinator
	Declare capacity based on most stringent limit*
Slot coordinator	Allocate slots
Fuel supplier ex-post	Monitor and report SAFs and conventional fuels sold
Airport ex-post	Gather information about the share or amount of SAFs sold
	Model emissions
ILT	Check compliance

* Part of existing procedures, albeit not for **CO_2**.

Fuel supplier option

The main features of the fuel option are:
- fuel suppliers (the entities selling fuel) at airports need allowances for the quantity of fossil fuels they supply to aircraft engaged in international aviation;
- allowances are auctioned at regular intervals; the number of allowances is reduced in line with the CO_2 ceiling;
- fuel suppliers have the right to trade allowances.

The administrative set-up has four elements:
- Auctioning allowances;
  - the government needs to set up an auction for fossil fuel allowances;
  - the government needs to create a registry for allowances, so that they can be created, auctioned, traded, and surrendered.
  - fuel suppliers need to register at the auction and participate.
- Reporting fossil fuel sales;
  - Fuel suppliers need to monitor and report fuel sales. In order to ensure the reliability of the reports, they should be verified.
- Surrendering allowances;
  - Once verified, fuel suppliers should surrender allowances.
- Enforcement.

Some of the administrative tasks need to be performed once, before implementation, and others are recurring annual tasks. Table 22 presents an overview of the administrative tasks.

Table 22 - Administrative tasks in the fuel option

Entity	Task
Regulator before implementation	Set up registry
	Set up/select auctioning platform
Fuel suppliers before implementation	Register with registry
Fuel suppliers annually	Purchase allowances
	Monitor and report fuel sales
	Have fuel sales verified
	Surrender allowances
Regulator annually	Inspect fuel sale reports
	Randomised periodic inspections

Airline option

The main features of the airline option are:
- airlines are required to surrender emission allowances for CO_2 emissions on international flights from Dutch airports;
- Dutch State auctions allowances;
- allowances are transferrable between airlines;
- the number of allowances is reduced over time in line with the emissions ceiling.

The airline option is an allowance-based system, like the fuel option. It therefore has a similar administrative set-up when empirical data are used. Table 23 presents an overview of the administrative tasks. It is also possible to model emissions. In that case, the administrative tasks are presented in Table 24.

Table 23 - Administrative tasks in the airline option when empirical data are used

Entity	Task
Regulator before implementation	Set up registry
	Set up/select auctioning platform
Airlines before implementation	Register with registry
Airlines annually	Purchase allowances
	Monitor and report fuel use
	Have fuel use verified
	Surrender allowances
Regulator annually	Inspect fuel use reports

Table 24 - Administrative tasks in the airline option when emissions are modelled ex-post

Entity	Task
Regulator before implementation	Set up registry
	Set up/select auctioning platform
Airlines before implementation	Register with registry
Airlines annually	Purchase allowances
	Submit flight schedules and modelling results
	Surrender allowances
Regulator annually	Inspect emissions reports

4.3.2 Methodology

To estimate the costs of the administrative tasks identified in Section 4.3.1, we follow the Standard Cost Model (EC, 2021f). We estimated the costs based on Impact Assessments of Fit for 55 proposals and older EU ETS Impact Assessments. We presented these estimates to stakeholders in a questionnaire, asking them for their view on the estimated time required and costs per administrative task. Where appropriate we adjusted our estimates based on the responses from stakeholders.

4.3.3 Results

We received three responses from stakeholders regarding the questionnaire, two of them were from airlines and one from an airport. This resulted in the following cost estimates for the administrative tasks.

Airport option

Table 25 and Table 26 presents an overview of the administrative costs when airports use empirical data for their emissions reports and when they model emissions, respectively. The total costs are calculated by multiplying the 'time required' by 'at cost' and the number of Dutch airports, which is 6. We distinguish total costs including Fit for 55, where also administrative costs which should already be carried out for Fit for 55 proposals are included, and total costs CO_2 ceiling, where only administrative costs exclusive to the CO_2 ceiling are included.

Table 25 - Administrative costs in the airport policy option when airports use empirical data ex-post

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Airport ex-ante	Estimate emissions ex-ante on the basis of modelling and draft flight schedule	0.5 FTE per year	1 FTE = € 91,358[46]	€ 274,074 per year	€ 274,074 per year	Exclusive CO_2 ceiling
	Determine the maximum capacity within existing regulations and infrastructure (capacity declaration) for slot	0.5 FTE per year	1 FTE = € 91,358	€ 137,037 per year[47]	€ 137,037 per year	Currently carried out/ Exclusive CO_2 ceiling

46 Eurostat average labour cost the Netherlands professional activities, multiplied with factor 1.5 to include indirect labour costs (adjusted from the response of stakeholders).

47 Three airports (Maastricht, Groningen and Lelystad) are not slot regulated and therefore have additional costs.

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
	allocation by independent slot coordinator					
	Declare capacity based on most stringent limit*	Included in 0.5 FTE				Currently carried out
Slot coordinator	Allocate slots	0.5 FTE per airport per year	1 FTE = € 91,358	€ 137,037 per year	€ 137,037 per year	Currently carried out / Exclusive CO_2 ceiling
Fuel supplier ex-post	Monitor and report SAFs and conventional fuels sold	-	-	-[48]	-	Fit for 55 - ReFuelEU Aviation
Airport ex-post	Gather information about the amount of SAFs sold from fuel suppliers	8 hours per year[49]	1 FTE = € 91,358	€ 2,190 per year	€ 2,190 per year	Exclusive CO_2 ceiling
	Gather information about the amount of conventional fuels sold from fuel suppliers	8 hours per year[50]	1 FTE = € 91,358	€ 2,190 per year	€ 2,190 per year	Exclusive CO_2 ceiling
Regulator	Check annual emissions report or check whether emissions stay below the ceiling	0.5 FTE per year	1 FTE = € 91,358	€ 45,679 per year	€ 45,679 per year	Exclusive CO_2 ceiling

* Part of existing procedures, albeit not for CO_2.

Table 26 - Administrative costs in the airport policy option when airports model emissions ex-post

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Airport ex-ante	Estimate emissions ex-ante on the basis of modelling	0.5 FTE per year	1 FTE = € 91,358	€ 274,074 per year	€ 274,074 per year	Exclusive CO_2 ceiling
	Determine the maximum capacity within existing regulations and infrastructure (capacity declaration) for slot allocation by independent slot coordinator	0.5 FTE per year	1 FTE = € 91,358	€ 137,037 per year	€ 137,037 per year	Currently carried out / Exclusive CO_2 ceiling
	Declare capacity based on most stringent limit*	Included in 0.5 FTE				Currently carried out
Slot coordinator	Allocate slots	0.5 FTE per airport per year	1 FTE = € 91,358	€ 137,037 per year	€ 137,037 per year	Currently carried out / Exclusive CO_2 ceiling
Fuel supplier ex-post	Monitor and report SAFs and conventional fuels sold	-	-	-	-	Fit for 55 - ReFuelEU Aviation

48 According to the impact assessment of RED III this will give no extra administrative burden.

49 No significant costs for airports expected as this will be reported on airport level by EASA following from ReFuelEU Aviation.

50 No significant costs for airports expected as they request amount of tanked conventional fuel from fuel suppliers.

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Airport ex-post	Gather information about the share or amount of SAFs sold	8 hours per year	1 FTE = € 91,358	€ 2,190 per year	€ 2,190 per year	Exclusive CO_2 ceiling
	Model emissions	0.5 FTE per year	1 FTE = € 91,358	€ 274,074 per year	€ 274,074 per year	Exclusive CO_2 ceiling
ILT	Check compliance	0.5 FTE per year	1 FTE = € 91,358	€ 45,679 per year	€ 45,679 per year	Exclusive CO_2 ceiling

* Part of existing procedures, albeit not for CO_2.

Note that three airports (Maastricht, Groningen and Lelystad) are not slot regulated at the moment. For these airports the introduction of slot regulation due to the CO_2 ceiling will be an additional administrative task, costed at € 45,679 per year per airport as listed in the tables.

Fuel supplier policy option

Table 27 presents an overview of the administrative costs for the fuel policy option. The costs made before implementation are one-time costs, these costs are discounted with an interest rate of 1.6% (Ministerie van Financiën, 2020) and a lifetime of ten years. To get to the total costs we accounted for ten fuel suppliers.[51]

Table 27 - Administrative costs in the fuel policy option

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Regulator before implementation	Set up registry		€ 2.5 million[52]	€ 272,524 per year	€ 272,524 per year	Exclusive CO_2 ceiling
	Set up/select auctioning platform	0.25 FTE	1 FTE = € 91,358	€ 2,490 per year	€ 2,490 per year	Exclusive CO_2 ceiling
Fuel suppliers before implementation	Register with registry		€ 2,000 per fuel supplier	€ 2,180 per year	€ 2,180 per year	Exclusive CO_2 ceiling
Fuel suppliers annually	Purchase allowances	0.25 FTE	1 FTE = € 91,358	€ 228,400 per year	€ 228,400 per year	Exclusive CO_2 ceiling
	Monitor and report fuel sales	-	-	-	-	Fit for 55 - ReFuelEU Aviation
	Have fuel sales verified		€ 900 per fuel supplier	€ 9,000 per year	€ 9,000 per year	Exclusive CO_2 ceiling
	Surrender allowances	8 hours per year	1 FTE = € 91,358	€ 3,650 per year	€ 3,650 per year	Exclusive CO_2 ceiling
Regulator annually	Inspect fuel sale reports	0.5 FTE[53]	1 FTE = € 91,358	€ 45,679 per year	€ 45,679 per year	Exclusive CO_2 ceiling
	Randomised periodic inspections		€ 411,500[54]	€ 411,500 per year	-	Fit for 55 - ReFuelEU Aviation

[51] Combination of multiple sources, such as (NOS, 2019).
[52] Based on impact assessment ETS Aviation Small Emitters 2014.
[53] Based on impact assessment Fit for 55 - ReFuelEU Aviation.
[54] Based on impact assessment Fit for 55 - ReFuelEU Aviation.

Airline policy option

Table 28 presents an overview of the administrative costs for the airline policy option. For the airline option where emissions are modelled, the administrative costs are presented in Table 29. For airlines also the costs made before implementation are discounted with an interest rate of 1.6% (Ministerie van Financiën, 2020) and lifetime of ten years. To get to the total costs we accounted for 104 airlines (Schiphol, 2022) (Eindhoven airport, 2022).

Table 28 - Administrative costs in the airline policy option when empirical data are used

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Regulator before implementation	Set up registry		€ 2.5 million	€ 272,524 per year	€ 272,524 per year	Exclusive CO_2 ceiling
	Set up/select auctioning platform	0.25 FTE	1 FTE = € 91,358	€ 2,490 per year	€ 2,490 per year	Exclusive CO_2 ceiling
Airlines before implementation	Register with registry		€ 2,000 per airline	€ 22,674 per year	€ 22,674 per year	Exclusive CO_2 ceiling
Airlines annually	Purchase allowances	0.25 FTE	1 FTE = € 91,358	€ 2,375,360 per year	€ 2,375,360 per year	Exclusive CO_2 ceiling
	Monitor and report fuel use	5 minutes per flight	€ 28.00/ hour[55]	€ 1.3 million per year (based on 550k flights/year)	-	Fit for 55 - ReFuelEU Aviation
	Have fuel use verified		€ 900 per airline[56]	-	-	Currently - EU ETS
	Surrender allowances	8 hours per year	1 FTE = € 91,358	€ 37,960 per year	€ 37,960 per year	Exclusive CO_2 ceiling
Regulator annually	Inspect fuel use reports		€ 650,000	€ 650,000 per year	-	Fit for 55 - ReFuelEU Aviation

Table 29 - Administrative costs in the airline policy option when emissions are modelled ex-post

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs CO_2 ceiling	Category
Regulator before implementation	Set up registry		€ 2.5 million	€ 272,524 per year	€ 272,524 per year	Exclusive CO_2 ceiling
	Set up/select auctioning platform	0.25 FTE	1 FTE = € 91,358	€ 2,490 per year	€ 2,490 per year	Exclusive CO_2 ceiling
Airlines before implementation	Register with registry		€ 2,000 per airline	€ 22,674 per year	€ 22,674 per year	Exclusive CO_2 ceiling
Airlines annually	Purchase allowances	0.25 FTE	1 FTE = € 91,358	€ 2,375,360 per year	€ 2,375,360 per year	Exclusive CO_2 ceiling
	Submit flight schedules and modelling results	8 hours per year	1 FTE = € 91,358	€ 365 per year	€ 365 per year	Exclusive CO_2 ceiling
Consultant	Model emissions	0.5 FTE per year	1 FTE = € 91,358	€ 45,679 per year	€ 45,679 per year	Exclusive CO_2 ceiling

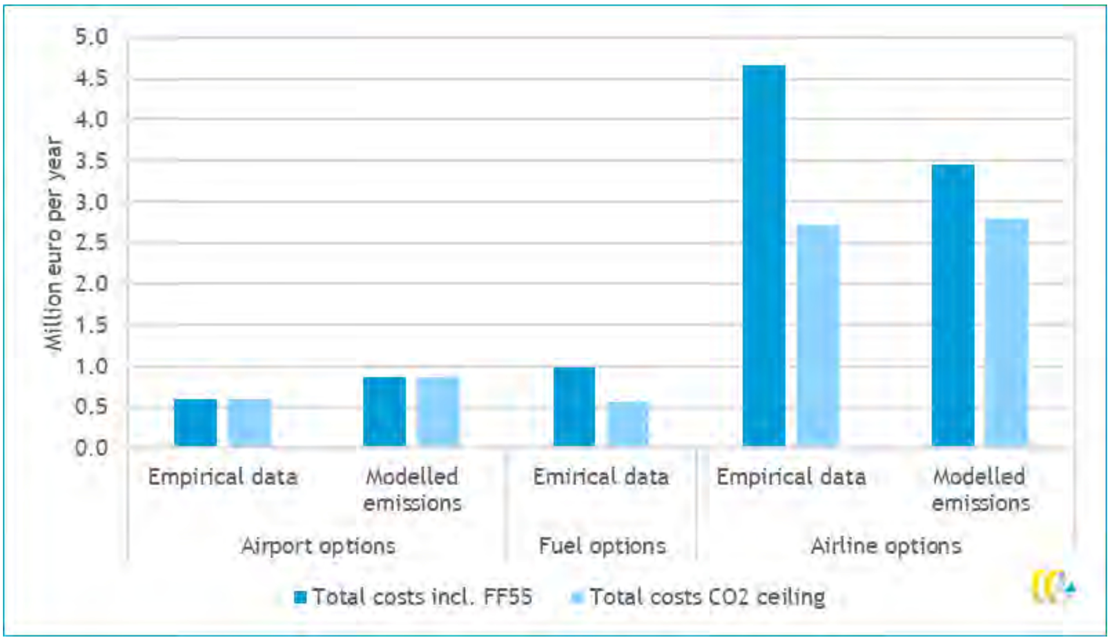
[55] Eurostat the Netherlands mean hourly transport earnings, multiplied with factor 1.5 to include indirect labour costs (adjusted from the response of stakeholders).

[56] Based on impact assessment EU ETS 2017.

Entity	Task	Time required	At cost	Total costs incl. Fit for 55	Total costs **CO_2 ceiling**	Category
Airlines annually	Surrender allowances	8 hours per year	1 FTE = € 91,358	€ 37,960 per year	€ 37,960 per year	Exclusive CO_2 ceiling
Regulator annually	Inspect emissions reports		€ 650,000	€ 650,000 per year	-	Fit for 55 - ReFuelEU Aviation

Figure 56 compares the total aggregated costs for the different policy options. The 'Total costs including Fit for 55' give an indication of the costs for the CO_2 ceiling including costs of administrative tasks which would already be performed if the Fit for 55 proposals would be accepted. 'Total costs CO_2 ceiling' indicate the costs exclusively for the CO_2 ceiling. We can see that the Airline options have significantly higher administrative costs than the airport and fuel policy options. This is mainly caused by the large number of airlines (~100) performing administrative tasks, compared to only ~10 fuel suppliers and six airports.

Figure 56 - Comparison of administrative costs (million euro per year) in the different policy options



4.4 CO_2 allowance price and auctioning revenue

4.4.1 Introduction

In this section we discuss the allowance market, allowance price and resulting auctioning revenues. Allowance prices and revenues are dependent on the form of provision of allowances. The regulator may choose to set up an open market trading platform for (daily) trading of allowances, an auctioning with fixed price, or enclosed auctioning where the regulated parties bid is undisclosed. When setting up an allowance scheme, the regulator should maximise the likelihood of a liquid market to increase the chance of right price incentives for the participants. In this section, the premise is an open competitive allowance market, which in theory leads to the optimal price formation and subsequent price incentives.

Auctioning revenues arise in the fuel supplier and airline option of the CO_2 ceiling when the ceiling actively restricts emissions (otherwise, permit prices are zero). Generally, the regulating entity receives the revenues from the allowance auction. However, two of the presented CO_2 ceiling options revenues are funnelled back to the sector. We calculated the auctioning revenue and the allowance price for the sector for all policy options.

In the airport options, no allowances auctioning system is set up due to the fact airports (and the slot coordinator) regulates the number of flights according to the remaining emission budget. This practice does not generate government revenues.

In the fuel supplier options, the fuel suppliers will have to buy allowances from the regulator which will generate revenues. Depending on the option, the revenues are for the government or funnelled back to the aviation sector.

The auctioning of allowances in the airline options functions similarly to the auctioning system in the fuel supplier options. In the airline options the airlines are the entities which are obliged to obtain the emission allowances for departing flights from the Netherlands.

4.4.2 Methodology

The auctioning revenue and allowance price is determined according to the cost of abatement. That is, difference in cost for alternative fuels or techniques to perform flights with (almost) zero GHG emissions. By multiplying the number of emissions to reduce and the cost difference per tonne CO_2 emission reduction (by using SAF), we determine the total cost for the emission reduction in a year. We divide the total cost for emission reduction by the number of allowed tonnes CO_2 emissions (which is thus the number of allowances) to receive the allowance price. The total auctioning revenues is consequently the product of the allowance price and the number of allowances per year.

The cost for emission reduction varies by segment: intra-EEA and extra-EEA flights have a different marginal cost for emission reduction. This is due to the fact at intra-EEA flights fuel excise duty and ETS cost need to be paid for, while on extra-EEA flights only additional CORSIA cost apply (which are in total significantly lower than fuel excise duty + ETS cost). Following the rule for the cost-effective emission reduction, the cost for emission reduction is the difference between the cost of kerosene and the cost for an equal volume of SAF. This explains why the emission reduction cost for intra-EEA and extra-EEA flights is different.

4.4.3 Results

We first present the estimated allowance prices in the relevant policy options. In the second part of this section we outline the total auctioning revenues following the sales of CO_2 ceiling allowances.

Allowance price

The allowance price (for the supply/use of kerosene) can be perceived as the incentive to reduce emissions to the required level. As described in the method, the allowance price gives the incentive to reduce emissions to the maximum level the CO_2 ceiling. The price of allowances is therefore directly related to the price of the most cost effective emission reduction option, which is the price of SAF. If the price of an allowance + the price of kerosene is higher than the price of an equal amount of SAF, users will choose to buy and use SAF rather than kerosene. The estimated allowance prices as traded in an open competitive market are stated in Table 30. The actual allowance price may be different according to the form of auctioning or trading the regulator chooses.[57]

Table 30 - CO_2 ceiling allowance prices, in EUR per allowance

Year	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
2030	€ 155	€ 153	€ 155	€ 155	€ 153
2040	€ 120	€ 120	€ 120	€ 120	€ 120
2050	€ 0	€ 0	€ 0	€ 0	€ 0

In the funnelled back options, the consumer receives a small sum back when buying a ticket. This amount is relatively higher on tickets with lower cost, i.e. tickets for shorter distances. The modelling results show there is a slightly higher number of intra-EEA flights in the funnelled back options (in both the fuel/airline option). As mentioned earlier, the cost for emission reduction varies between intra-EEA and extra-EEA flights. Due to the fact the ratio of intra-/extra-EEA flights is slightly higher in the funnelled back options, the total cost for emission reduction is lower (less extra-EEA flights with the higher cost for emission reduction) which results in a lower allowance price compared to the options without auctioning revenue funnelled back.

Due to the higher base price of kerosene, fuel excise duty and ETS cost is the price of kerosene for intra-EEA flights in 2040 higher than the price for SAF. Therefore, theoretically all intra-EEA flights are performed using SAF while extra-EEA uses kerosene (partly). Emission reduction by using SAF only needs to be performed in one segment (extra-EEA), meaning there is only one price for emission reduction. This leads to the equal price of the allowance in all policy options.

Auctioning revenue

Following the auctioning of allowances for the CO_2 ceiling, the regulator obtains auctioning revenues which are either for the state or for the use of a rebate for the sector. The total auctioning revenues are indicated in Table 31.

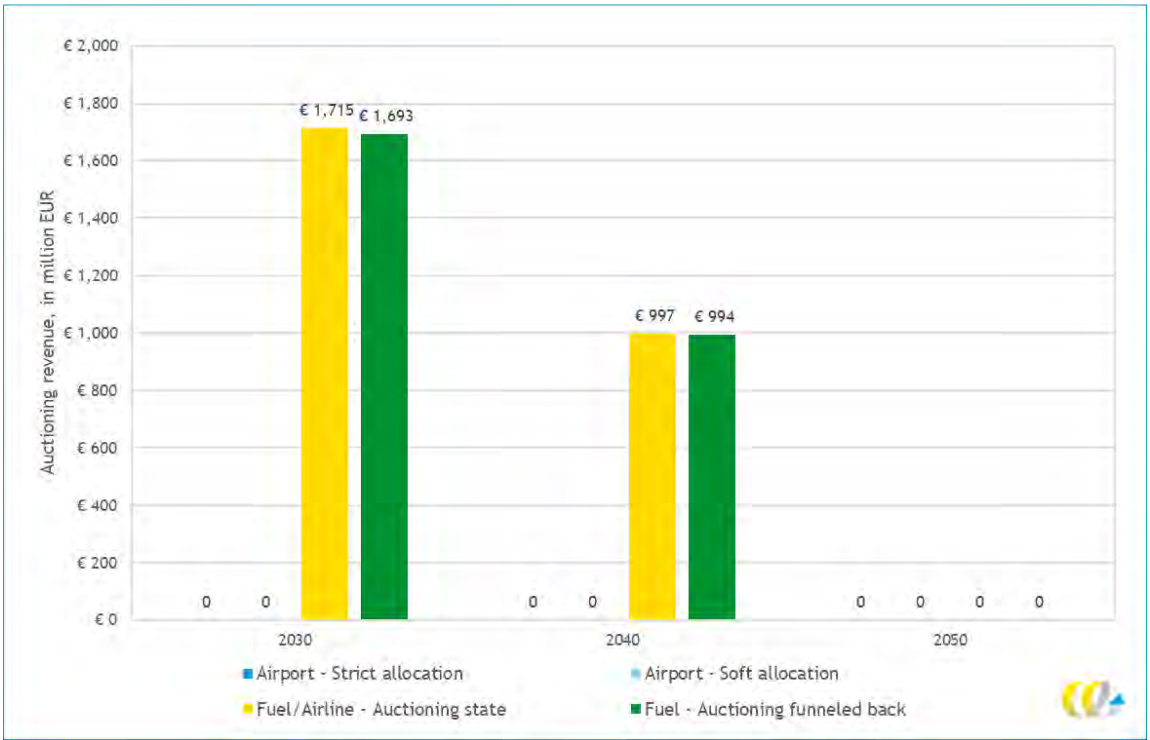
Table 31 - CO_2 ceiling auctioning revenues, in million EUR per year

Year	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
2030	€ 1,715	€ 1,693	€ 1,715 (1,700 to 1,818)	€ 1,715	€ 1,693
2040	€ 997	€ 994	€ 997 (950 to 1,027)	€ 997	€ 994
2050	€ 0	€ 0	€ 0	€ 0	€ 0

57 For example, a closed auctioning of allowances may result in higher prices paid for allowances (and excess revenues) compared to the price in an open competitive market trade.

Figure 57 presents the auctioning revenue in the relevant CO_2 ceiling options, *before* auctioning revenue is (potentially) funnelled back. In the airport options, no auctioning of rights takes place meaning auctioning revenue is zero for these options. The auctioning revenue in 2030 is about € 1.7 billion, and in 2040 € 1.0 billion. Because baseline emissions in 2050 will be under the maximum emission level of the ceiling, the emission rights will be zero meaning no revenues. The auctioning revenue in the Fuel supplier and Airline - funnelled back options is given back to the sector. This means the revenues are funnelled back to the sector and are not for the state.

Figure 57 - Auctioning revenue in the CO_2 ceiling options (million EUR per year)



4.4.4 Discussion

In this section we discuss some aspects of the allowance system which are relevant for a well-functioning allowance market. Furthermore, we outline measures to prevent and minimize the risk of unwanted behaviour from participants.

Unwanted behaviour from actors

In a competitive market, when market parties have no market power (i.e. cannot set the supply), there is not a lot of room for irrational behaviour (i.e. buying more rights than one can use). We determine the cost of the allowances according to the marginal cost of compliance, i.e. cost price of SAF. This is because in case the allowance price plus fossil kerosene price (per tonne fuel) is higher than the price a tonne SAF, airlines will use SAF - simply because this is the option with the lowest cost to comply to the CO_2 ceiling.

Only considering compliance cost, there is no economical reason for parties to buy more allowances than they use. However, the regulated entities are competitors at the airport (fuel suppliers) and at routes they operate (airlines). With the aim to hurt competitors and increase market share, fuel suppliers and airlines may want to buy a significant part of the allowances and try to sell them back for a higher price (or hold the allowances so other parties cannot supply fuel or operate flights). We expect different risks concerning unwanted competitive allowance trading behaviour by the regulated parties in the fuel supplier and the airline policy options.

In case a fuel supplier buys more allowances than the party has agreed to deliver by the contracts for the relevant year, another fuel supplier cannot obtain sufficient allowances for their foreseen fuel deliveries. In that case there may be contract breach and the market share may decrease for the affected fuel supplier in that year. However, fossil jet fuel suppliers at Dutch airports are large multinational fuel suppliers, of which the aviation fuel market is only a small share of total sales. Therefore, a one year decrease of sales at the Dutch aviation fuel market may not significantly hurt the affected fuel supplier.

The barrier to entry is low in this market and in theory the next year the fuel supplier may retaliate and try to buy its market position back. Therefore, we expect there is no sustainable long-term strategy for fuel suppliers to use the CO_2 ceiling allowances to manipulate the market. Still, we suggest some rules should be in place in the allowance system to avoid large yearly changes in suppliers of fuel (and the unlikely event of yearly changing monopolies).

In the airline policy options there is an additional barrier to entry, namely the airport slots. This leads to a different situation with a relative higher risk for parties trying to manipulate the market. In case airline A buys more allowances than the number of flights planned, another airline B cannot obtain sufficient allowances for the number of flights airline B intents to operate. In that case the next year airline B may lose historical right of all slots from the previous years, because this airline could not use the slots. These slots are now part of the slot pool and may be obtained by airline A, meaning the market share of airline B may decrease significantly, and airline A expands their market share. Therefore, we suggest preventive measures in the allowance allocation or auctioning to airlines to use the CO_2 allowance auctioning/trade to manipulate the local air transport market.

Still, the extent to which this practice is possible depends on the availability of SAF and the initial size of operations. Affected airlines can use in the short term SAF or other emission saving measures to maintain (part of) their operations at the same level.
A measure which could decrease the risk of retaliation and other unwanted competitive behaviour is applying a relation between the historical emissions (or number of slots in relation to the average fuel blend) of the regulated entity and the maximum number of allowances an entity is allowed to buy. When using for example a limit of 100% + X% of historical emissions applies, the regulator can avoid parties buying a number of allowances exceeding their actual fuel supply or actual operated number of flights, solely with the aim to push out competitors. This is an important aspect for the design of a well functioning allowance market, and there may be other measures to prevent misuse of this instrument.

Liquidity of the allowance market

The liquidity of the allowance market is dependent on the form allowance auctioning and trading may take place. We discuss the liquidity of the allowance market in an open market where the allowances can be (daily) traded freely between the participating parties

We are uncertain whether the market for allowances will be liquid due to a few factors. First, most allowances will not be traded due to the fact the majority of fuel and flights is planned and thus fixed for the operating parties. This means the allowances which will be traded between the regulated entities are those allowances which are in excess of expected fuel deliveries or possible additional flights – which may be operated or not following sufficient demand. Thus, we expect the number of allowances (volume) will be low. Second, the number of parties participating in the allowance trade has some impact on the liquidity as well. In the fuel supplier variant only small number of parties will trade the allowances leading to (even) lower liquidity of the allowance market. In the airline variants, about 100 airlines operating flights to and from Dutch airports and will therefore participate in allowance trading. This may impact the liquidity of the allowance market positively.

A possible problem of an allowance market with low liquidity is it will be uncertain whether proper equilibrium price formation will arise from market transactions. Optimal equilibrium prices are no necessity for the aim of the instrument, safeguarding the emission reduction goals, but with the lack of optimal allowance prices regulated entities may not receive the right pricing information to choose the most cost-effective emission reduction strategy. Thus, the required emission reduction will take place, however possibly not always at the most optimal price or using the most optimal measures and techniques.

4.4.5 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, there are no expected auctioning revenues as the price for allowances will be zero.

In the scenario with the highest projected baseline emissions (baseline Scenario 6, or extreme scenario, from Figure 20) the impacts are higher. Due to a higher ratio of intra-EEA over extra-EEA flights in the extreme scenario, and subsequent CO_2 emissions from these segments, the allowance auctioning revenues are different than in the main/central scenario.

Because there are relatively more emissions from intra-EEA flights (21% compared to 20% in the central scenario), and the price difference between kerosene and alternative reduction by blending SAF is lower in this segment than the price difference in extra-EEA segment, the allowance price is estimated to be lower in this scenario. Therefore the total auctioning revenues are also lower in the options of the CO_2 ceiling compared to the reference scenario. See Table 32 for an overview of the auctioning revenues. Note that the auctioning revenue in the fuel supplier/Airline – funnelled back options is given back to the sector, minus a small fee for the administrative procedure. This means the revenues are funnelled back to the sector and are not for the state.

Table 32 - Overview of auctioning revenues in extreme scenario (Scenario 6)

Year	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
2030	€ 1,680	€ 1,660	€ 1,680 (1,710 to 1,830)	€ 1,680	€ 1,660
2040	€ 990	€ 980	€ 990 (940 to 1,020)	€ 990	€ 980
2050	€ 0	€ 0	€ 0	€ 0	€ 0

4.5 Fiscal impacts

4.5.1 Introduction

The introduction of the CO_2 ceiling would lead to a multitude of fiscal effects. A priori, it is unclear whether these fiscal effects sum up to more or less government income, and whether these results differ between the options of the CO_2 ceiling. In this paragraph we describe the mechanisms by which the CO_2 ceiling can influence public finance and quantify the corresponding effect sizes.

4.5.2 Methodology

We distinguish eight different mechanisms by which the CO_2 ceiling can influence fiscal revenue and government expenditures of the national government. Here we list all of these mechanisms and describe the methodology by which their effect size was calculated. Note that changes in import duties are not on the list as the corresponding tax income flows to the European Union. Changes in income taxes due to changes in employment are assumed to be negligible (over longer time horizons, most people that used to work in aviation find jobs elsewhere in the economy and thus continue to pay income tax).

1. *The CO_2 ceiling can influence total government income from the Dutch aviation tax.*
   When the CO_2 ceiling leads to a change in the number of passengers departing from Dutch airports, this translates to a change of government income from the aviation tax. Total income from the aviation tax is standard AEOLUS output; no additional calculations are required.

2. *The CO_2 ceiling can influence revenues from EU ETS auctions.*
   When the CO_2 ceiling causes a decline in intra-EU emissions from Dutch airports, the number of aviation emission allowances which the Dutch government is allowed to auction in future periods will decrease. The distribution of allowances to be auctioned by each member state is determined at each revision of the EU ETS. As of 2022, the number of allowances the Netherlands can auction is based on the Dutch share of emissions during the period 2016-2018. Since we do not know when the EU ETS will be revised for upcoming monitoring periods, we approximate the change in auctioning volume by assuming EU ETS auctioning income scales linearly with intra-EU emissions from Dutch flights.

3. *The CO_2 ceiling can generate allowance revenues in the fuel supplier and airline options*
   In the Fuel supplier - Auctioning State option and the Airline - Auctioning State options of the CO_2 ceiling, the government will generate revenues from the auctioning of fuel- or CO_2 emission allowances. These revenues are equal to the corresponding figure of allowance revenue as included in the compliance costs, calculated in Section 4.2.

4. *The CO_2 ceiling can influence tax revenues from the ETD*
   When the CO_2 ceiling leads to a decrease in fuel use, or to change in the percentage of SAF being blended at Dutch airports, this will impact government revenues from the ETD fuel taxes, if the ETD is adopted as proposed by the European Commission. The size of this effect was calculated previously under compliance costs in Section 4.2.

5. *The CO_2 ceiling can impact revenues from user taxes (VAT, excise duties, etc.)*
   When the CO_2 ceiling causes some resident passengers to cancel their travels entirely (not to be confused with flying from a foreign airport, or traveling by car or train),

these passengers will spend less of their earnings abroad. We can consequently assume that the same passengers will spend their saved earning in the Netherlands, where they pay an average of 18,2% user taxes over their expenditures (SEO et al., 2021). These tax revenues would not have fallen to the Dutch government had the passengers continued their travels. In a similar manner, non-Dutch passenger who cancel their travels to the Netherlands will spend less of their earnings in the Netherlands. Roughly 18,2% of these lost expenditures are missed revenues for the Dutch government. Based on CE Delft, (2018), we assume that Dutch business passengers spend on average € 930 while on an international trip, while regular passengers spend on average € 858 per trip. Foreign business travellers spend on average € 838 while on a business trip to the Netherlands, while foreign vacationers spend an average of € 634.

6. *The CO_2 ceiling could decrease profits of Dutch airport and hence lead to a decline in profit tax revenues*
When the CO_2 ceiling causes fewer passengers to fly from Dutch airports, this will influence the profitability of Dutch airports. In the Netherlands, airports are obliged to relinquish an average of 25,8% of their profits in the form of profit taxes, so mutations in profits have fiscal effects. AEOLUS does not yield information on the profitability of airports. We hence assume that that Dutch airports make a fixed average profit of € 4,32 per passenger, in line with CE Delft, (2021c). We further assume that capacity-constrained airports make additional economic profits, equal to € 2,92 per passenger, based on the same analysis from CE Delft, (2021c). Note that mutations in profits by Dutch airports can have effects on profits elsewhere in the Dutch economy.
For instance, if parking revenues at Dutch airports decline as a result of passengers cancelling their travels altogether, the additional domestic expenditures made by these passengers (which are enabled by their savings) lead to higher profits elsewhere in the Dutch economy (but, generally, not to *economic* profits). Over these profits, the Dutch government would again collect profit taxes. Note too that a large share of airport's revenues stem from airport charges. Based on annual reports from Schiphol we estimate that on average 60% of total revenue is linked to aeronautic activities, and the remaining 40% stems from non-aeronautic activities like parking. Airports can only make economic profits over their non-aeronautic activities (aeronautic activities are regulated). We only calculate the mutations in profit taxes over the part of the profit that is made from non-Dutch airlines and non-Dutch passengers to account for mutations in profits in the rest of the Dutch economy. Over the part that is made from Dutch passengers, we only calculate the mutations in economic profits as these will not generally me made in the rest of the Dutch economy.

7. *The CO_2 ceiling could decrease profits of Dutch airlines and hence lead to a decline in profit tax revenues*
Just like the CO_2 ceiling can influence the profitability of airports, it can also impact the profitability of airlines. Note that only the Dutch airlines are required to pay profit taxes to the Dutch government. In line with a previous analysis of CE Delft, (2018), we assume 59% of flights departing from a Dutch airport are from Dutch airlines (CE Delft, 2018). We follow the same methodology as for the mutations in airport profits, distinguishing between Dutch and non-Dutch passengers, and accounting for scarcity profits (a form of economic profit) that are not made elsewhere in the Dutch economy. We presuppose that airlines make an average profit of € 6,27 per passenger based on analysis of historic IATA data (CE Delft, 2018). This figure includes profits from freight - profits are simply expressed in a per passenger manner. Additional scarcity profits are distilled from the AEOLUS outputs.

8. *The CO_2 ceiling could affect the dividends paid by publicly owned airports and by airlines in which the State holds shares*
   The CO_2 ceiling can influence dividend payments from the Schiphol group, by impacting its profits. The Dutch state is the largest shareholder of the Schiphol group with a total capital share of almost 70%. Dividend payments will hence largely flow to the treasury. Based on historic data between 2010 and 2019, we estimate that the Schiphol Group pays out an average of 50% of its yearly profits as dividend, such that a net 35% of profits indirectly flow to the Dutch government (Schiphol, 2022). The Dutch government also has (a much smaller) share in KLM Royal Dutch Airlines and its mother-company KLM-Air France. These companies have, however, not paid out significant dividends to its shareholders in the past ten years. We thus assume the corresponding fiscal effects are negligible.

Finally, aforementioned fiscal effects have another additional indirect effect on government expenses and revenues. If the CO_2 ceiling leads to a net increase of government income, the government can lower its existing taxes (we assume net government income is fixed as result of the early government budget). Lower taxes translate to more expenditures, over which user taxes are levied. We thus calculate 18,2% additional tax income over the mutation in fiscal effects, following SEO, (2018).

4.5.3 Results

Figure 58 show the fiscal effects (changes in tax revenues) for each of the individual component described in the previous paragraph, excluding the CO_2 ceiling allowances revenues. The fiscal effects are mostly modest (less than 50 million euro per year) and comparable between the different scenarios. Because the actioning revenues are about 1.7 billion EUR and 0.9 billion EUR in 2030 and 2040 respectively, these changes are not represented in the graph below (because this does not fit for clear visual presentation of the graph). FXX presents the total change of tax revenues, including the CO_2 ceiling allowance revenues in the Fuel supplier/Airline - Auctioning state variants. Thus, the fuel and airline options without revenues funnelling back lead to large additional fiscal income.

Figure 58 - Changes in tax revenues (excluding CO_2 ceiling allowance revenues) in million EUR per year

Figure 59 - Total change in tax revenues in the reference scenario (million EUR per year)

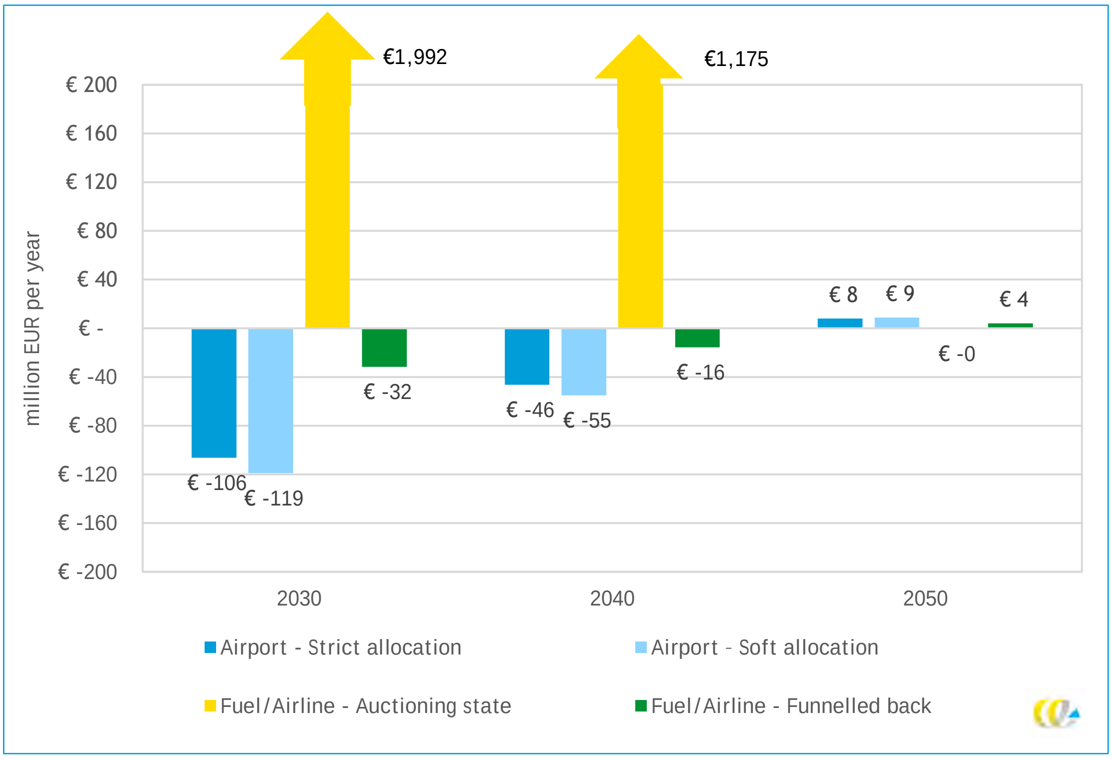


Table 33 shows the net fiscal effects of the different options of the CO_2 ceiling, compared to the reference scenario baseline. Note that these results are already corrected for changes in user tax income resulting due to second-order effects. Again, we see substantial differences between the auctioning options (fuel and airline) and the other options of the CO_2 ceiling. These differences stem mostly from fiscal income generated by revenues of allowance auctions. Note that additional government revenues also come at the price of lower profits for airlines, and/or higher ticket prices.

Table 33 - Total change in tax income compared to the reference scenario, corrected for second-order effect on user taxes

Year	Baseline revenue	Airport -strict (3-year cycle)	Airport -strict (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ 1,976	€ -106 (€ -168 to € -106)	€ -106 (€ -175 to € -106)	€ -128 (-181 to -128)	€ 1,992	€ -32	€ 1,965 (€ 1,944 to € 2,091)	€ 1992	€ -32
2040	€ 2,172	€ -46 (€ -159 to € -46)	€ -46 (€ -164 to € -46)	€ -65 (-169 to -65)	€ 1175	€ -16	€ 1,165 (€ 1,104 to € 1,204)	€ 1175	€ -16
2050	€ 2,213	€ 8 (€ -178 to € 31)	€ 8 (€ -158 to € 28)	€ 8 (-178 to 31)	€ 0	€ 4	€ 2 (€ -83 to € 21)	€ 0	€ 4

4.5.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact in the fiscal domain. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the net fiscal impacts add up to €-200 to €-400 million euros depending on the given year and ceiling option. Exceptions are the fuel supplier and airline options in which auction income is not funnelled back to the sector. For these options, results are comparable to the reference scenario. In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in the annex tables.

4.6 Costs of enforcement

4.6.1 Introduction

The cost of enforcement are the cost for the regulating entity in case a regulated party has not (fully) complied with the requirements of the CO_2 ceiling. These costs can stem from correction of emission figures, appeal or fining of entities in violation.

According to the NEa (Dutch emissions authority), monitoring of CO_2 emissions is fairly straight forward in the aviation sector compared to other emitting sectors. This is due to the fact Eurocontrol closely monitors and registers all (commercial flight) movements in airspace.[58] Using accurate flight data, Eurocontrol calculates historical emissions figures. This makes enforcement easier for the enforcing entity because they have a data source for emission figures by flight, airline or airport - independent from the reporting party.

The enforcing party can give warnings, perform corrections of emission figures and give fines in case of violations. Moreover, an important part of their task is 'invisible enforcement'. This is done by providing monitoring formats and communicating information concerning regulation very clearly to regulated entities. According to the NEa, non-compliance with emission registration and use of EU ETS allowances is rare. The few prevailing non-compliance cases are almost always (human) mistakes or entities that are unknown with the need for emission registration.

4.6.2 Discussion of enforcement cost

- The level of enforcement cost depends on a number of factors:
  - the number of parties to be regulated.
  - the provision of information (by the regulator) and standardisation of procedures.
  - availability of (independent) valid data on emissions.
  - legal status of the policy, whether the CO_2 ceiling is supplementary to or in conflict with existing aviation regulations.
  - accessibility of the regulated parties, establishment in the Netherlands (or EU).
- Based on these factors, we highlight the enforcement costs and outline a qualitative indication. We do this for the three main options of the CO_2 ceiling.

[58] Eurocontrol is a European organisation supporting European aviation. Eurocontrol has a vast collection of flight data by monitoring and high-level management of the European airspace.

Airport options

In the airport options of the CO_2 ceiling, airports are required to monitor the emissions of departing flights and restrict the number of flights to maintain emissions under the maximum allowed level. The actual number of slots (flights) provided in a year depends on the emission factor of the average fossil kerosene-SAF blend. If the rate of SAF in the fuel mix is increased, the average emissions per tonne fuel blend decreases. In that case the regulator may allow an increase in the number of flights, while the total emissions still remain within the emission boundaries of the CO_2 ceiling.

Emission figures by flight can be obtained via Eurocontrol to monitor the emissions by all departed flights from Dutch airports. At most airports in the Netherlands (AMS, EIN and RTM), the number of flights is regulated by airport decrees (luchthavenbesluiten) in number of 'slots' which airlines have to use to show legal right to operate a start or landing at an airport. The slots are coordinated and monitored by ACNL (airport coordination Netherlands). The enforcement and sanctioning are with the ILenT (inspectie leefomgeving en transport).

In the years when the CO_2 ceiling forces to reduce emissions and thus the number of flights, the number of slots will have to be reduced by the slot coordinator to a level for which the CO_2 emissions of the total number of flights remains under the maximum allowed CO_2 level of the ceiling in the relevant year. In practice, this means the regulator calculates - according to the proposed flight plans (number of flights and destinations) of the airlines and the average emission factor following the kerosene-SAF blend at the airports – the allowable number of flights to stay under the CO_2 ceiling. This may imply a reduction in the number of flights from one year to the next, meaning airlines may face receive a less slots even though they may have had historical right for the use of a higher number of slots. In practice, the total allowable number of flights is dependent on the emission factor of the fuel blend (and to a lesser extend the development of the energy efficiency of the fleet).

We suggest the practice of the regulator being 'strict' beforehand – issuing a number of slots for which total emissions will certainly remain under the CO_2 ceiling - rather than having to intervene during a slot season (by restrictive the number of slots at the very short term). This is to avoid legal claims by the regulated entities and possible additional cost for compensation. In the impact assessment we assume the regulator applies a strict issuing, and does not have to intervene during the slot season. We assume the regulator can model the emissions using the flight plans (airlines have to report which destination they intend to fly to for a particular departure slot). Therefore, we do not estimate additional cost for intervening and claims. Moreover, it appears to be very complex to estimate the value of an airport slot.

Because the majority of European airports for commercial flights apply slots, airlines are familiar with this type of regulation. Therefore, we expect a low chance in difficulties concerning regulation of flights by restriction of slots. The enforcement of violations is similar to the enforcement currently in place by ILenT. We do foresee similar or slightly different cost in enforcement in this option because:
- regulated entities only have to deal with a well-known instrument (airport slots);
- the regulator can use an existing instrument for regulation, no additional set up cost;
- current rules and sanctions in place are adequate instruments to avoid slot misuse;
- there is no change in the number of regulated entities (six airports).
- For the airports GRQ, MST and LEY a slot regime will have to be set up in order to put these airports under the CO_2 ceiling regime. This requires administrative set up costs. However, for these airports (certainly for LEY) a slot system may be set up regardless

of a possible CO_2 ceiling in the future. In case the slot system is in place at these airports too, we expect enforcement is of the same magnitude as in the current situation.

— The ILenT has the task to evaluate whether proper monitoring and enforcement can be performed with available means, which will be the case as well if the CO_2 ceiling is about to be implemented. Depending on details of the policy option the required additional workforce can be estimated required for enforcement.

Fuel supplier options

In the fuel supplier options, fuel suppliers have to report the volume of fuel supplied to airports, and are not allowed to supply more fuel than the CO_2 ceiling allows by the maximum allowable carbon emissions (which is emitted by the combustion process). With a fuel allowance system in place, fuel suppliers will have to obtain these rights in order to supply fuel to airports. The enforcement of these allowances can (logically) be assigned to the Dutch emissions authority (NEa), which currently has the task to monitor and enforce the allowances of the EU ETS in the Netherlands.

The number of regulated entities is relatively manageable. The regulated entities are fuel suppliers who supply kerosene or non-fossil aviation fuel to airports. The estimated number of parties supplying aviation fuels to Dutch airports is around ten, depending on the development of the market for SAF in future year.

Because the number of parties to be regulated is relatively low, the effort by the regulator for the provision of proper information and MRV formats can be relatively low. Due to the fact fuel suppliers will have to report the quantities of aviation fuel (fossil and SAF) for the upcoming SAF blending requirements, data is readily available. Moreover, after the revision of the ETD is implemented, the quantities of fuel supplied to airports will be monitored by the tax authority with the aim to calculate the amount of owed aviation fuel excise duty. Therefore, data on the quantities of fuel supplied to airports can be gathered from different (independent) sources which helps the enforcing authority for the CO_2 ceiling to verify the reported efficiently.

The fuel supply chain to the airport is in the EU market, with firms operating from an EU country. Therefore, the legal status of the policy should be tested against the rules governing the open EU market. International aviation regulation does not apply to fuel supply as this is done in a national context.

The fuel suppliers are located and have a legal status in either the Netherlands or another EU country. Therefore, in case of eventual rectifications and fines, the regulating party can relatively easy trace the entity liable for the case or fine.

Airline options

In the CO_2 ceiling Airline options, the final users of aviation fuel – airlines - have to report the volume of fuel used in their aircraft, and are (as a whole) not allowed to use more fuel than the CO_2 ceiling allows by the maximum allowable carbon emissions (which is emitted by the combustion process). For the use of kerosene, airlines will have to obtain allowances in order to fuel their aircraft. The enforcement of these allowances can also be assigned to the Dutch emissions authority (NEa), which currently has the task to monitor and enforce the allowances of the EU ETS in the Netherlands, in which airlines located in the Netherlands are already partaking.

The number of regulated entities is much higher than in the fuel supplier options. The regulated entities are fuel suppliers who supply kerosene or non-fossil aviation fuel to airports. The estimated number of airlines flying to and from Dutch airports is around 100, with several airlines from extra-EU countries.

Because the number of parties to be regulated is relatively high, the effort by the regulator for the provision of proper information and MRV formats may be very extensive. There is no obligatory framework in place for the monitoring of the quantities fuel supplied to aircraft. Therefore, independent monitoring of supplied quantities will be an additional task for the enforcing party which may involve relative high cost for additional personnel.

Airlines operating flights from Dutch airports are firms from EU and non-EU countries. Currently, international aviation is exempt from national regulation in the broad sense of the word. Legal appeal against this option of the CO_2 ceiling could arise from both EU based airlines as non-EU based airlines. Therefore, this policy option should be tested against the rules governing the open EU market and rules for free international aviation. There is a higher chance of that (in particular) internationally operating airlines will start cases against a national policy restrictive the use of kerosene.

Moreover, due to the fact airlines can be located in any country while operating flights to and from the Netherlands, effort from the regulator to retrieve contact information if warnings or fines are given may rise significantly.

Comparison of factors impacting enforcement cost

In Table 34 an overview is presented of the most important factors impacting the enforcing effort by the regulator and thus the degree of enforcement cost. The policy options can be compared at the different factors.

Table 34 - Factors impacting enforcement effort and cost for options of the **CO_2** ceiling

Factor	Airport options	Fuel supplier options	Airline options
The number of parties to be regulated	Low - (six airports), under current slots framework	Low - (+/-10 fuel suppliers)	High - (+/-100 airlines)
Effort for provision of policy information (by regulator)	Low - regulation by existing slot policy	Low - by requirement of RED and ETD (fuel duty) contact will be established with these parties[a]	High - many entities operating globally are unaware/may be unwilling to comply to national ETS
Availability of (independent) valid data on emissions	Good - Eurocontrol provides (estimated) emission data by flight	Good - volumes of fuel to be provided by the tax authority[b]. This may be complemented with data from Eurocontrol which the NEa has access to	Sufficient - Eurocontrol can provide (estimated) emission data by flight. However, due to fuel blending real emissions by airline may differ
Legal status: complementing or in conflicting with existing aviation regulations	Complementing	Complementing	Possibly conflicting - national regulation restrictive international aviation
Accessibility of the regulated parties	Good - airports located in the Netherlands	Moderate - fuel suppliers established either in NL or EU countries	Poor - airlines located worldwide may require considerable effort for the

Factor	Airport options	Fuel supplier options	Airline options
			small emitters (non-EU airlines)

[a] New fuel suppliers (e.g. SAF producers) will have to report themselves at the authorities (tax authority) before allowed to supply fuel to airports. For least effort regulation the NEa should be able to receive information on new fuel suppliers by the tax authority.

[b] This is because fuel suppliers are required to report volume of fuel and SAF delivered to airports, to comply with blending rates as set by the RED and remittance of fuel excise duty for kerosene and SAF from 2024 onwards.

It is clear the airport policy options involve relatively lower effort for the enforcing entity and therefore the expected enforcement costs are lower compared to other CO_2 ceiling policy options. The airport policy option of the CO_2 ceiling may also face the least resistance to compliance from the regulated parties (see also Section 4.3 for cost of the regulated entities).

4.7 Upstream and downstream effects

4.7.1 Introduction

We distinguish two types of upstream and downstream economic effects. The first are agglomeration effects. This concerns effects regarding potential positive spillovers of high density clustered businesses around the airport regions. These effects are discussed qualitatively in Subsection 4.7.2 and 4.7.3 for passengers and cargo. The second are the impacts of changes in household expenditures. Dutch passengers who cancel their travels altogether will spend additional money in the Netherlands. Similarly, non-Dutch passengers who do not travel to the Netherlands anymore do not spend money in the Netherlands. These effects are assessed quantitatively in Subsection 4.7.4.

4.7.2 Results for passenger transport

A restrictive CO_2 ceiling could increase ticket prices and lower the quality of Schiphol Airport's network. A priori, it seems possible that this makes the Amsterdam region less attractive for businesses that are dependent on cheap and quick air transport. If fewer firms settle in the Amsterdam region in the future, or more firms leave the area, this could also impact the productivity of existing firms that do not decide to relocate. After all, a high density of clustered and productive businesses can lead to positive spillovers (agglomeration benefits). A similar argument can be made for cargo. In this section we consider whether such undesirable upstream and downstream effects are likely to occur. We also provide a quantitative estimates of the indirect effects the different option of the CO_2 ceiling have on (domestic and foreign) consumer spending.

CE Delft, (2017a) investigated whether agglomeration effects resulting from changes in air connectivity are likely. The study concludes that the connectivity and accessibility of a region is indeed a location factor. The literature is, however, not unequivocal about the importance of this location factor compared to many other relevant location factors. It is also unclear whether the location of head offices will increase the demand for flight movements or whether causality runs the other way around. Furthermore, not all destinations in the network are equally important. For the business climate, the business destinations are clearly more important than holiday destinations.

The recently published *'Werkwijzer Luchtvaartspecifieke MKBA's'(SEO et al., 2021)*, notes that as of yet, there is no scientific basis for the occurrence of agglomeration benefits through aviation. Zhang and Graham (2020) note that aviation-specific studies are lacking and that this is an important gap in scientific knowledge. SEO et al. provide a comparison with agglomeration benefits from land transport. For instance, Graham (2007) shows, based on a methodology developed by Venables (2007),[59] that the agglomeration benefits of the Crossrail metro project in London increased total benefits by 25 %. As SEO et al. note though, the indirect effects of land transport have a very different characteristic than the those of air transport. It seems likely that agglomeration effects through aviation are much smaller than those through land transport as air connectivity is likely a much smaller contributor to the attractiveness of jobs than a short commute.

We recommend further research into the specific agglomeration effects of aviation. At this point, there is no scientific basis for assuming the effects are substantial, and we will therefore ignore them in the remainder of this impact assessment.

4.7.3 Results for cargo

As described under Subsection 4.8.2 various literature describes the relationship between airport size and regional economic development. Larger airports have a positive impact on regional economic development. However, causality between the two is uncertain. On firm level though, it is known from past expert interviews that global logistics service providers are inclined to invest at locations with significant transport possibilities. Higher volumes create economies of scale which will in turn contribute to volume in a region. Also, the possibility to interact with other entities in the transportation chain will create additional volume.

Vice versa it can be stated that decreasing air cargo volumes, will likely make a region less attractive to invest in. This effect is not expected to manifest itself immediately after decreased transport capacity, but when land leases or rents are renegotiated, global logistics service providers may reconsider their relative position at one airport, compared to another.

Supporting this relationship is found during a period of previous airport slot scarcity (2017-2019). A decrease in available air cargo capacity did not immediately lead to less interest, but did cause a modal shift. Logistics service providers focussed more on trucking and used Amsterdam Airport Schiphol also for additional cross docking movements, facilitating road-road transport feeding into other air cargo hubs in North-western Europe.

4.7.4 Indirect effects on consumer spending

The CO_2 ceiling can indirectly influence consumer spending because it impacts the proportion of earnings spend domestically and that spent abroad. Dutch passengers who cancel their travels altogether will spend additional money in the Netherlands – money they saved by not buying goods and services abroad. Similarly, non-Dutch passengers who cancel their trip to the Netherlands will spend less of their earnings in the Netherlands. The corresponding fiscal effect was previously described in Section 4.5. Here we show the net effect on consumer spending for each of the ceiling options, as compared with the reference baseline scenario.

Table 35 shows the effect on consumer spending of Dutch passengers changing their travel behaviour. In most ceiling options the CO_2 ceiling leads to a net decrease in travels, causing Dutch inhabitants to spend more money domestically. Exceptions are formed by the two

[59] Graham, D. J. (2007). Agglomeration, productivity and transport investment. Journal of transport economics and policy (JTEP), 41(3), 317-343.

ceiling options in which auctioning income is funnelled back. This is explained by the facts that in these options more Dutch passengers fly to nearby (European) destinations, where they consequently spend their earnings.

Table 35 - Effects on consumer spending by mutations in travelling behaviour by Dutch passengers **(in € million)**

Year	Airport - strict (3-year cycle)	Airport - strict (1-year cycle)	Airport - soft	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ 102 (€ 0 to € 102)	€ 102 (€ 0 to € 102)	€ 113	€ 334	€ -789	€ 334 (€ 334 to € 334)	€ 334	€ -789
2040	€ 115 (€ 0 to € 115)	€ 115 (€ 0 to € 115)	€ 131	€ 133	€ -656	€ 133 (€ 133 to € 133)	€ 133	€ -656
2050	€ 21 (€ 21 to € 0)	€ 21 (€ 21 to € 0)	€ 5	€ -35	€ -19	€ -35 (€ -35 to € -35)	€ -35	€ -19

Table 36 shows the effect on consumer spending of non-Dutch passengers changing their travel behaviour. In most ceiling options fewer non-Dutch passengers visit the Netherlands than in the reference baseline scenario, leading to a decline in consumer spending. Only in the options in which auctioning income is funnelled back do we see an increase in consumer spending due to an increase in tourism.

Table 36 - Effects on consumer spending by mutations in travelling behaviour of non-Dutch passengers **(in € million)**

Year	Airport strict (3-year cycle)	Airport strict (1-year cycle)	Airport soft	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ -57 (€ 0 to -57)	€ -57 (€ 0 to -57)	€ -63	€ -187	€ 447	€ -187 (€ -187 to € -187)	€ -187	€ 447
2040	€ -67 (€ 0 to € -67)	€ -67 (€ 0 to € -67)	€ -76	€ -78	€ 385	€ -78 (€ -78 to € -78)	€ -78	€ 385
2050	€ -13 (€ -13 to € 0)	€ -13 (€ -13 to € 0)	€ -3	€ 21	€ 12	€ 21 (€ 21 to € 21)	€ 21	€ 12

Table 37 shows the net effect on consumer spending in the Netherlands. The results shown in Table 35 and Table 36 cancel out to a significant extend, but the impacts of Dutch passengers is dominant (mainly due to their higher foreign expenditures).

Table 37 - Net effect on consumer spending of Dutch and non-Dutch passengers changing their travel behaviour **(in € million)**

Year	Airport strict (3-year cycle)	Airport strict (1-year cycle)	Airport soft	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ 45 (€ 0 to € 45)	€ 45 (€ 0 to € 45)	€ 50	€ 147	€ -342	€ 147 (€ 147 to € 147)	€ 147	€ -342
2040	€ 48 (€ 0 to € 48)	€ 48 (€ 0 to € 48)	€ 54	€ 55	€ -270	€ 55 (€ 55 to € 55)	€ 55	€ -270
2050	€ 8 (€ 8 to € 0)	€ 8 (€ 8 to € 0)	€ 2	€ -14	€ -7	€ -14 (€ -14 to € -14)	€ -14	€ -7

We can also display the effect changes in consumer spending have on Dutch GDP. To do so we assume that 75,5% of additional consumer spending translates to increases in GDP. This assumption is in line with CE Delft, (2018) and is based on the CBS data showing that roughly 25% of consumer expenses of Dutch households are imports. Table 38 shows the GDP effects of the mutations in consumer spending. Note that these results do not encompass *all* GDP effects - we only show the GDP effects of changes in consumer spending.

Table 38 - GDP effects of mutations in consumer spending **(in € million)**

Year	Airport strict (3-year cycle)	Airport strict (1-year cycle)	Airport soft	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ 34 (€ 0 to € 34)	€ 34 (€ 0 to € 34)	€ 38	€ 111	€ -258	€ 111 (€ 111 to € 111)	€ 111	€ -258
2040	€ 36 (€ 0 to € 36)	€ 36 (€ 0 to € 36)	€ 41	€ 42	€ -204	€ 42 (€ 42 to € 42)	€ 42	€ -204
2050	€ 6 (€ 6 to € 0)	€ 6 (€ 6 to € 0)	€ 1	€ -11	€ -5	€ -11 (€ -11 to € -11)	€ -11	€ -5

4.7.5 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no significant upstream or downstream effects to occur. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the impacts will be substantially higher. Domestic consumer spending increases in the airport option with up to € 2 billion in 2050. For most other years and ceiling options, mutations in consumer spending are positive. Exceptions are formed by the Airline - Grandfathering and Fuel supplier - Auctioning state options, in which domestic consumer spending decreases with up to € 1 billion. In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in Annex H.

4.8 Impacts on innovation

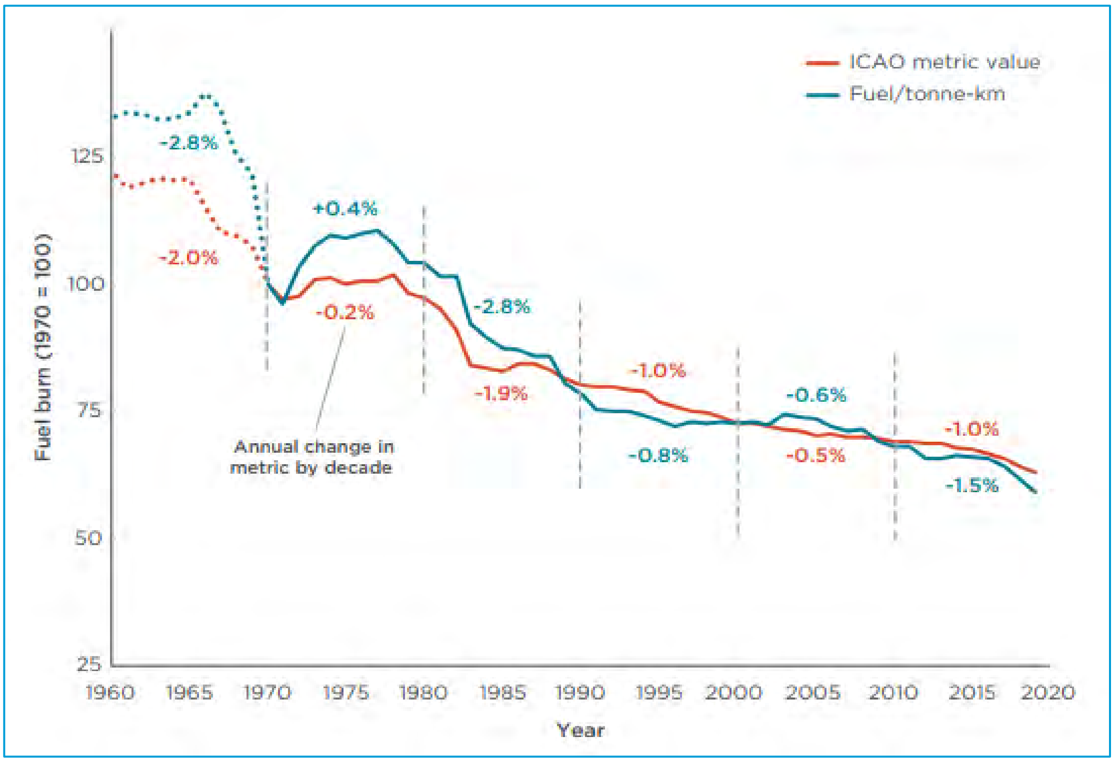
The innovation in technology is related to the aircraft and its ground operations. The airports and the operators will benefit from innovations within the aviation sector, where the operators will be the ones driving to change their aircraft up to current standards. The fuel suppliers will potentially try to influence the innovations to retain their grip on the market, as less fuel consumed due to innovation will negatively impact their business case. Air traffic management and air operations and their innovations are not considered here.

This section can be considered an addition to the section on fleet renewal (Section 3.6). The focus will be on the renewed aircraft with innovative technologies and their benefits. The implementation of these renewed aircraft within a fleet and their operational impact was discussed previously (in Section 3.6).

Aviation innovations have consequently reduced the fuel consumption throughout the past decades. Figure 60 shows the reduction in average fuel burn since 1960, where the average fuel burn of 1970 was taken as the reference (Xinyi Sola Zheng, 2020). Sidenote, the information presented was evaluated during the COVID pandemic with data up until 2019, where the effect of COVID on the aviation sector was factored in. On average it is stated that the aviation fuel burn is reduced by 1.9% per year, as is stated by IATA (International Air Transport Association (IATA), 2022). A study by the NLR states a value of 2.4% of fleet-average annual improvements between 1971 and 1998 (Peeters P.M., 2005). These numbers represent a general average trend, which is a combination of technology innovation and operational changes on a global scale. The purpose of showing them here is to highlight that changes to aircraft design are not only related to environmental concerns, but are always ongoing (in different levels).

As can be seen in Figure 60, pending on the decade and innovations being implemented, the fuel burn is affected accordingly. The 1970's were marked by the introduction of the Boeing 747, the first modern twin aisle aircraft with the first high bypass turbofan engine. As air traffic started to explosively increase around the millennium, the reduction in fuel consumption started to stagnate. Nowadays the need for climate change readdresses the need for innovations to reduce fuel burn. The implications of COVID also affect the innovation within the aviation sector, as demand and investments are fluctuating. Uncertainties exist on clean sheet developments of aircraft, where one could argue that developments on the existing airframes might not suffice. The trend for coming years is therefore uncertain. .

Figure 60 - Average fuel burn for new commercial jet aircraft, 1960 to 2019 (1970 = 100)



Source: (Xinyi Sola Zheng, 2020).

To further reduce CO_2 emissions and effectively fuel burn, one can rely on the intensity of flights or the emissions per flight. The operational or aircraft design are affected respectively. On the operational side, several advances can be implemented to reduce the amount of energy required per flight. The aircraft design can be optimized to reduce fuel burn, energy required or potentially cancel specific emissions. In all cases the changes can be categorized as conservative or disruptive, pending on the impact of the changes when compared to current aircraft and infrastructure. Nowadays conservative technology advances are already being implemented to reduce fuel burn, as presented in Figure 60.

The CO_2 ceiling will probably not create leverage towards aircraft manufacturers to speed up research and technological advances, thus the CO_2 ceiling will not have an effect on aircraft level technological innovations. The incentive for airlines connecting through the Netherlands to renew their fleet will however be high. Pending on effect of the policies to the airlines will thus determine to what extent fleet changes are implemented, as was discussed within the fleet renewal section (Section 3.6). The analysis presented here is to outline and detail the innovation of technology on an aircraft level, which are not included within the models.

A qualitative study of the technological advances and innovations is the focus of this section, which is an addition to the level of detail of the fleet renewal section. This section analyses whether or not there is a difference between the policy options in the incentive they provide for innovations aimed at reducing the CO_2 emissions or improve the fuel-efficiency of aircraft. Furthermore an opinion towards how the CO_2 ceiling will affect innovation is briefly discussed within the conclusions. Although this section is based on a techno-economic analysis of specific technical and operational measures to improve efficiency, it is not a thorough review of these measures, as this would be beyond the scope of this report.

4.8.1 Methodology

The results presented here include an overview of all relevant technologies and innovations that are found in the public domain and that are currently being studied. The list is not exhaustive but provides an overview of what can be expected. The technologies are listed according to the impact:
- system implementation;
- aircraft implementation;
- operational implementation.

System implementation is related to the addition of a new or revised element/system within the aircraft, where the aircraft implementation is an innovation related to the aircraft as a whole. The operational implementation is related to the usage of the aircraft. For each level of implementation, a distinction is made between conservative and disruptive. The technology was investigated and an overall impact assessed. After all technologies are elaborated, an overview on fuel consumption and Technology Readiness Level (TRL) is provided. Both parameters provide insight into how aircraft will change coming decades, which can be related to the results within the section of fleet renewal.

4.8.2 Results

First a brief discussion relating to all technological implementations, broken down into the three levels of implementation, is presented. The results presented are based on information found in literature in combination with ADSE experience on technology implementation. A summary is provided, relating each technology to a reduction in fuel consumption, directly relating to a reduction in CO_2 emissions. TRL and development/implementation costs are presented to provide a background into the feasibility of the technology within the timeframe of the coming decades.

System implementation

The technologies presented on the system level imply changes to aircraft systems and elements, without the need for large aircraft design changes. The evaluated technologies presented here include:
- riblets;
- electric aircraft taxi system;
- fixed ground power system instead of auxiliary power unit (APU).

The systems presented are considered to be conservative, as they can be implemented within current aircraft of all types.

Riblets is a technology in which the aircraft skin of the fuselage and wings have a roughness pattern, either implemented within the material or by adding a thin layer of material to the top surface. Often the comparison is made with the skin of a shark, which contains micro patterns to reduce friction drag. The additional installation of the riblets reduce the friction drag of the surface in a free stream. Currently research and tests are ongoing to further develop the technology and it is planned to be rolled out on the Lufthansa Cargo freighter fleet in 2022. An initial test on a Boeing 747 with a lower fuselage modification showed a 0.8% friction reduction. This would translate into annual fuel savings of 300 metric tons of kerosene for the Lufthansa fleet (Technik, 2019).

Electric aircraft taxi systems can be subdivided into two types, the E-tug and the E-taxi. The first relates to an electric ground vehicle moving the aircraft around the airport where the latter relates to the aircraft taxiing on itself by making use of electric motors included within the aircraft.

The electric ground vehicle (E-tug) requires no changes to the aircraft but a change in ground operations and infrastructure. It does only impact the emissions during ground operations. The E-tug would be most suitable for narrow body regional aircraft operations, as the impact of ground operations is more noticeable due to the relative short cruise flight phase. It should however be noted that aircraft engines still require a warm-up time of a few minutes, which implies that even though the taxi can be electric, the engine warm-up still creates emissions. Only airports with larger taxi-distances, like Runway 18R - 36L at Schiphol (the so-called 'Polderbaan') would offer a significant impact (Air Transport Analytics, 2018) (Mototok, sd).

The E-taxi solution implies an electric powered landing gear (main or nose) to perform all ground movements. This would imply a design change and an increased weight, to account for the electric systems. The design change and weight penalty would make the technology most suitable for long range widebody aircraft. The effect on emissions and fuel burn will diminish, as wide body aircraft have a longer cruise flight phase as well as the weight penalty which needs to be accounted for. Likewise the aircraft still requires an engine ramp-up of 5 minutes before departure (Warwick, 2020).

Electric taxi-systems in itself can offer a relatively easy reduction in fuel burn and emissions during ground operations, where the overall impact on the aircraft emissions is low as the ground phase only accounts for a small portion of the flight.

Fixed ground power systems can replace the need for an auxiliary power unit (APU) within the aircraft. During ground operations the APU provides the power to aircraft systems, like environmental control within the cabin. The savings on emissions can be considerable, especially in hot or cold conditions on the ground. The savings are limited to APU and not general fuel consumption. The effect would thus only be noticeable on ground, when the APU is required. The solution can already be implemented, where the ground infrastructure needs to support and facilitate a fixed ground power system. The investment is thus on the airport side and not the aircraft. An aircraft saving can be achieved by removal or downscaling of the APU. The effect of removal was not considered (Sustainable Aviation, 2018).

Aircraft implementation

On the aircraft implementation level, the distinction was made into conservative and disruptive technologies. The distinction was made on experience related to impact of implementation. First the conservative technologies are introduced followed by the disruptive ones.

Conservative technologies

Conservative technologies include:
- geared turbofans;
- very high bypass ratio turbofan;
- composite structures.

The geared turbofan is the current solution to the fuel burn and emissions problem. Currently the next generation geared turbofans are under development, which can offer additional reductions in fuel burn, but only incremental changes. Often trends in fuel reduction for aircraft is related to the engine developments, referring to the next generation geared turbofan solutions. The solution of the geared turbofan is to change rotational speed according to the flight phase and thrust required. The gearbox allows the turbine and the fan to run on different rotational speeds, i.e. higher speeds for the turbine and lower speeds for the fan. This reduces the size and weight of the turbine and increases the fan efficiency, respectively. The optimization results in a fuel burn allocated to each flight phase compared to one-size-fits-all.

The very high bypass ratio turbofan is, similar to the geared turbofan, a solution by optimizing the aircraft engine to further reduce fuel consumptions. Nowadays more effort and research is put into the geared turbofan, as the increased size of the very high bypass ratio turbofan would require redesign of the engines on the aircraft, to ensure a fit underneath a wing. Potentially, more is to gain using this technology. By increasing the bypass ratio, the propulsive efficiency can further be increased, resulting in a lower fuel burn, whilst still offering a one-size-fits-all engine. A combination of the geared turbofan and a very high bypass ratio would potentially offer even more promising results (Clean Sky, 2021) (ICCAIA, 2019).

Alongside suggested engine changes, the increased usage of composite materials can be used to further reduce the aircraft weight. The reduction in aircraft weight will result in a lower fuel burn and emissions. A lower weight to be carried is rather effective to reduce fuel burn, but weight reductions are often compensated by carrying more payload. Effectively the same amounts of emissions are present, where it is more distributed over the payload (Tecolote Research, 2015).

The above presented solutions are the conservative and conventional ways to reduce fuel burn and emission on the aircraft implementation level. These changes do not result in large gains, but do follow the current aircraft innovation trend as seen by Airbus, Boeing and Embraer.

Disruptive technologies

Disruptive technologies include:
- windowless fuselage;
- morphing airframes;
- variable camber with new control surfaces;
- natural laminar flow wing;
- hybrid laminar flow wing;
- ultra-high aspect ratio wings;
- truss-braced or strut-braced wing;
- blended Wing Body;
- boundary Layer Ingestion engine;
- counter rotating open rotor;
- hybrid electric powertrain;
- full electric turbine propeller engine;
- hydrogen fuel cells for electric turbine propeller engine;
- hydrogen fuel cells for electric turbine jet engine;
- hydrogen fueled gas turbine jet engine.

The windowless fuselage is one of the few disruptive implementations that would actually be cheaper to implement, compared to a conventional fuselage. A fuselage construction without cabin windows, applicable to all ranges and aircraft configurations, would result in a simpler construction as the stress concentrations in the load bearing structure caused by the holes for the windows do not have to be taken into account. This reduces the weight of the structure. A windowless fuselage will also provide a smoother outer surface reducing the drag of the aircraft. The weight and drag reductions mean a decrease in fuel burn. The potential deployment depends mainly on passenger acceptance. For commercial flight this is considered the biggest hurdle. For cargo flights this should not be an issue (IATA, 2019).

A morphing airframe allows for the optimization of the aircraft for all flight phases. It reduces the need for compromise by adjusting during flight to match the flight phase, reducing the energy consumed. This is mainly applicable to aircraft wings by changing the sweep angle, for example. It requires an additional system that performs and controls the movement of the airframe. This will add weight and complexity to the aircraft and is considered a challenge for all aircraft designs (IATA, 2019).

Related to the morphing airframe, although less complex and less disruptive, is the variable camber wing. As for the morphing airframe a variable camber wing reduces the need for compromise by adjusting during flight to match the flight phase. In this case the wing airfoil section is adjusted to better match the flight phase. The system may incorporate control functions in the varying wing shape rather than separate control surfaces. The decrease in gaps between wing and control surfaces further reduces drag. The implementation of variable camber is currently done on small scale on business jets (IATA, 2019).

The closed layer of flow around a surface, i.e. the boundary layer, can be laminar, turbulent or separated. A laminar boundary layer creates less drag compared to a turbulent layer resulting in a lower thrust requirement, i.e. a lower fuel burn. However, a laminar boundary layer is prone to natural transition to turbulent or even separation of the flow. With the concepts of a natural laminar flow wing and a hybrid laminar flow wing the aircraft surface shape is designed to maximize the extent of the laminar flow in the boundary layer. For hybrid laminar flow design this is supported by suction systems to maintain the laminar flow even more. These technologies are mainly applicable to wing and tail surfaces. The natural laminar flow design is considered less disruptive than the hybrid laminar flow and is ongoing on a small scale (Air Transport Analytics, 2018) (IATA, 2019) (ICCAIA, 2019) (Clean Sky, 2021).

An ultra-high aspect ratio wing is a longer, narrow-chord wing that can deliver the same lift as a conventional wing at lower drag. These wings are most applicable to short and medium range narrow body aircraft, because the increase in span has implications for the structure and for the airport gate requirements. These wings are often seen together with truss-braced or strut-braced wings. These will support the wing and carry the loads. This allows the wing structure design to be tailored to the aerodynamic requirements. The weight and drag reduction potential leads to decreased fuel burn (Air Transport Analytics, 2018).

A Blended Wing Body (BWB) is an aircraft design where the wing and the fuselage are 'blended' together. A BWB provides a large area wing and no tail surfaces, resulting in an overall lower drag and lower mass for the same payload capacity. The volumetric efficiency is higher compared to a conventional aircraft and offers more internal storage capabilities. The BWB concept is disruptive on almost everything that is common in aircraft today and the deployment cost will be very high (Clean Sky, 2021).

The boundary layer ingestion (BLI) concept is related to re-energizing the boundary layer, which reduces the drag. This can be done with an engine located aft of the fuselage in a way that the air intake of the engine takes in the fuselage boundary layer and re-energizes this boundary layer. The result is a decrease in total aircraft drag and a lower thrust setting required by the engine. This is applicable to all aircraft, but most appropriate for long range wide-body aircraft as the effect is most significant during cruise. Implementation of BLI impacts structure aerodynamics, operations and maintenance among others (IATA, 2019)(Clean Sky, 2021).

A Counter Rotating Open Rotor (CROR) is an engine design in which the fan design is unshrouded and two blade rows are used, rotating in opposite directions. This provides improved efficiency compared to a conventional turbofan engine and a higher speed capability than a conventional turboprop. This results in a decrease in fuel consumption. Implementation has effects on noise emissions, which are expected to be higher. This may require a relocation of the engine to the aft of the fuselage, i.e. having an impact on the aircraft structure (Clean Sky, 2021).

A hybrid or all electric powertrain can be used to stop all aircraft emissions during operation. It most probably comes at an increased weight and added unknowns/complexity and a change in operations. A hybrid electric powertrain combines a conventional gas turbine engine with battery electric systems. Electric power is used when high thrust is required. The hybridization factor determines the level of emissions (ICCAIA, 2019).

A full electric powertrain uses electric motors which are powered by batteries. This requires a complete redesign of the propulsion system. There will be no emissions for a full electric powertrain.

Electric powertrains are appropriate for short and medium range aircraft due to the low specific energy and specific power of current batteries, resulting in significant weight challenges (Schäfer, et al., 2018).

Hydrogen is considered as a fuel because, of all available fuels, it has the highest energy content by weight. However, the density of hydrogen is very low, requiring significant volumes. Compared to kerosene, liquid hydrogen requires 4 times the volume for the same energy content. Hydrogen can be used in combination with a fuel cell or it can be combusted directly in a jet engine.

In case of a fuel cell the hydrogen is used to produce electric energy to drive electric motors or to provide additional thrust to gas turbine engines. Using hydrogen in a fuel cell produces no emissions. The fuel cell does produce a significant amount of heat that leads to significant cooling requirements. This requires a complete redesign of an aircraft and the propulsion system (McKinsey & Company, 2020).

In case of direct combustion, the hydrogen is burned by the jet engines. A new engine design and a new fuel system design are required. There will be no CO_2 emissions, but NO_x and contrails are still present. The emission of water vapor, i.e. leading to contrails, will be higher compared to kerosene powered aircraft (Mukhopadhaya & Rutherford, 2022).

4.8.3 Operational implementation

On the operational level, some quick gains can be attained by changing the usage of the aircraft. Although this might sound easy to implement, often operational changes require multiple parties to agree on new sets of interactions and agreements. Air traffic control, airports and the regulatory bodies need to agree before changes can be made. The aircraft and its technology is often less of influence on these choices. The operational implementations relevant are:

- optimum cruising altitude and speed;
- reduced take-off thrust;
- single engine taxi;
- SAF (HEFA-DSHC-AtJ-Biomass-CHJ);
- E-kerosene.

By selecting the optimum cruising altitude and speed, one can tweak the aircraft fuel burn to its nominal minimal value. The altitude and speed nowadays are selected according to operations and air traffic. The skies are organized into corridors and aircraft fly in sequence according to the predefined slots and positions. Some optimizations are feasible, as long as it is deemed feasible by air traffic control. The Single European Skies project, among others, do investigate the options to fly aircraft in dedicated paths, compared to the predefined paths. The dedicated paths could be optimized per aircraft and per flight to further reduce the fuel burn, but would require a complete rethinking of the current use of airspace and air traffic management (EUROCONTROL, 2021). 10% CO_2 could be saved, where the effort the past decades has not resulted in an operational change.

Similarly, the aircraft can take-off at a reduced thrust setting. Although this sounds promising and easy to implement, often airlines already instruct their pilots to use a reduced thrust setting during take-off, to reduce wear and tear of the engines. The effective fuel reduction is potentially already implemented (Koudis, et al., 2017).

Single engine taxi can similarly impact the emissions during ground operations, as for the system level solutions regarding E-taxi and E-tug (Sustainable Aviation, 2018).

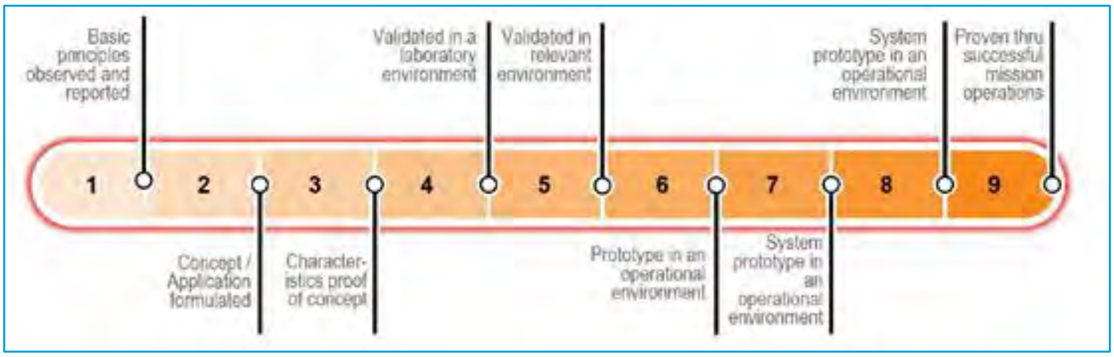
The most promising operational change, would be the shift of Jet A1 fuel to Sustainable aviation fuels (SAF) and E-kerosene. SAF is made from renewable biomass and waste resources and has the potential to deliver the performance of petroleum-based jet fuel but with a fraction of its carbon footprint. It would provide airlines a solid footing for decoupling greenhouse gas emissions from flight. Different chemical processes exist that can be used to produce SAF. Currently up to 50% SAF is allowed to be blended with Jet A1 fuel. The main drawbacks with SAF are limited production capacity and high costs. Operational limits exist on the usage and implementation of SAF, where the current generation of aircraft engines can only cope with 80% of SAF fuel mixes. Potential improvements in engine designs might allow a SAF mix up to 100% to be used, pending on the SAF under consideration (Sustainable Aviation, 2018).

To have zero greenhouse gas emissions one could shift to E-kerosene. E-kerosene is made by combining hydrogen and carbon dioxide. The hydrogen needs to be produced using renewable electricity and the carbon dioxide is captured from the atmosphere. E-kerosene is assumed to be used as is, without the need for a mix, thus allowing a full reduction of emissions, assuming that the E-kerosene is produced as a means of sustainable fuel source.

4.8.4 Technology innovation summary

The following table contains an overall summary of all technologies presented and analysed. The applicable aircraft type, Technology Readiness Level (TRL) and potential benefit is stated alongside with the estimated investment costs. The TRL are used to assess the maturity of a technology. The TRL go from levels 1 to 9, like depicted in Figure 61. Generally speaking, levels 1 to 3 are the discovery phases, levels 4 to 6 are regarding development, levels 7 and 8 are regarding demonstration and TRL 9 is regarding deployment of the product.

Figure 61 - Overview of Technology Readiness Levels



Source: (Aecom, 2020).

Table 39 presents the estimated investment cost for the various technologies presented in this section. The investment costs are the estimated costs to develop the technology from its current TRL to TRL8. The deployment costs are the costs which aircraft manufacturers would need to make to integrate the technology in new aircrafts and prove them successful in mission operations, i.e. TRL 9. Note that the costs cannot be added over various technologies, as a combination of technologies will multiply the risk and the cost with a higher factor. Lastly, the cost estimates presented are regarding the aircraft airframes, excluding the costs for engine development and deployment. They also do not include the aircraft acquisition, only development of technologies. The information as presented in the table is what is required or what is expected to be required in the future, not what is available or feasible. It is no indication of a strategy or plan where the aviation sector is heading, only the current status of the various technologies. Government funding and European research projects might have an effect on the costs and the speed at which TRL can increase.

Table 39 - Summary technology innovations and estimated effects

Technology	Applicable aircraft	TRL	Reduction energy consumed	Investment costs [million USD (Price level 2021)]	Deployment cost [million USD (Price level 2021)]
Riblets	All types	6	1-2%	$ 25	-
Electric taxi - E-tug	Narrowbody	9	3-5%	$ 70	-
Electric taxi - E-taxi	Widebody	7	1%	$ 20	$ 10-30
Fixed ground power	All types	9	40-75% of APU	-	$ 10-30
Geared turbofan	All types	7-9	5%	$ 1,000	-
Very high bypass ratio turbofan	Widebody	7	20%	$ 335	-
Composite structures	All types	9	7-11%	$ 150	Depends on implementation
Windowless fuselage	All types	7	5-7%	-	-
Morphing airframes	All types	3	5-10%	$ 130	-
Variable camber with new control surfaces	All types	4-5	5-10%	$ 125	-
Natural laminar flow wing	All types	4-5	5-10%	$ 130	-

Technology	Applicable aircraft	TRL	Reduction energy consumed	Investment costs [million USD (Price level 2021)]	Deployment cost [million USD (Price level 2021)]
Hybrid laminar flow wing	All types	6-9	10-15%	$ 210	-
Ultra-high aspect ratio wings	Narrowbody	4	10-15%	$ 190	-
Truss-braced or Struct-braced wing	Narrowbody	4	10-15%	$ 210	-
Blended Wing Body	Widebody	6	30%	$ 500	$ > 30 bn
Boundary Layer Ingestion engine	Widebody	3-4	8.5%	$ 140	$ 25 bn
Counter rotating open rotor	Narrowbody	7	14%	$ 235	-
Hybrid electric powertrain	Narrowbody	3	Pending on hybridization	$ 670	$ 100 - 1 bn
Full electric turbine propeller engine	Narrowbody	5-6	50%	$ 600-1,000	$ 100 - 1 bn
Hydrogen fuel cells for electric turbine propeller engine	Narrowbody	3	8-10%	$ 340	$ 100 - 1 bn
Hydrogen fuel cells for electric turbine jet engine	All types	3	4%	$ 340	$ 100 - 1 bn
Hydrogen fueled gas turbine jet engine	All types	3	5-25%	$ 1,500	$ > 1 bn
Optimum cruise altitude and speed	All types	-	9-11%	-	-
Reduced take-off thrust	All types	-	23% during take-off	-	-
Single engine taxi	All types	-	20-40% during taxi	-	-
Sustainable Aviation Fuels	All types	6-8	80 %	-	-
E-kerosene	All types	6-8	80 %	-	-

The technologies presented are based on the broader world view and technology innovations, they are not related to solely the Netherlands. Regarding the impact of different Dutch CO_2 ceiling options on innovation it is expected that certain technological solutions are not influenced or not significantly influenced by the different policies. The solutions which have a high TRL with relatively low investment cost, may already be ongoing or are expected to be included in future development programs. It is expected that these technologies will be implemented anyway to reduce the operating cost of the airline by reducing energy consumption, independent of the Dutch policies or type of fuel used and its emissions. The technologies would include Riblets, composite structures, geared turbofans, very high bypass ratio turbofans, electric taxi with E-tugs, reduced take-off thrust, single engines taxi and fixed ground power.
The CO_2 ceiling options will imply higher costs for CO_2. Buying new aircraft and implementing new technologies will be driven by the need to reduce associated costs of emitting CO_2 by airline operators. If the increase in cost due to the CO_2 ceiling is more than the cost saving

by the uninfluenced technologies discussed above, the impact might be a shift by airlines to more disruptive or novel technology implementations, for a bigger reduction of fuel use and CO_2 emissions, hence operating cost.

4.8.5 Conclusions

The airport, the fuel supplier and airline option are equally affected by technological innovations. All options can introduce a local effect, where certain airlines can affirm their position by implementing novel technologies to reduce costs and potentially increase allowed flights (as less CO_2 is emitted). Currently Low-Cost-Carriers (LCC) already use novel aircraft to minimize fuel costs, in comparison to legacy carriers which use the fleet available to reduce operating costs. The policy on emissions can be a second drive to continue on that path.

As mentioned, the CO_2 ceiling options will imply higher costs for CO_2. From an airline perspective higher costs for CO_2 has the same implication as an increase in fuel cost due to the direct relation between fuel use and CO_2. The drive for operators to reduce costs by implementing novel technologies within their fleet will be to reduce fuel consumption in general, with the additional benefit of reducing costs relating to CO_2 emissions.
The incentive for airlines to implement novel technologies or renew their fleet, is pending on the associated costs. If the cost do not outweigh the benefit, a government incentive as the CO_2 ceiling can enforce this change.

The conservative technologies, within aircraft and system implementation, and the operational implementation are expected to be feasible. The costs are considered low, compared to the benefit on fuel consumption, which is a goal in itself for airlines. The Dutch CO_2 ceiling policies will affect the airlines travelling through the Netherlands, providing the additional incentive. A potential European ruling will also affect other airlines, creating a larger impact.

The disruptive technologies require the aircraft manufacturers to invest in new technologies, potentially funded by the government or by the European Commission. Probably these new aircraft will have a higher acquisition cost, pending on funding. Next to the higher acquisition cost, the airport infrastructure needs to accommodate for these technologies. If the market (airlines) are willing to pay for these investments and the airports adapt their infrastructure, the manufacturer will invest as they desire a return on investment. The Dutch CO_2 ceiling might not create enough leverage to make these disruptive technologies appealing to the manufacturers and airlines. Again, potential European ruling will also affect other airlines, creating a larger impact.

One should consider that current choices on innovation and technology shape the emissions on the long term. An aircraft life span is 30 years, implying that current aircraft will phase out service in 2060-2070. All incentives to further reduce fuel consumption and emissions are a step in the right direction.

5 Environmental impacts

5.1 Introduction

This chapter presents the environmental impacts of the CO_2 ceiling for Dutch aviation. It starts with an assessment of the impacts on aviation CO_2 emissions in Section 5.2. Like other sections, this section first presents the methodology followed by the impacts of the CO_2 ceiling in the reference scenario in detail (the reference scenario is defined in Section 2.2 and Annex B). The final subsection discusses how the impacts in the extreme scenario differs from the impacts in the reference scenario.

Section 5.3 analyses the impacts on land transport CO_2 emissions, Section 5.4 on ETS and CORSIA, and Section 5.5 presents the overall impacts on global CO_2 emissions. Section 5.6 presents the non-CO_2 climate impacts of aviation. The final two sections focus on local impacts: Landing and Take-Off (LTO) emissions in Section 5.7 and airport noise in Section 5.8.

5.2 Impacts on aviation CO_2 emissions

5.2.1 Introduction

In our analysis of the greenhouse gas (GHG) emissions we consider the 'well-to-tank' (WTT) emissions and 'tank-to-wing' (TTW) emissions separately[60]. The reason for presenting these emissions separately is that both the TTW and the WTT emissions determine the climate impact, whereas only the TTW emissions are considered for the CO_2 ceiling. In line with the EU ETS accounting principles, it is assumed that SAF has zero TTW emissions, whereas the WTT emissions from the fuel production vary for the different types of aviation fuel, both fossil and SAF types.

Table 40 shows the greenhouse gas emissions in the reference baseline scenario.

Table 40 - Baseline TTW and WTT CO_2 emissions for flights departing from Dutch airports (million tonnes)

Year	TTW CO_2 emissions	WTT CO_2 emissions
2017	12.0	2.5
2030	11.9	2.7
2040	8.7	2.6
2050	4.2	2.3

5.2.2 Methodology

The aviation TTW CO_2 emissions are output of the AOLUS model. We compare the CO_2 emissions of flights from all Dutch airports in the reference baseline with the different options.

60 'Well-to-tank' emissions are emissions associated to the production of the fuel. 'Tank-to-wing' emissions are the emissions associated with the combustion of the fuel in the airplane in stationary situations and at LTO and on-route.

To calculate the WTT emissions we use the emission factors as displayed in Table 41. For the WTT GHG emissions of kerosene we used the EU average value of 0.65 g CO_2-equivalent/g fuel (EXERGIA S.A. et al., 2015). For the different types of non-synthetic SAF we used values from (ICAO, 2021), for RFNBO we used a conservative estimate of 85% reduction compared to the 'well-to-wing' (WTW[61]) factor of fossil kerosene (EC, 2021e).

The values in the literature were given in grCO_2-eq./MJ, we multiplied these values by the fuel's energy content to get to the emission factors in kgCO_2-eq./kg. Note that we use CO_2 emissions for the TTW calculation, whereas CO_2-*equivalent* emissions are used for the WTT calculation[62]. Non-CO_2 climate effects of aviation, such as contrails are not included in these emissions factors (these are discussed separately in Section 5.6).

Table 41 - Aviation fuel emission factors used

Fuel	WTT (kgCO_2-eq./kg)	TTW (kgCO_2/kg)
Kerosene	0.65	3.15
HEFA	0.51	0
Gas + FT	0.35	0
ATJ	0.96	0
RFNBO	0.61	0

The report distinguishes the impacts on CO_2 emissions from flights departing from Dutch airports and emissions from flights departing from foreign airports. The CO_2 ceiling results in a change in the latter emissions if OD passengers fly to and from foreign airports instead of to and from Dutch airports (evasion), and when transfer passengers make a connection at a foreign hub airport instead of at Schiphol. This section about CO_2 evasion is based on the new AEOLUS runs. Therefore results of CO_2 emissions from flights departing at Dutch airports could be slightly different than in the old runs.

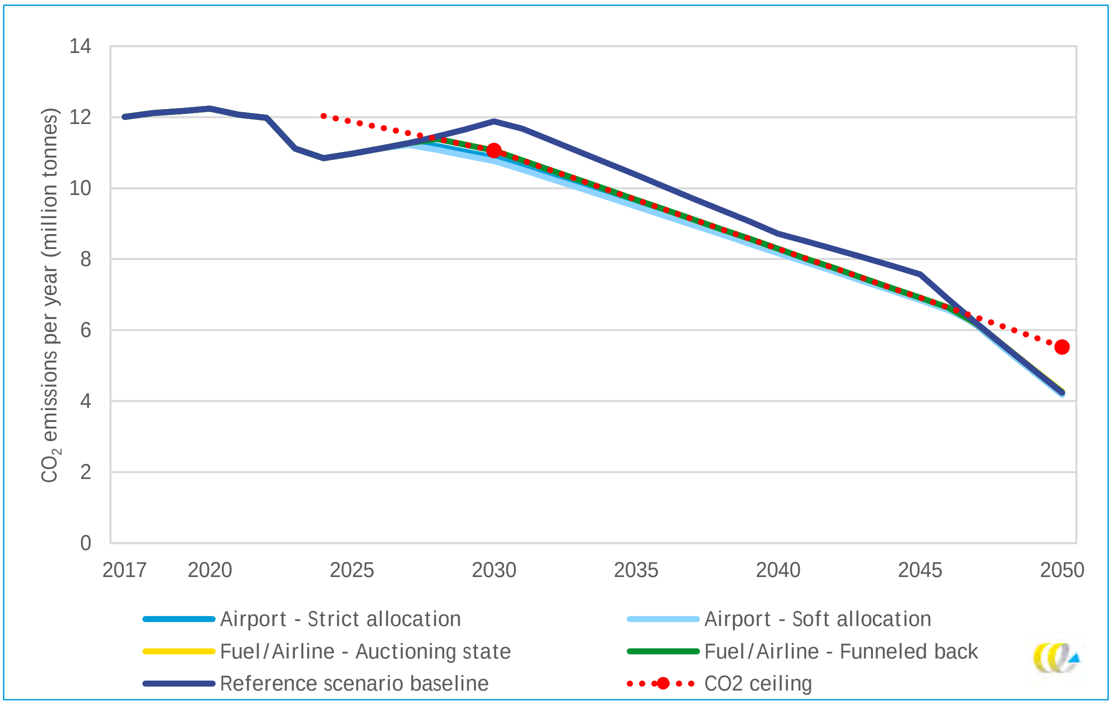
5.2.3 Results

Figure 62 displays the development of the TTW CO_2 emissions of flights departing from Dutch airports. The red dotted line represents the upper limit of the proposed CO_2 ceiling, while the red markers represent the CO_2 reduction targets from the 'Duurzame luchtvaarttafel'.

61 The 'well-to-wing' emissions are the sum of the 'tank-to-wing' emissions and the 'well-to-tank' emissions.

62 The choice to calculate only the CO_2 emissions for the TTW part was made because this aligns with the definition of the CO_2 ceiling. Since the contribution of CH_4 and N_2O emissions from fuel combustion in aviation to the CO_2-eq. emissions is very low, the calculated emissions can be interpreted as CO_2-eq. emissions as well. For the WTT emissions of the different fuels, CH_4 and N_2O can be relevant contributions to the CO_2-eq. emissions. For this reason, the CO_2-eq. emissions were used for the WTT calculations.

Figure 62 - Development of the TTW **CO_2** emissions of flights departing from Dutch airports



We can see that in the reference baseline scenario the CO_2 ceiling is restrictive in the period of 2028 until 2046. By summing over the difference between the reference scenario and the options in this period, we find that the CO_2 ceiling saves respectively 13.1 and 14.7 million tonnes of cumulative TTW CO_2 emissions for the Airport - Strict allocation and Airport - Soft allocation options. For the fuel supplier and airline options 11.0 million tonnes TTW CO_2 emissions is saved.

In the airport options, the emissions occasionally remain below the CO_2 ceiling, for example in the period 2028-2033. This is a result of the fact that, in this option, the CO_2 ceiling is determined for each individual airport. At Schiphol and Lelystad airport the ceiling is reached from 2027, whereas the ceiling is not reached yet at the other airports. Therefore, not all available CO_2 budget is used on a national level. In the fuel supplier and airline options, the CO_2 ceiling is determined on a national level so in these options the full available CO_2 budget is used.

5.2.4 Evasion

This section about CO_2 evasion is based on the new AEOLUS runs (model update August 2022). The upcoming addendum to this report regarding lower airport capacity for Schiphol will also be based on the new actualised version of AEOLUS. Due to this difference in AEOLUS version, results of CO_2 emissions from flights departing at Dutch airports could be slightly different than presented in the remaining part of this report, which is based on the previous AEOLUS version.

Emissions at foreign airports are also affected by the Dutch CO_2 ceiling because of evasion due to travellers changing routes. We distinguish two types of evasion here:
1. Passengers who in baseline would make a flight with origin or destination at a Dutch airport, but now shift to an airport in a surrounding country.

2. Passengers who in baseline would make a transfer stop at a Dutch airport, but now transfer at a foreign airport or fly direct.

We investigate here the combined effect of these two types of evasion. We do this by comparing the reduction of CO_2 emissions from flights departing at Dutch airports to the change in the CO_2 emissions from flights departing in the rest of the world. For a full explanation of all the separate evasion effects on transfer and OD passengers we refer to Subsection 3.2.4.

The AEOLUS outcomes for the CO_2 emissions of flights departing at a Dutch airport, flights departing at airports in the rest of the world and the net effect are displayed in Table 42. Effects on TTW and WTT emissions are displayed separately.

The net aviation TTW and WTT CO_2 savings are for all options in a similar range, with 0.33 to 0.45 million tonnes saved in 2030. The impact of evasion is relatively low in the suboptions where the auctioning income is for the state. About 33% of the decrease in CO_2 from flights on Dutch airports is emitted by flights on foreign airports in 2030. Therefore, the net CO_2 reduction in these suboptions is relatively high.

For 2040 the effects are significantly smaller, this is because the CO_2 ceiling is only slightly restrictive here in the new AEOLUS runs. In 2050 the CO_2 ceiling is not restrictive anymore: the slight remaining CO_2 effects visible are remnants of the restrictive period.

Table 42 - Change in aviation TTW and WTT CO_2 emissions for the different CO_2 ceiling options compared to reference scenario (million tonnes)

CO_2 ceiling option	Year	Aviation TTW **CO_2** emissions			Aviation WTT **CO_2** emissions		
		Flights departing from Dutch airports	Flights departing from non-Dutch airports	Net effect	Flights departing from Dutch airports	Flights departing from non-Dutch airports	Net effect
Airport - Strict allocation (3-year cycle)	2030	-0.85 (-1.16 to -0.85)	0.48	-0.37 (-0.68 to -0.37)	-0.19 (-0.26 to -0.19)	0.12	-0.08 (-0.15 to -0.08)
	2040	-0.18 (-0.58 to -0.18)	0.19	0.02 (-0.39 to 0.02)	-0.05 (-0.17 to -0.05)	0.06	0 (-0.12 to 0)
	2050	-0.02 (-0.35 to 0.02)	0.11	0.08 (-0.25 to 0.13)	-0.01 (-0.19 to 0.01)	0.03	0.02 (-0.16 to 0.04)
Airport - Strict allocation (1-year cycle)	2030	-0.85 (-1.2 to -0.85)	0.48	-0.37 (-0.68 to -0.37)	-0.19 (-0.27 to -0.19)	0.12	-0.08 (-0.15 to -0.08)
	2040	-0.18 (-0.62 to -0.18)	0.19	0.02 (-0.39 to 0.02)	-0.05 (-0.18 to -0.05)	0.06	0 (-0.12 to 0)
	2050	-0.02 (-0.32 to 0.02)	0.11	0.08 (-0.25 to 0.13)	-0.01 (-0.17 to 0.01)	0.03	0.02 (-0.16 to 0.04)
Airport - Soft allocation (3-year cycle)	2030	-0.95 (-1.26 to -0.95)	0.54	-0.41 (-0.72 to -0.41)	-0.22 (-0.29 to -0.22)	0.13	-0.08 (-0.15 to -0.08)
	2040	-0.24 (-0.64 to -0.24)	0.25	0.01 (-0.39 to 0.01)	-0.07 (-0.19 to -0.07)	0.07	0 (-0.12 to 0)
	2050	-0.02 (-0.35 to 0.03)	0.11	0.09 (-0.24 to 0.14)	-0.01 (-0.19 to 0.01)	0.03	0.02 (-0.16 to 0.04)
Fuel - Auctioning state	2030	-0.68	0.23	-0.45	-0.16	0.06	-0.09
	2040	-0.22	0.24	0.02	-0.07	0.07	0.00
	2050	-0.06	0.07	0.02	-0.03	0.03	0.00
Fuel - Auctioning funnelled back	2030	-0.70	0.37	-0.33	-0.16	0.09	-0.07
	2040	-0.22	0.25	0.03	-0.06	0.07	0.01
	2050	-0.05	0.08	0.03	-0.03	0.03	0.01
Fuel - No stability	2030	-0.68 (-0.71 to -0.65)	0.23	-0.45 (-0.49 to -0.42)	-0.16 (-0.16 to -0.15)	0.06	-0.09 (-0.1 to -0.09)
	2040	-0.22 (-0.24 to -0.2)	0.24	0.02 (0 to 0.04)	-0.07 (-0.07 to -0.06)	0.07	0 (0 to 0.01)

CO_2 ceiling option	Year	Aviation TTW CO_2 emissions			Aviation WTT CO_2 emissions		
	2050	-0.06 (-0.21 to -0.03)	0.07	0.02 (-0.13 to 0.05)	-0.03 (-0.11 to -0.01)	0.03	0 (-0.08 to 0.02)
Airline - Auctioning State	2030	-0.68	0.23	-0.45	-0.16	0.06	-0.09
	2040	-0.22	0.24	0.02	-0.07	0.07	0.00
	2050	-0.06	0.07	0.02	-0.03	0.03	0.00
Airline - Funnelled back	2030	-0.70	0.37	-0.33	-0.16	0.09	-0.07
	2040	-0.22	0.25	0.03	-0.06	0.07	0.01
	2050	-0.05	0.08	0.03	-0.03	0.03	0.01

5.2.5 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, there are no impacts on aviation CO_2 emissions. In the scenario with the highest projected baseline emissions (baseline Scenario 6 'extreme scenario' - see Figure 18) the CO_2 ceiling is significantly more restrictive. The Dutch cumulative CO_2 savings are about six times as high as in the reference scenario. The net effect on CO_2 emissions for OD flights are also higher, with 38% in the airport options and 35 to 50% in the fuel supplier and airline options. Resulting in a significant increase of net CO_2 savings in the extreme scenario, with reductions up to 2.5 million tonnes CO_2 in the fuel supplier and airline policy options.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between those in the two outlined scenarios (also shown in Annex H).

5.3 Impacts on land transport CO_2 emissions

5.3.1 Introduction

In this section we discuss the impacts of land transport CO_2 emissions in the context of flying. The factors impacting land transport emissions are determined by choices of the transport mode for before and after transport to and from Dutch airports, evasion to other airports, and passengers choosing another transport modes for the entire trip. Moreover, passengers may also choose not to fly anymore due to the restrictions and (price) effects of the CO_2 ceiling.

The CO_2 ceiling can have an impact on land transport CO_2 emissions in several ways:

a Passengers choosing for different use of the car and train in the before-/after transport.
b Passengers choosing for travel from foreign airports.
c Passengers choosing to not fly anymore at all.
d Passengers choosing to the use of the car and train as an alternative for flying.

The expected effects are:

a Possibly fewer car- and train kilometres in the before/after transport to Dutch airports.
b This leads on the one hand to less kilometres for the before/after transport to Dutch airports and on the other hand to more kilometres for the before/after transport to foreign airports.
c This leads to fewer net emissions from both not flying and not using before/after transport.
d This leads on the one hand to fewer car- and train kilometres in the before/after transport to Dutch airports. On the other hand this leads to more kilometres by people travelling with the car or train to foreign destinations.

5.3.2 Methodology

The AEOLUS model output is used to calculate the car and train WTW CO_2 emissions[63]. For this section the new actualised version of AEOLUS (August 2022) is used. For the change in the head mode of transport (people using the car or train instead of flying) we used the

[63] Note that these emission factors exclude other greenhouse gases. Since these are a relatively small percentage of the CO_2-equivalent emissions, these can in practice be interpreted as CO_2-eq. emissions as well.

change in number of travellers over land from AEOLUS. We multiplied this by the modal split car/train, the average trip length and the WTW emissions factors. The emission factors are constructed based on the assumptions in the studies (Planbureau voor de Leefomgeving, 2021b; Ministerie van Infrastructuur en Waterstaat, 2021). The resulting values used are summarized in Table 43. The modal split as well as the average trip length are AEOLUS output.

Table 43 - Assumptions for head mode land transport **CO_2** emission calculation

Variable	Unit	Year	Car	Train
WTW emission factor	g CO_2/ passenger km	2030	117	8
		2040	66	1
		2050	35	1
Modal split	Car/train	2030	85%	15%
		2040	84%	16%
		2050	84%	16%
Average trip length	km	2030	855	748
		2040	844	745
		2050	830	741

The change in land transport to and from the airport is AEOLUS output. We multiplied these by the WTW emissions factors.

5.3.3 Results

The resulting impacts on CO_2 emissions by land transport are displayed in Table 44. It can be seen that the impacts from rail transport are negligible. This is because the (electric) passenger trains have a relative low impact in emissions compared to cars, and increasingly low well-to-tank CO_2 emissions are assumed from 2030 due to the increasing share of electric vehicles in the fleet and the expected increase in use of renewable energy in the electricity production.

For cars, the impact is by far the largest in 2030. For the Airport options there is an increase in land transport emissions. These suboptions have the largest decrease in passengers at Dutch airports, many of those passengers will ravel to their destination by land transport. For the Fuel supplier and Airline options we see the opposite: there is a decrease in land transport emissions. This is due to the shift of long to short flights in these options. Short flights become more attractive, such that there actually is an increase in passengers on short flights compared to baseline. These passengers would have used the car or train to get to their destination without the CO_2 ceiling. In 2040 and 2050, the impact is lower for two reasons. First of all, less evasion to land modes is estimated in these years. Furthermore, the emission factors decrease quickly due to electrification and increased efficiency.

Table 44 - Changes in WTW **CO_2** emissions by land transport (million tonnes per year)

CO_2 ceiling option	Year	Car	Train	Total
Airport - Strict allocation (3-year cycle)	2030	0.016	0.000	0.017
	2040	0.013	0.000	0.013
	2050	0.016	0.000	0.016
Airport - Strict allocation (1-year cycle)	2030	0.016	0.000	0.017
	2040	0.013	0.000	0.013

CO_2 ceiling option	Year	Car	Train	Total
	2050	0.016	0.000	0.016
Airport - Soft allocation (3-year cycle)	2030	0.018	0.000	0.018
	2040	-0.001	0.000	-0.001
	2050	0.007	0.000	0.007
Fuel supplier - Auctioning state	2030	-0.028	0.000	-0.028
	2040	-0.007	0.000	-0.007
	2050	0.001	0.000	0.001
Fuel supplier - Auctioning funnelled back	2030	-0.049	0.000	-0.050
	2040	-0.008	0.000	-0.008
	2050	-0.001	0.000	-0.001
Fuel supplier - No stability	2030	-0.028	0.000	-0.028
	2040	-0.007	0.000	-0.007
	2050	0.001	0.000	0.001
Airline - Auctioning State	2030	-0.028	0.000	-0.028
	2040	-0.007	0.000	-0.007
	2050	0.001	0.000	0.001
Airline - Funnelled back	2030	-0.049	0.000	-0.050
	2040	-0.008	0.000	-0.008
	2050	-0.001	0.000	-0.001

5.3.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on land transport CO_2 emissions. In the scenario with the highest projected baseline emissions (Scenario 6 from Figure 18) the land transport emission are 36% higher in the airport options and 80 to 93% higher in the fuel supplier and airline options compared to the impacts in the reference scenario (Table 44). In 2040 land transport emissions increase due to more land transport, in 2050 however the emissions decrease due to a high share of electric vehicles.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in Annex H

5.4 Impacts on EU ETS and CORSIA

5.4.1 Introduction

In theory, the introduction of a Dutch CO_2 ceiling for aviation could influence the effectiveness of the EU ETS and CORSIA through price effects. In this section, we investigate whether such a mechanism is likely, and if so, what the effect size might be for the different options of the CO_2 ceiling. We also pay attention to the question to what extent the introduction of the CO_2 ceiling can lead to emission reductions within CORSIA and the EU ETS.

5.4.2 Methodology

EU ETS

If the collective emissions of intra-EEA flights from the Netherlands decrease due to the introduction of the CO_2 ceiling, this will lead to a decrease in the demand for emission allowances. This decrease in demand can then translate into a price decrease, which means that other participants in the EU ETS have a lower incentive to reduce emissions. A sudden fall in prices (as a result of the introduction of the ceiling) can also lead to more uncertainty about price developments. Such unpredictability complicates investment decisions and could in theory undermine the effectiveness and support for the EU ETS.

In this section we estimate the decrease in ETS prices based on the additional intra-European CO_2 reductions in each option. To do so, we compare the first-order emissions reduction that results from the CO_2 ceiling to the cumulative yearly emissions from EU ETS participants. Given that relative changes in demand for allowances are expected to be small, we can assume the relationship between the ETS price and total emissions is roughly linear (historically, the relation has not been strictly linear, but at the margin, this assumptions seems to be a valid approximation). Awaiting the aforementioned AEOLUS update, we estimate the effect on EU ETS prices based on mutations in CO_2 emissions of flights that depart from the catchment area including NL (this should yield a reasonable order-of-magnitude approximation to the intra-European emissions mutations).

Since the yearly allocation number of allowances within the EU ETS is - to a first degree - fixed, one would not expect the Dutch CO_2 ceiling to enable emissions reductions within the EU. After all, the allowances that are no longer being used by airlines departing from the Netherlands, can now be used by other participants (both airlines and stationary installations). This mechanism has been called the 'waterbed effect'. However, the presence of the market stability reserve (MSR) complicates the situation. Since the introduction of the MSR, allowances can be included in a special reserve if the total number of allowances exceeds a set limit.

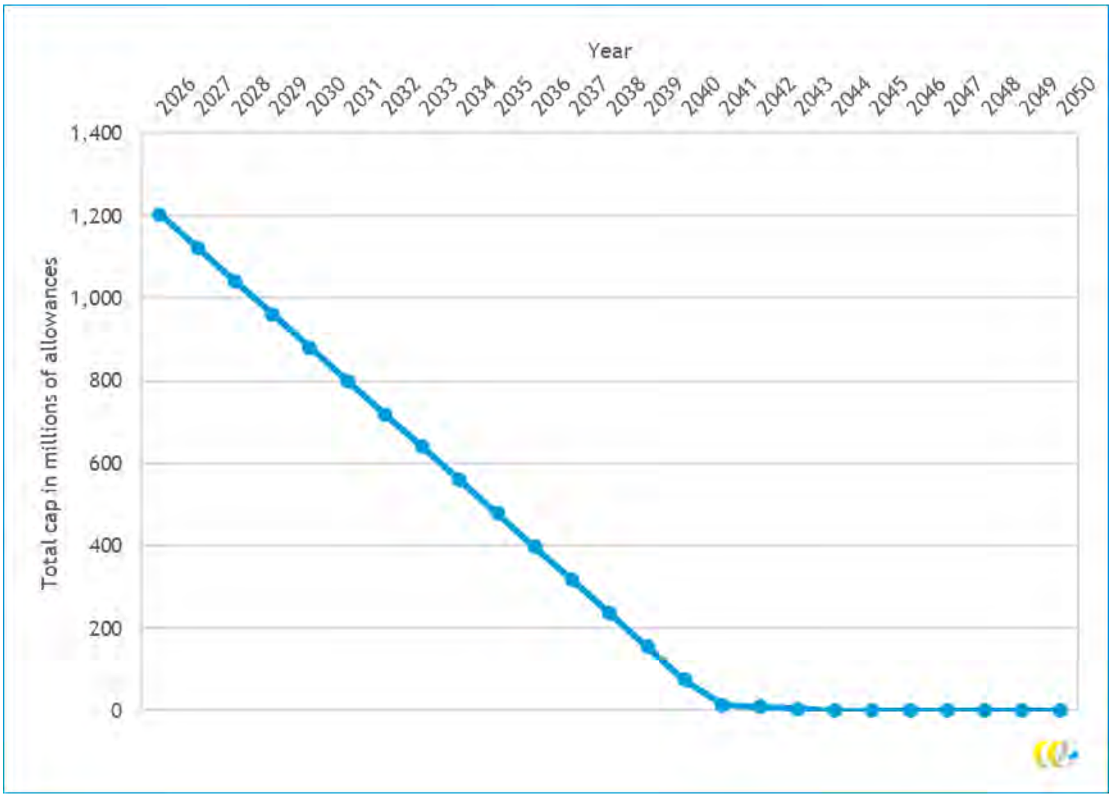
More specifically, under Fit for 55 proposals, 24% of the Total Number of Allowances in Circulation (TNAC) - including Aviation Emission Allowances - will be placed in the MSR when the TNAC exceeds 833 million allowances. Allowances are placed into the MSR by decreasing the auction volume in the next year. This mechanism is to be maintained until 2030. Under Fit for 55, the Commission also proposes to cap the number of allowances in the MSR at 400 million (ERCST, 2021). When more than these 400 million allowances flow into the MSR, the surplus is destroyed. In this way, the MSR can de facto influence the cap.

If the Dutch CO_2 ceiling reduces demand during a period in which the total number of allowances in circulation is large, the saved allowances can hence be included in the MSR and subsequently destroyed. Emissions that were originally allowed under the cap are no longer allowed after cancellation. In this way, the CO_2 ceiling can provide additional reduction, despite the fact that the EU ETS's linear reduction factor is fixed. In practice, allowances can also flow out of the MSR again if the number of allowances in circulation falls below a set limit: 100 million allowances are to be released from the MSR if the total number of allowances (TNAC) is below 400 million Emission Allowances. In a given year, the MSR therefore leads either to an additional reduction in emissions or to more permitted emissions.

Based on a recent review of the MSR by ERCST (ERCST, 2021), we predict that the TNAC will still exceed the set limit in 2030 under implementation of Fit for 55. Moreover, since the TNAC is also likely to exceed the threshold in the years up to 2030, the number of allowanced banked at the start of 2030 can be assumed to be equal to 400 million. This means that every additional allowance that flows into the MSR will subsequently be destroyed. Note that not all allowances that are unused as a result of the Dutch CO_2 ceiling will flow into the MSR: in a given year only 24% of the overshoot is admitted into the MSR. However, when allowances are not admitted to the MSR, they contribute to the TNAC in the following year. If the TNAC exceeds the threshold in the following year too, 24% of the 76% of the remaining rights will be cancelled. This process continues as long as the TNAC exceeds the threshold. When we assume that the TNAC exceeds the threshold up to 2032 (based on ERCST, (2021)), we find that roughly 56% of the intra-European emissions reduction caused by the Dutch CO_2 ceiling does not leak as a result of the waterbed effect (see for the calculation method Perino, (2018)).

Since the cap of the EU ETS approaches zero in 2040 and becomes zero in 2050 (see Figure 63), we do not expect the TNAC to exceed the threshold anymore in 2040. After all, allowances will become scarce when cheap abatement measures have already been implemented. We hence assume that intra-European emissions reduction will leak to other ETS participants in 2040 (by the waterbed effect). By 2050 the EU ETS cap has reached zero. As a result, the CO_2 ceiling can no longer meaningfully influence the effectivity of the system. Potential banked allowances will be scarce and very much sought after - if airlines that reduce their CO_2 emissions due to the CO_2 ceiling have some remaining banked allowances, they will sell these to other ETS participants.

Figure 63 - Total emissions cap (all sectors) in the EU ETS under Fit for 55



CORSIA

CORSIA is an offsetting mechanism and not an emissions trading system. The waterbed effect sketched above does hence not apply to CORSIA. Nevertheless, lower demand for offsets could theoretically decrease the offset price. In practice, this effect will not be noticeable because the supply of offsets is much larger than the anticipated demand over the lifetime of CORSIA (NewClimate Institute et al., 2020). Hence, the supply of offsets does not fall to zero (as does the ETS cap).

5.4.3 Results

EU ETS waterbed effect

Table 45 summarizes the extent to which potential emissions reductions in the different ceiling options result in net reduction or will leak away due to the EU ETS waterbed effect.

Table 45 - Size of the EU ETS waterbed effect in 2030, 2040 and 2050

Year	Percentage of emissions reduction that leaks away due to the waterbed effect
2030	44%
2040	100%
2050	No allowances allocated, 100% of banked allowanced

In Paragraph 5.5.3 we show how large the absolute effect is of the EU ETS waterbed effect.

EU ETS price effects

The mutations to CO_2 emissions from flights departing from the catchment area (including the Netherlands) was shown previously in Table 42. Differences with baseline emissions are quite modest. The largest emission reductions found between all ceiling options is 0.26 million tonnes CO_2 for 2030, 0.16 million tonnes in 2040 and 0.02 Million tonnes in 2050.

As Figure 54 showed, there will still be almost 900 million emissions allowances issued within the EU ETS in 2030. At the assumed ETS price in 2030 of € 85.00 per tonne CO_2 and assuming a linear relation between the ETS price and demand for allowances, we find a decrease in ETS prices of less than € 0.03/tonne CO_2 - a negligible amount. By 2040 only 75 million allowances are allocated to the market. Furthermore, we assume the ETS price has risen to € 200.00 at that point. We therefore find a slightly larger price reduction of € 0.42/tonne CO_2. By 2050 the EU ETS cap has reached zero. As a result, the CO_2 ceiling can no longer meaningfully influence ETS prices.

Table 46 - Potential ETS price reductions resulting from emission abatement in the catchment area (including NL)

Year	Maximum ETS price reduction due to emission abatement in the catchment area (including NL)
2030	€ 0.03 (from € 85.00 to € 84.97)
2040	€ 0.42 (from € 200 to € 199.58)
2050	No allowances allocated

CORSIA price effects

Because the supply of offsets does not fall to zero (as does the ETS cap), and because CORSIA prices are lower than ETS prices, and because the impact on ETS prices was already established to be very limited, we can conclude price impacts to be negligible.

5.4.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on the EU ETS and CORSIA. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 18) the impacts on the EU ETS price are estimated to be roughly three times larger. In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in Annex H

5.5 Total impact on global CO_2 emissions

5.5.1 Introduction

In this section we combine the CO_2 effects found in the previous paragraphs to determine the total impact on global CO_2 emissions.

5.5.2 Methodology

We combine the TTW and WTT aviation CO_2 emissions for the Netherlands and the evasion to non-Dutch airports (from Section 5.2) to approximate the total effect on aviation WTW CO_2 emissions. We include the effects from land transport CO_2 emissions (from Section 5.3) and the effects on CO_2 emissions in other EU ETS sectors (from Section 5.4), to get to the total combined effect from the CO_2 ceiling on global CO_2 emissions. Note this section is therefore using data from the new actualised version of AEOLUS.

Apart from the modelling results so far presented, we estimate the impact of possible behavioural responses which have not been modelled. These are:
- Voluntary emission reductions in the airport option. It is possible that airlines will take voluntary action to reduce emissions under the CO_2 ceiling when they are faced with a threat that the airport capacity will be limited. This has been discussed in Section 2.6. Such action could comprise reduced outbound tankering, increased inbound tankering, increased use of sustainable aviation fuels, etc. This will result in more airport capacity and reduced evasion by passengers.
- Reduced outbound tankering and increased inbound tankering. According to (Peeters, et al., 2021), 1-5% excess fuel is sold at Dutch airports on intra-EEA flights (see Text box 1). In cases Dutch aviation CO_2 emissions are projected to increase above the ceiling, or in case fuel sold at Dutch airports becomes more expensive in the fuel supplier option, it becomes more attractive to reduce outbound tankering or to increase inbound tankering. The total maximal leakage of emissions due to a shift in tankering is estimated at 4% of total Dutch aviation emissions.

Text box 1 - Tankering and possible carbon leakage

> In all options, especially in the fuel and airline option, airlines may react to increased fuel prices by buying less fuel in the Netherlands and more at corresponding airports (inbound tankering). We do not account for tankering in the calculations of the impacts as we assume the new anti-tankering regulations in ReFuelEU Aviation render it unlikely airlines will be able to circumvent fuel cost at large scale by tankering.
>
> The PBL report on tankering estimates currently 1-5% *outbound* tankering is taking place from Dutch airports (due to relative low fuel prices at Dutch airports). The anti-tankering measure in ReFuelEU Aviation requires airlines to refuel at least 90% of the fuel required for a departing flight at the relevant Union airport, which leaves in theory room for 10% inbound tankering (Planbureau voor de Leefomgeving, 2021).

For long-haul (intercontinental) flights tankering is not likely to happen due to lower excess fuel storage capacity available, small fuel price differences between hubs and the poor trade-off of increased fuel consumption due to increased aircraft weight by carriage of additional fuel during the flight. Tankering is therefore only likely to happen at intra-EEA flights.

Using these input, we can estimate the possible amount of carbon leakage. The share of CO_2 emissions by departing flights from Dutch airports to intra-EEA destinations is about 25% in 2030 (this share is similar in the modelled baseline and the CO_2 ceiling policy options). For 25% of the emissions of departing flights, up to 10% inbound tankering might be induced by the CO_2 ceiling, leading to a maximum shift of 15% tankering compared to the current situation. Dependent on the method of calculating emissions from departing flights (modelled emissions by flight data, or measured emissions by historical aviation bunker-fuel data) tankering may lead to a maximum of 4% leakage of total emissions of departing flights under the CO_2 ceiling. We expect the carbon leakage figure decreases over time when fuel supply at all Union airports are subject to the SAF blending rules as stated in the Fit for 55 package for aviation.

The potential carbon leakage is not accounted for in the outcomes of this impact assessment, given the expected size of the effect. For further information on possible tankering and carbon leakage see PBL (2021).

5.5.3 Results

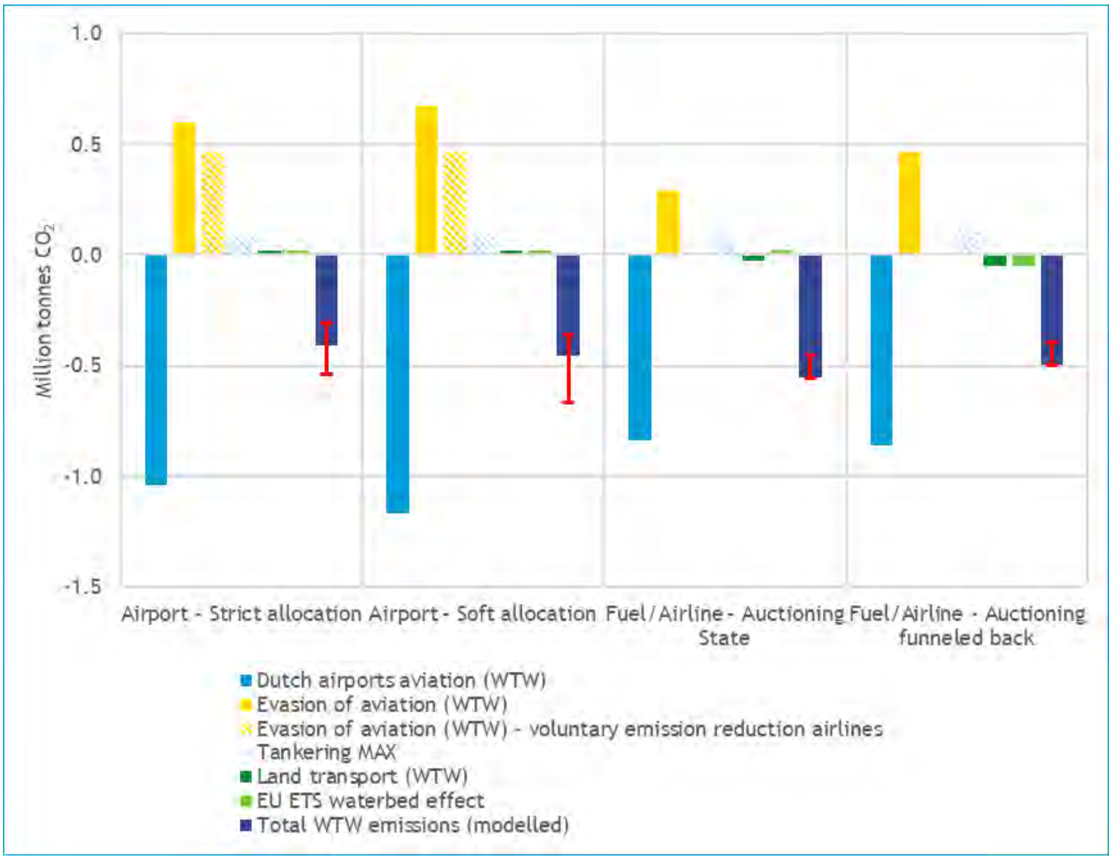
In this section we discuss the change in total CO_2 emissions from aviation, land transport and other EU sectors combined. We observe all the CO_2 ceiling policy options yield a net reduction of the CO_2 emissions in years when the CO_2 ceiling is restrictive. In 2040 the CO_2 ceiling is barely restrictive in the new AEOLUS runs, therefore there effects are negligible. In 2050 the CO_2 ceiling is not restrictive anymore.

Figure 64 presents the change in CO_2 emissions in the reference scenario graphically and also introduces the estimates of behavioural responses that have not been modelled: voluntary action by airlines in the airport options and tankering in all options. The modelled impacts are presented as solid columns, the non-modelled estimates as shaded columns.

We can see that all policy options show significant net CO_2 reductions ranging from 0.41 to 0.55 million tonnes for the modelled results in 2030. The net reductions are highest for the fuel supplier and airline auctioning state options. This is caused by the relatively small amount of evasion here. The red error bar represents the variance in the net CO_2 reductions due to voluntary emission reductions by airlines (in the airport options) and tankering. Increased inbound tankering could lead to an increase in net CO_2 emissions and therefore represents the upper side of the error bar. Voluntary emission reduction by airlines (in the airport options) could lead to more emission reduction, and therefore represents the lower side of the error bar.

The columns in the airport options indicate that when airlines take voluntary action, they can reduce the rerouting of passengers to the level of other policy options. The shaded yellow bar is considerably lower than the solid bar, especially in 2030. Another possible behavioural response is an increase in tankering, also indicated as a shaded bar. With these impacts, the net global CO_2 emissions would still decrease in most cases, as indicated by the shaded dark blue bar.

Figure 64 - **Change in CO_2 emissions in the reference scenario**



Note: in this figure we used a red error bar to show the uncertainty in the total WTW emissions due to voluntary emission reduction of airlines and increased inbound tankering.

Table 47 - Change in total CO_2 emissions of aviation, land transport and other EU sectors combined; the different CO_2 ceiling options compared to baseline (million tonnes)

CO_2 ceiling option	Year	Effects on global aviation CO_2 emissions		Effects on land transport CO_2 emissions	Effect on CO_2 emissions in other EU ETS sectors	Total combined effect on global CO_2 emissions
		The Netherlands aviation WTW emissions	Evasion of aviation WTW emissions	Land transport WTW emissions	EU waterbed effect	Total WTW emissions
Airport - Strict allocation (3-year cycle)	2030	-1.04 (-1.42 to -1.04)	0.60	0.02	0.02	-0.41 (-0.79 to -0.41)
	2040	-0.23 (-0.76 to -0.23)	0.25	0.01	0.01	0.04 (-0.48 to 0.04)
	2050	-0.04 (-0.54 to 0.04)	0.13	0.02	0	0.11 (-0.39 to 0.19)
Airport - Strict allocation (1-year cycle)	2030	-1.04 (-1.48 to -1.04)	0.60	0.02	0.02	-0.41 (-0.85 to -0.41)
	2040	-0.23 (-0.8 to -0.23)	0.25	0.01	0.01	0.04 (-0.53 to 0.04)

CO_2 ceiling option	Year	Effects on global aviation CO_2 emissions		Effects on land transport CO_2 emissions	Effect on CO_2 emissions in other EU ETS sectors	Total combined effect on global CO_2 emissions
		The Netherlands aviation WTW emissions	Evasion of aviation WTW emissions	Land transport WTW emissions	EU waterbed effect	Total WTW emissions
	2050	-0.04 (-0.5 to 0.03)	0.13	0.02	0	0.11 (-0.35 to 0.18)
Airport - Soft allocation (3-year cycle)	2030	-1.17 (-1.55 to -1.17)	0.67	0.02	0.02	-0.45 (-0.83 to -0.45)
	2040	-0.31 (-0.83 to -0.31)	0.32	0.00	0.01	0.02 (-0.5 to 0.02)
	2050	-0.03 (-0.54 to 0.04)	0.14	0.01	0	0.12 (-0.39 to 0.19)
Fuel supplier - Auctioning state	2030	-0.84	0.29	-0.03	0.02	-0.54
	2040	-0.29	0.31	-0.01	-0.01	0.00
	2050	-0.09	0.11	0.00	0	0.02
Fuel supplier - Auctioning funnelled back	2030	-0.86	0.46	-0.05	-0.05	-0.55
	2040	-0.28	0.32	-0.01	-0.06	-0.09
	2050	-0.08	0.12	0.00	0	0.04
Fuel supplier - No stability	2030	-0.84 (-0.88 to -0.8)	0.29	-0.03	0.02	-0.54 (-0.6 to -0.52)
	2040	-0.29 (-0.31 to -0.26)	0.31	-0.01	-0.01	0.00 (-0.02 to 0.04)
	2050	-0.09 (-0.31 to -0.04)	0.11	0.00	0	0.02 (-0.21 to 0.07)
Airline - Auctioning State	2030	-0.84	0.29	-0.03	0.02	-0.54
	2040	-0.29	0.31	-0.01	-0.01	0.00
	2050	-0.09	0.11	0.00	0	0.02
Airline - Funnelled back	2030	-0.86	0.46	-0.05	-0.05	-0.55
	2040	-0.28	0.32	-0.01	-0.06	-0.09
	2050	-0.08	0.12	0.00	0	0.04

5.5.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, there is no impact on global CO_2 emissions. In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the total CO_2 savings in 2030 are 43% higher in the airport options and 27% higher in the fuel supplier and airline options. In 2040 and 2050 the total CO_2 savings increase significantly, because the CO_2 ceiling is way more restrictive in this scenario.

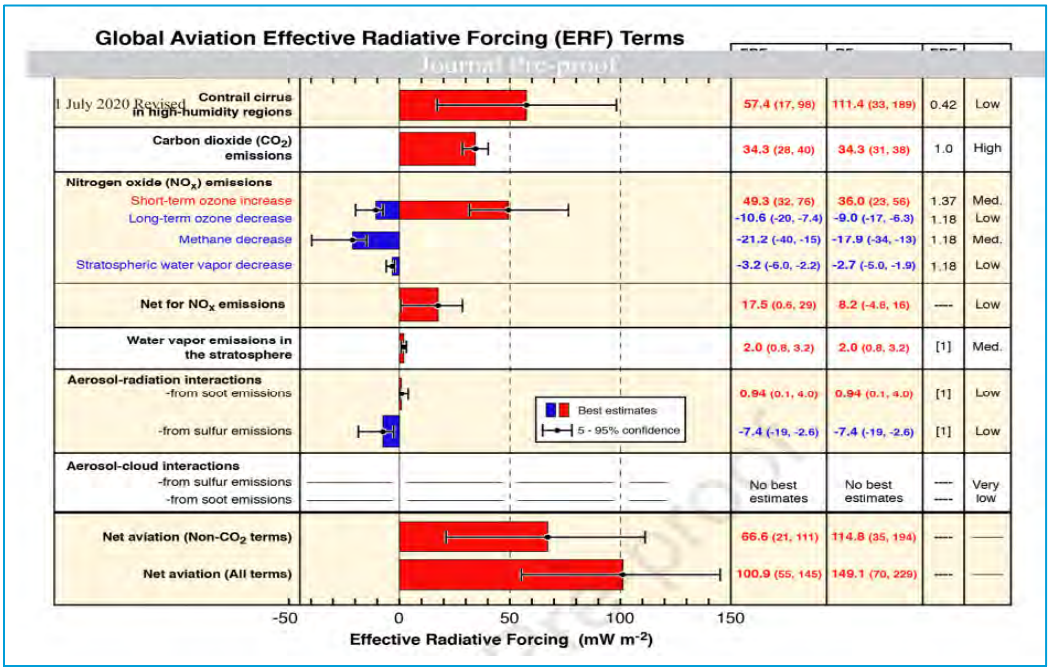
In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes. The extreme scenario is shown in Annex H.

5.6 Non-CO_2 climate impacts of aviation

5.6.1 Introduction

In addition to climate impacts related to CO_2 emissions, aviation also causes non-CO_2 related warming effects. The magnitude of these effects is still uncertain but recent modelling suggests that aviation's non-CO_2 impact on global warming may be twice as large as the direct CO_2 impact (Lee et al., 2021). The largest non-CO_2 impact stems from the formation of contrails and contrail cirrus, and NO_x emissions (see Figure 65).

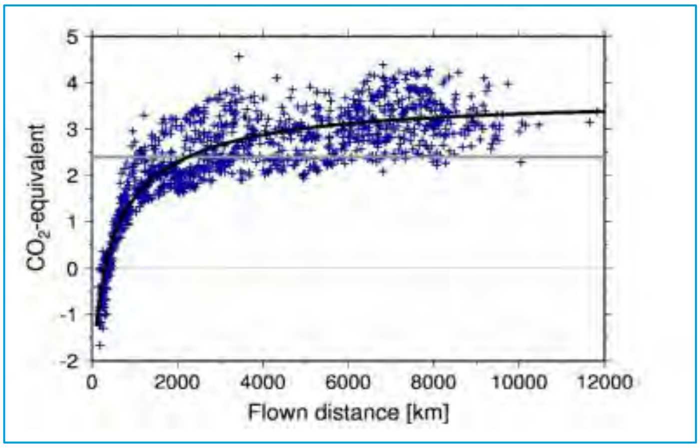
Figure 65 - Contribution of different non-**CO_2** effects from aviation to effective radiative forcing



Source: Lee et al., (2021).

There are four ways in which the Dutch CO_2 ceiling could influence net non-CO_2 emissions. First, the CO_2 ceiling could lead to a reduction in the number of flights, causing both a reduction of CO_2 and non-CO_2 climate effects. Second, the magnitude of the non-CO_2 effects described above is heavily dependent on cruise height and, in turn, on flight distance (see Figure 66). The Dutch CO_2 ceiling could hence influence the non-CO_2 warming effects of aviation by forcing airlines to modify their destination network and/or route frequencies.

Figure 66 - Relationship between flight distance and average **CO_2** and non-**CO_2** climate effects



Source: Dahlmann et al., (2021).

Third, the use of SAF can decrease contrail formation because SAF generally has a lower concentration of aromatics, including naphtalenes, which cause PM emissions (CE Delft, 2022).[64] Jet fuel standards set a maximum limit for aromatics of 25% by volume. One of the ways to reduce the average aromatics concentration in the fuel mix is to blend SAF in increasing volumes, while not increasing the concentration of aromatics in the fossil part of the blend. Because lowering the aromatics concentration in the refinery is costly, there is a theoretical possibility that refineries will raise effective aromatics concentrations in the fossil fuel part in order to reduce costs, thus eliminating (part of) the non-CO_2 climate benefits of blending SAF. However, this seems unlikely in practice, as currently, refineries do not maximize their aromatics concentrations.

Fourth, changes in utilised aircraft type resulting from the CO_2 ceiling can lead two differences in non-CO_2 warming effects. The direction of this change depends on the characteristics of the old and new plane.

5.6.2 Methodology

We estimate the impact of the CO_2 ceiling on the non-CO_2 effects of aviation on a route-level detail based on AEOLUS output. For each route departing from the Netherlands and other airports in the Catchment area, we determine a specific multiplication factor to calculate the non-CO_2 effects from the CO_2 emissions on that route. Multiplication factors are based on the previously shown distance-to-non-CO_2 relationship by Dahlmann et al., (2021) and consequently scaled for consistency with Lee et al., (2021), whose estimates for a global non-CO_2 factor (non-CO_2 = 2*CO_2 based on GWP*100) seem at this point most reliable. Note that the correction factor by Lee et al. is based on historical data and not on projected data. The real non-CO_2 correction factor can change in the future due to changes in atmospheric concentrations in the reference baseline scenario. At this point, there not does however, exists reliable projections of such effect, hence we base our analysis on the historical data by Lee et al.

The resulting non-CO_2 impacts were subsequently corrected for the influence of SAF.
We assumed that a tonne of SAF will on average lead to 50% less contrail formation than a tonne of kerosene. This assumption was based on CE Delft, (2022).
All the results are expressed in GWP*100 of CO_2, and therefore shortly as CO_2 equivalents.

5.6.3 Results

Table 48 shows the non-CO_2 impacts of the different options of the CO_2 ceiling, compared to the baseline. As can be seen the introduction of the CO_2 ceiling leads to a modest reduction in non-CO_2 climate effect. These are explained by a reduction in the number of flights (mostly in the airport options) and higher SAF blending percentages (mainly in the fuel and airline options).

64 If, in the future, airplanes will also fly on hydrogen - in addition to SAF - this would probably increase contrail formation.

Table 48 - Effect of the CO_2 ceiling options on non-CO_2 climate impacts, compared to the baseline (million tonnes CO_2e, GWP*100)

CO_2 ceiling option	Year	Non CO_2 emissions in million tonnes CO_2-eq.		
		Flight with origin at a Dutch airport	Flight from non-Dutch airports in the Catchment area	Net effect
Airport - Strict allocation (3-year cycle)	2030	-0.4 (-0.67 to -0.4)	0.1 (-0.61 to 0.1)	-0.3 (-1.28 to -0.3)
	2040	-0.11 (-0.45 to -0.11)	0.04 (-1.01 to 0.04)	-0.07 (-1.46 to -0.07)
	2050	0 (-0.51 to 0.07)	-0.02 (-1.76 to 0.21)	-0.02 (-2.27 to 0.28)
Airport - Strict allocation (1-year cycle)	2030	-0.4 (-0.7 to -0.4)	0.1 (-0.71 to 0.1)	-0.3 (-1.41 to -0.3)
	2040	-0.11 (-0.48 to -0.11)	0.04 (-1.1 to 0.04)	-0.07 (-1.58 to -0.07)
	2050	0 (-0.47 to 0.06)	-0.02 (-1.61 to 0.19)	-0.02 (-2.08 to 0.25)
Airport - Soft allocation (3-year cycle)	2030	-0.43 (-0.7 to -0.43)	0.13 (-0.59 to 0.13)	-0.31 (-1.29 to -0.31)
	2040	-0.13 (-0.47 to -0.13)	0.05 (-1 to 0.05)	-0.07 (-1.47 to -0.07)
	2050	0 (-0.51 to 0.07)	-0.02 (-1.76 to 0.2)	-0.02 (-2.27 to 0.27)
Fuel supplier - Auctioning state	2030	-0.36	-0.03	-0.40
	2040	-0.21	0.07	-0.14
	2050	0.01	0.01	0.02
Fuel supplier - Auctioning funnelled back	2030	-0.36	-0.09	-0.45
	2040	-0.21	0.03	-0.18
	2050	0.01	-0.01	0.01
Fuel supplier - No stability	2030	-0.51 (-0.54 to -0.48)	-0.03 (-0.1 to 0.04)	-0.54 (-0.64 to -0.44)
	2040	-0.35 (-0.37 to -0.34)	0.07 (0.01 to 0.13)	-0.28 (-0.36 to -0.21)
	2050	0.01 (-0.23 to 0.06)	0.01 (-0.79 to 0.17)	0.02 (-1.02 to 0.23)
Airline - Auctioning State	2030	-0.36	-0.03	-0.40
	2040	-0.21	0.07	-0.14
	2050	0.01	0.01	0.02
Airline - Funnelled back	2030	-0.36	-0.09	-0.45
	2040	-0.21	0.03	-0.18
	2050	0.01	-0.01	0.01

5.6.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on non-CO_2 emissions. In the scenario with the highest projected baseline emissions (WLO high, Fit for 55 reduced, increased airport capacity and no Dutch SAF blending) the net impacts on non-CO_2 emissions are again negative (less non-CO_2 emissions) and roughly four times as large compared to the impacts in the reference scenario. In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes (as shown in the tables in Annex H)

5.7 Impacts on air pollutant LTO emissions

5.7.1 Introduction

The effects of air pollution on humans and nature occur on the location where the pollutants are deposited[65]. This is different from the effect of greenhouse gasses, which is relevant globally. Because of the local relevance of air pollution, this section presents the impacts on air pollutant Landing- and Take-off (LTO) emissions at Dutch airports[66]. The air pollution at foreign airports and during the cruise phase of the flight are not quantified, since the impact of these emissions in the Netherlands is limited.

Emissions of air pollutants are affected by the CO_2 ceiling when it results in a change in activity. In Table 49 the local air pollutant emissions per airport in the reference scenario are displayed (output of the AEOLUS model). We can see that for all Dutch airports local emissions are increasing up to a peak around 2030. Thereafter local emissions are declining. This trend is mainly caused by the decrease of local emissions around Schiphol, which are driven by technological developments and an increasing use of SAF. For regional airports local emissions will keep increasing at least until 2050, mainly because the number of flights and/or the average aircraft size increases.

Table 49 - Development of air pollutant LTO emissions at Dutch airports in the reference scenario baseline (without CO_2 ceiling, tonnes per year)

Airport	Year	CO	NO_x	VOC	SO_2	PM_{10}
Total	2017	3,075	4,000	382	111	112
	2030	3,260	4,322	390	104	61
	2040	3,056	4,256	313	82	43
	2050	2,796	4,018	223	52	30
Amsterdam	2017	2,818	3,690	349	101	101
	2030	2,942	4,043	340	95	56
	2040	2,636	3,892	256	73	38
	2050	2,316	3,585	175	45	26
Lelystad	2017	-	-	-	-	-
	2030	58	38	11	2	1
	2040	94	64	15	2	1
	2050	113	82	13	2	1
Eindhoven	2017	126	148	17	5	6
	2030	122	81	22	3	1
	2040	156	106	24	3	1
	2050	190	137	22	3	1
Rotterdam	2017	53	54	6	2	2
	2030	47	30	7	1	1
	2040	69	44	8	1	1
	2050	74	50	7	1	1

65 In this study we only quantified the emissions of air pollutants. We did not determine where precisely these pollutants are deposited.

66 This includes the emissions up to 1 km altitude.

Airport	Year	CO	NO_x	VOC	SO_2	PM_{10}
Maastricht	2017	67	96	9	2	2
	2030	80	123	9	2	2
	2040	83	139	8	2	1
	2050	82	150	5	1	1
Groningen	2017	11	12	1	0	1
	2030	11	7	2	0	0
	2040	18	11	3	0	0
	2050	21	14	2	0	0

5.7.2 Methodology

In this section we compare the output of the AOLUS model for the different CO_2 ceiling options to the baseline run. We will investigate each Dutch airport separately, because of the local character of air pollutants.

Per air pollutant, the emission reduction per MJ of fuel use was determined compared to fossil kerosene. These determine the reductions per unit of fuel use. Furthermore, the AEOLUS model makes assumptions about improved aircraft technology over time[67], which together with the absolute fuel use also affects the air pollutant emissions. The assumed reduction factors for the different air pollutants are summarized in Table 50 and Table 50. It is important to note that there is a relatively large uncertainty in these numbers, since the air pollutant emissions of SAF depend amongst others on the type of fuel, the composition of the fuel (e.g. aromatic content), the aircraft engine type and the engine thrust. Also, the emissions of fossil kerosene depend on these factors. Lacking standard emission factors in the literature, we constructed these reduction factors based on various sources in the academic literature (CE Delft, 2017b, Durdina et al., 2021, ICAO, ongoing, Kurzawska & Jasiński, 2021)[68].

Table 50 - Relative reduction of air pollutant emissions during LTO phase using SAF compared to fossil kerosene

Air pollutant	Relative reduction in emissions
CO	17.5%
NO_x	0%
VOC	75%
SO_2	95%
PM_{10}	75%

Note: NO_x emissions are a function of engine technology, not of fuel choice.

5.7.3 Results

Figure 67 indicates the change in air pollutant LTO emissions for all Dutch airports compared to baseline. We can see that all of the CO_2 ceiling options cause a decrease in emissions for the total of all Dutch airports in 2030 and 2040. This is mainly caused by the decrease in emissions from Schiphol, see Table 51. Emissions in the Airport options for some

[67] The assumptions about aircraft technology improvements are in line with the WLO assumptions (CPB & PBL, 2016).

[68] Note that these reduction factors might in reality change over time, for example if they are dependent on the engine technique. Since we were unable to model such details, the constant factors shown in Table 48 were used for all years.

regional airports seem to increase in 2030 and 2040, see the tables in the Annex G.3. This indicates a shift of passengers from Schiphol to regional airports, caused by the CO_2 ceiling being reached earlier at Schiphol.

Figure 67 - Total changes in LTO emissions at all Dutch airports in the compared to the reference scenario baseline (% change per year)

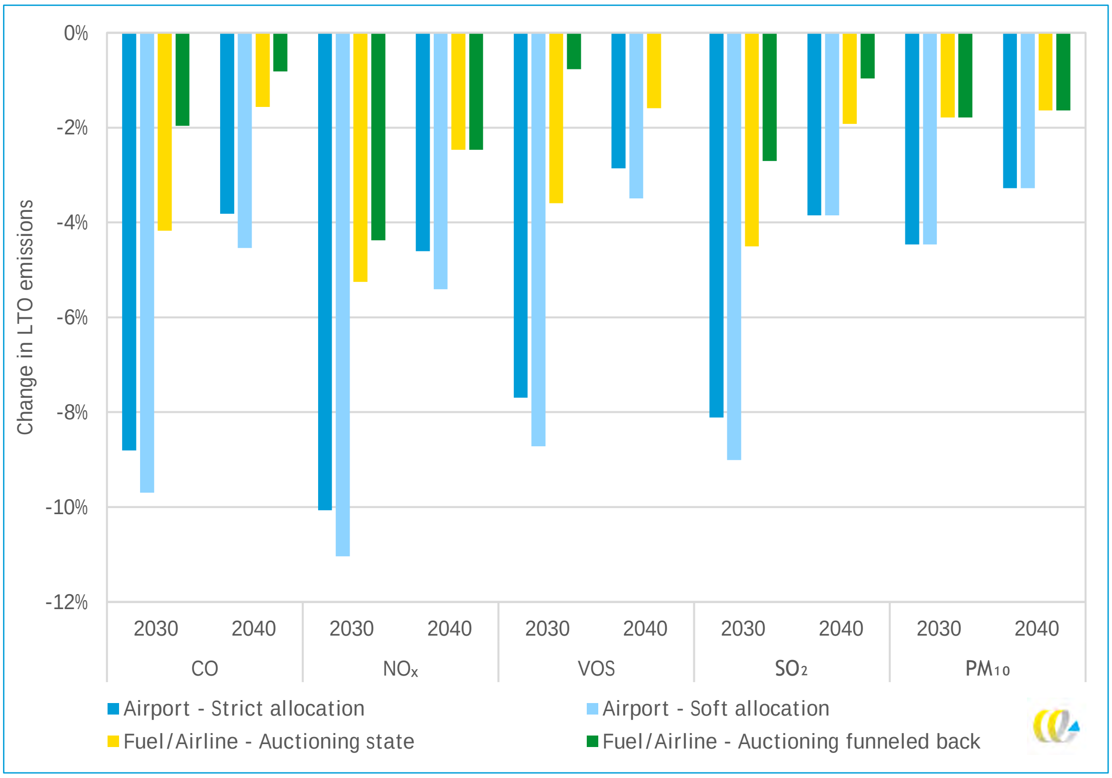


Table 51 - Change for all Dutch airports of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3 year cycle)	Airport - Strict allocation (1 year cycle)	Airport - Soft allocation (3 year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-287 (-372 to -287)	-287 (-384 to -287)	-316 (-400 to -316)	-136	-64	-136 (-145 to -127)	-136	-64
	2040	-117 (-262 to -117)	-117 (-275 to -117)	-139 (-282 to -139)	-48	-25	-48 (-56 to -40)	-48	-25
	2050	-5 (-239 to 25)	-5 (-219 to 23)	-2 (-236 to 28)	1	-1	1 (-107 to 23)	1	-1
NO_x	2030	-435 (-547 to -435)	-435 (-563 to -435)	-477 (-588 to -477)	-227	-189	-227 (-239 to -216)	-227	-189
	2040	-196 (-395 to -196)	-196 (-413 to -196)	-230 (-428 to -230)	-105	-105	-105 (-116 to -94)	-105	-105
	2050	-24 (-359 to 20)	-24 (-330 to 16)	-22 (-357 to 21)	14	4	14 (-141 to 45)	14	4
VOS	2030	-30 (-41 to -30)	-30 (-42 to -30)	-34 (-44 to -34)	-14	-3	-14 (-15 to -13)	-14	-3
	2040	-9 (-24 to -9)	-9 (-26 to -9)	-11 (-26 to -11)	-5	-0	-5 (-5 to -4)	-5	-0
	2050	0 (-18 to 3)	0 (-17 to 3)	1 (-18 to 3)	-0	-0	0 (-9 to 1)	-0	-0
SO_2	2030	-9 (-12 to -9)	-9 (-13 to -9)	-10 (-13 to -10)	-5	-3	-5 (-5 to -5)	-5	-3
	2040	-4 (-7 to -4)	-4 (-8 to -4)	-4 (-8 to -4)	-2	-1	-2 (-2 to -1)	-2	-1
	2050	0 (-5 to 0)	0 (-4 to 0)	0 (-5 to 0)	0	0	0 (-2 to 1)	0	0
PM_{10}	2030	-5 (-6 to -5)	-5 (-7 to -5)	-5 (-7 to -5)	-2	-2	-2 (-3 to -2)	-2	-2
	2040	-2 (-4 to -2)	-2 (-4 to -2)	-2 (-4 to -2)	-1	-1	-1 (-1 to -1)	-1	-1
	2050	0 (-3 to 0)	0 (-2 to 0)	0 (-3 to 0)	0	0	0 (-1 to 0)	0	0

5.7.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no impact on air pollutant LTO emissions.

In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Table 20) the emissions in 2030 are about 20% lower for the airport options. There is almost no impacts from the fuel supplier and airline policy options. In 2040 and 2050 the impacts increase for the airport options. with in 2050 a drop of more than 1,300 tonnes CO, 2100 tonnes NO_x, 128 tonnes VOS, 39 tonnes SO_2 and 20 tonnes PM_{10} per year. For the other policy options the impacts are smaller, but still significant and depend on the substance.

In other scenarios in which the projected emissions are higher than the CO_2 ceiling, the impacts are between the two extremes, as shown in the tables in Annex H.

5.8 Impacts on airport noise

5.8.1 Introduction

This section analyses how the implementation of a CO_2 ceiling influences airport noise in the Netherlands. Noise impact is for a large part a function of the composition of the fleets being operated at these airports. The noise impacts at Schiphol airport are directly modelled in AEOLUS. The noise impacts at the regional airports are quantified using the L_{den} tool[69] and with the provided AEOLUS outputs for these airports. These outputs describe the fleet compositions that result from implementation of a CO_2 ceiling (as discussed in Section 3.7). The effects on noise load in the surroundings of the airports are presented through quantification of the number of houses and severely annoyed people within the legally defined L_{den} noise contours levels.

5.8.2 Methodology

Schiphol Airport

The number of houses within the 58 dB L_{den}-contour, as calculated based on the buildings around Schiphol airport in the 2005 situation is directly modelled in AEOLUS. The other contours are not implemented in AEOLUS and the noise computations for the regional airports therefore require a model specifically designed to compute the noise contours at the regional airports. The modelled results for the different policy options are directly documented in this report.

Regional airports

The noise impact at regional airports within the Netherlands is quantified using the prescribed modelling techniques. The L_{den} tool is therefore used to achieve this, as it was specifically designed to compute the noise contours for airports other than Schipol Airport.

[69] The L_{den} tool was developed by Adecs Airinfra and by the Netherlands Aerospace Centre in assignment of ministry of Infrastructure and Water management in order to compute L_{den} noise contours in accordance with the Dutch decree 'Regeling burgerluchthavens'. This tool has been validated by Vital Link Beleidsanalyse in assignment of the ministry of Infrastructure and Water management (Vital Link Beleidsanalyse, 2015).

It requires traffic data that describes the distribution of aircraft movements over ICAO aircraft types, airport runways, flight routes, flight procedures as well as the distribution over the day. The AEOLUS output provides the number of movements on an annual basis for each of the regional airports being considered, distributed over technology classes, weight classes and the period of day. The distribution of these movements over the airport runways, flight routes and flight procedures is assumed to be equal to the distribution upon which the current airport licenses are based.

The data provided by the AEOLUS model cannot be used directly as input for the L_{den} tool. A conversion step is therefore needed to convert the technology and weight classes provided by the AEOLUS model to ICAO aircraft types being operated in the forecasted years (2017, 2030 and 2050). AEOLUS model output for research year 2040 was not available to quantify the noise impact in 2040. The NLR Appendices (NLR, 2014) for Schiphol Airport define the acoustic representative aircraft type for each combination of weight and technology class, except for those classes (TE. TF and TG) that are added to AEOLUS to incorporate future aircraft technology improvements. The technology classes implemented in the AEOLUS model are based on (NLR, 2014) and shown in Table 52. These three newly defined technology classes (TE. TF and TG) are considered in order to represent quieter aircraft.
It is assumed that these classes provide a 3 dB(A) noise reduction during take-off in comparison to their alphabetically preceding (see Table 52) technology class. These noise corrections are indicated in Table 53, which shows the result of this conversion step.

Table 52 - Definition of the technology classes utilised by AEOLUS

Technology class	ΔEPNdB[70]
TA	ΔEPNdB > 0
TB	0 ≥ ΔEPNdB > -9
TC	-9 ≥ ΔEPNdB > -18
TD	-18 ≥ ΔEPNdB > -21
TE	-21 ≥ ΔEPNdB > -24
TF	-24 ≥ ΔEPNdB > -27
TG	-27 ≥ ΔEPNdB > -30

The available set of acoustic representative aircraft types for these combinations of classes obtained from (NLR, 2014) was identified as insufficiently up-to-date to accurately quantify the future noise impact at regional airports, due to the presence of phased-out aircraft types within this dataset. This finding, together with the introduction of additional technology classes (TE, TF and TG) required the identification of up-to-date acoustic representative aircraft types for each of the possible combinations of weight and technology classes in order to provide accurate results regarding noise.

This identification of acoustic representative aircraft types is performed through analysis of the traffic composition underlying the Schiphol MER NNHS 2020 (Advanced Decision Systems Airinfra BV & To70 BV, 2020), which is based on an expected 500,000 aircraft movements in 2020 without consideration of the influence of the COVID-19 pandemic. Analysis of the cumulative noise levels (in EPNdB)[65] of the aircraft types within this traffic composition resulted in an up-to-date set of ICAO aircraft types for the combinations of weight and

[70] The EPNdB is defined as the sum of the noise limits in EPNdB at the lateral, flyover and approach certification measurement locations specified by ICAO Annex 16, Volume 1, Chapter 3, deducted by the sum of the certified noise levels that adhere to ICAO Annex 16, Volume 1, Chapter 3 (NLR, 2014).

technology classes, which is shown in Table 53 . A worst-case scenario in terms of cumulative noise level margin was considered most relevant for those combinations of weight and technology classes that could be represented by several aircraft types, such that each combination in Table 53 is represented by a single acoustic representative ICAO aircraft type. This approach prevents underestimation of the L_{den} contours.

An inherent limitation of the AEOLUS output and the definition of these classes of aircraft is that movements by light aircraft (with a maximum take-off weight of less than 6,000 kg) are not modelled. The effects of light aircraft on noise and external safety impacts within this project are however considered to be insignificant in comparison to the effects resulting from aircraft with an maximum take-off weight (MTOW) of at least 6,000 kg. Light aircraft are excluded from the noise and external safety calculations due to an unavailability of the required data.

Table 53 - Acoustic representative ICAO aircraft types for each combination of weight and technology class

Weight class	Technology class	Acoustic representative ICAO aircraft type	Noise correction [dB(A)]
G1	TA	JS31	-
G1	TB	JS31	-
G1	TC	JS31	-
G1	TD	JS31	-
G1	TE	JS31	-3
G1	TF	JS31	-6
G1	TG	JS31	-9
G2	TA	F100	+6
G2	TB	F50	-
G2	TC	F100	-
G2	TD	F70	-
G2	TE	F70	-3
G2	TF	F70	-6
G2	TG	F70	-9
G3	TA	B732	+6
G3	TB	F100	-
G3	TC	B733	-
G3	TD	B462	-
G3	TE	B462	-3
G3	TF	B462	-6
G3	TG	B462	-9
G4	TA	B722	-
G4	TB	B733	-
G4	TC	B738	-
G4	TD	A318	-
G4	TE	A318	-3
G4	TF	B38M	-
G4	TG	A20N	-
G5	TA	A310	+6
G5	TB	A310	+3
G5	TC	A310	-
G5	TD	B752	-
G5	TE	B752	-3
G5	TF	B752	-6

Weight class	Technology class	Acoustic representative ICAO aircraft type	Noise correction [dB(A)]
G5	TG	B752	-9
G6	TA	B763	+6
G6	TB	B763	+3
G6	TC	B763	-
G6	TD	B788	-
G6	TE	B788	-3
G6	TF	B788	-6
G6	TG	B788	-9
G7	TA	DC10	+3
G7	TB	DC10	-
G7	TC	A332	-
G7	TD	B772	-
G7	TE	A333	-
G7	TF	A333	-3
G7	TG	B78X	-
G8	TA	B744	+6
G8	TB	B744	+3
G8	TC	B744	-
G8	TD	B77W	-
G8	TE	B77W	-3
G8	TF	B77W	-6
G8	TG	B77W	-9
G9	TA	A388	+15
G9	TB	A388	+12
G9	TC	A388	+9
G9	TD	A388	+6
G9	TE	A388	+3
G9	TF	A388	-
G9	TG	A388	-3

The unique circumstances at Lelystad and Eindhoven Airport required some assumptions to be made in order to quantify the environmental impacts. These are as follows.

The airspace requirements at Lelystad Airport require special flight procedures to be applied. These flight procedures enforce that aircraft remain at relatively low flight levels during both approach and landing. At the time of performing the noise computations for this research, these procedures had not yet been described for all relevant aircraft types, as this airport has not yet been opened. Development of these flight procedures is out of scope of this research however. The flight procedures that are applied at Lelystad Airport to quantify the noise impact therefore assume normal NADP2-take-off procedures and normal arrival procedures, instead of taking level starts and arrivals (as used in the airport licence) into consideration. By assuming such normal take-off and landing procedures, the noise impacts at Lelystad Airport are likely to underestimate the expected noise impact that would be experienced in reality. Due to the unavailability of more realistic flight procedures the noise impact at Lelystad Airport is therefore computed with the aforementioned flight procedures mentioned.

Due to Eindhoven Airport being a military airport. combined with civil usage. the noise calculation methods in use for military aircraft should be used. This method quantifies the noise impact in KE ('KostenEenheden'), rather than relying on the 'Nederlands Rekenmodel' (NRM) to quantify the L_{den} contours resulting from aircraft movements. The AEOLUS output specifies the period of day (morning. afternoon. evening. night), but this is not specified at a greater level of detail, which is required to quantify the noise impact according to the KE method. This method requires data regarding the exact hour of each flight being operated. In addition the AEOLUS model output does not specify the movements of military aircraft. Utilising the L_{den} calculation method therefore prevents the introduction of additional assumptions and is therefore considered a reasonable alternative to using the KE calculation method. The L_{den} calculation method, which is used for the civil airports, is therefore used for noise computations at Eindhoven Airport as well. The results presented for Eindhoven Airport are therefore different from the results that would be obtained when relying on the KE method. Since the focus of this research is to analyse the difference in effects resulting from implementation of a CO_2 ceiling, the influence of this alteration is considered to be minor and therefore acceptable. Additionally, Eindhoven Airport does not have an airport licence like the other regional airports under consideration. The traffic distribution of 2019 is therefore used as substitution.CO_2.

The calculations of the noise impacts at Maastricht Airport, Eindhoven Airport, Groningen Airport, Lelystad Airport and Rotterdam Airport are performed within a study area that is large enough to encompass the 48 dB(A) L_{den}-contour. The results discussed in the next section quantify the noise impact at the regional airports through quantification of the number of homes and the amount of severely annoyed persons within the 48, 56 and 70 dB(A) L_{den}-contours. This research analyses the noise impact within these specific L_{den}-contours for the regional airports in order to align with Dutch law. The decree 'Besluit Burgerluchthavens' describes limitations regarding the environmental impact within these specific L_{den}-contours, resulting from the aviation industry. Separate calculations of the L_{night} contours to analyse the effects of flights during the night hours (23:00 - 07:00 local time) were not performed as the differences in effects resulting from implementation of de CO_2 ceiling policy are expected to be relatively small. In addition, the regional airports being considered are mainly closed during these night hours.[71] The counts are performed with data of the homes updated Q1 2022, provided by the Dutch register of addresses and buildings, the BAG ('Basisregistratie Adressen en Gebouwen'), and the most recent population data ('CBS Wijken en Buurten'), which originates from 2020, provided by the Dutch Central Statistics Office (CBS). These datasets are used for all three research years (2017, 2030 and 2050). This research therefore does not take into account future developments regarding construction of new homes and the redistribution of the population in quantifying the future noise impacts within the 48 dB(A) L_{den}-contours.

The scope of this research, combined with the large amount of possible future scenarios, requires a selection of the suboptions to be analysed for the reference baseline scenario being considered. Limitations within the AEOLUS model in modelling all CO_2 ceiling policies affect the availability of data with the required level of detail in the traffic distribution, which is required to compute the noise (and external safety) impacts. A scoring function was therefore used to select a best- and a worst-case CO_2 ceiling policy for a given baseline scenario, from the four policy options, shown in Table 54, that do meet the required level of detail in traffic data. This scoring function quantifies the relative amount of noise that can be expected through a sum-product of the technology class number and the number of movements, for which a working example is shown in Table 53. The technology classes represented by relatively quiet aircraft are given a smaller weight in the resulting score by

[71] For further details on the operational hours at the airports, see the Aeronautical Information Services provided by the LVNL.

inverting the technology class numbers. The total score, obtained after multiplication and a summation over all sub-scores, does not have a physical unit.

Table 54 - Working example of the implemented score function

Technology class		Movements	Score
TA	1	5	= (8-1) x 5
TB	2	10	= (8-2) x 10
TC	3	15	= (8-3) x 15
TD	4	20	= (8-4) x 20
TE	5	25	= (8-5) x 25
TF	6	30	= (8-6) x 30
TG	7	35	= (8-7) x 35
Total score			420

The resulting score provides an insight in the relative amount of noise being produced over all airports during all three research years. This level of aggregation is applied to be able to compare the various CO_2 ceiling policies and select a single policy as best- and worst-case. The larger the magnitude of the score. the larger the total amount of noise is being produced within such a CO_2 ceiling policy. This approach allows quantification of the bandwidth of the noise impacts resulting from implementation of a CO_2 ceiling policy. relative to its respective baseline scenario. This also provides a good. quantitative. estimation for the best- and worst-case scenario regarding external safety. discussed in Section 6.2. since the amount of noise produced by an aircraft and the impact on external safety generally increases with the weight of an aircraft.

The obtained score values in Table 55 show that suboption ‘Airport - soft allocation’ and ‘Fuel supplier/airline - auctioning state’ are the best- and worst-case CO_2 policies for the reference baseline scenario respectively, in terms of noise. The following section therefore presents the noise impact at the regional airports for the reference baseline scenario, as well as the impact of these two CO_2 ceiling policies.

Table 55 - Comparison of **CO_2** ceiling policies based on scoring function.

Baseline	Result of scoring function			
	Airport - strict allocation	Airport - Soft allocation (3-year cycle)	Fuel supplier/ airline - auctioning state	Fuel supplier/ airline auctioning funnelled back
Reference baseline scenario (23)	3,180,452	3,172,199	3,231,106	3,230,855
Scenario with highest projected emissions (6)	3,024,532	3,016,540	3,443,549	3,473,790

5.8.3 Results

Schiphol airport

The number of houses within the 58 dB Lden-contour is shown in Table 56. In the reference baseline scenario. the number of houses within the contour declines rapidly. especially after 2040. This can be explained due to new aircraft producing lower noise levels. In the different suboptions. the number of houses within the contour is lower compared to the baseline when the ceiling is reached. This is due to lower aviation levels. The largest decline in noise is reached in the Airport - strict allocation and Airport - soft allocation suboptions. In the other suboptions. the reduction in aviation noise is smaller. since the reduction of flights is not as large.

Table 56 - Number of houses (thousands) within the 58 db Lden-contour at Schiphol airport

Year	Reference baseline	Airport - strict allocation	Airport - Soft allocation (3-year cycle)	Fuel supplier/ Airline - auctioning state	Fuel supplier/ Airline auctioning funnelled back
2017	11.2	11.2	11.2	11.2	11.2
2030	8.7	8.0	7.9	8.3	8.7
2040	6.1	5.5	5.5	6.0	6.0
2050	0.8	0.8	0.8	0.8	0.8

Regional airports

The noise impact is presented through quantification of the number of houses and severely annoyed people within the legally defined L_{den} noise contours. These consist of the 48, 56 and 70 dB(A) L_{den}-contours, as described in Dutch law by the decree 'Besluit Burgerluchthavens". The results for the central scenario are shown below in Table 57 to Table 58[72] and are presented for each airport separately. The counts of the number of houses and severely annoyed people, using the housing situation data for regional airports discussed in Section 5.8.2, within the 70 dB(A) L_{den}-contour are excluded from the tables below. These results are excluded, since these counts of the number of houses and severely annoyed people were found to be zero at each regional airport under consideration and for all three research years. AEOLUS model output for research year 2040 was not available to quantify the noise impacts in 2040.

The definition of the worst- and best-case CO_2 ceiling policy (see Table 55) is based on a score function (see Section 5.8.2) that does not differentiate between the airports and the different research years. The consequence is that it can happen that the noise impacts presented below can show a smaller noise impact at an airport in the worst-case scenario compared to the situation in the best-case scenario.

Table 57 - Rotterdam The Hague Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to central scenario

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	14,970	14,970	14,970
		2030	4,170	4,167	5,506
		2050	5,944	5,947	5,828
	≥ 56 dB(A) L_{den}	2017	664	664	664
		2030	33	33	38
		2050	36	36	36

72 The airport noise results for the regional airports were obtained with an older version of the AEOLUS model. The same AEOLUS model version was used to quantify the impacts regarding airport noise and external safety. Analysis of the newer AEOLUS version outputs showed that the changes in traffic composition, relative to these outputs obtained with an older version of AEOLUS, were such that the traffic compositions can be considered to be equal. No significantly different effects are to be expected in terms of noise impact as a result from relying on a different AEOLUS model version to quantify these effects. The currently presented results are therefore considered to be accurate.

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Severely annoyed	≥ 48 dB(A) L_{den}	2017	9,395	9,395	9,395
		2030	2,734	2,721	3,595
		2050	3,776	3,778	3,703
	≥ 56 dB(A) L_{den}	2017	1,188	1,188	1,188
		2030	246	246	286
		2050	278	278	277

Table 58 - Maastricht Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to central scenario

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	13,943	13,943	13,943
		2030	14,024	13,773	14,146
		2050	10,832	10,813	10,826
	≥ 56 dB(A) L_{den}	2017	1,879	1,879	1,879
		2030	1,712	1,692	1,718
		2050	951	943	951
Severely annoyed	≥ 48 dB(A) L_{den}	2017	8,150	8,150	8,150
		2030	8,126	7,994	8,185
		2050	6,153	6,139	6,150
	≥ 56 dB(A) L_{den}	2017	1,873	1,873	1,873
		2030	1,730	1,705	1,738
		2050	986	978	985

Table 59 - Eindhoven Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to central scenario

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	2,859	2,859	2,859
		2030	234	232	225
		2050	401	401	399
	≥ 56 dB(A) L_{den}	2017	141	141	141
		2030	9	9	9
		2050	32	32	31
Severely annoyed	≥ 48 dB(A) L_{den}	2017	1,880	1,880	1,880
		2030	262	261	253
		2050	450	450	447
	≥ 56 dB(A) L_{den}	2017	286	286	286
		2030	23	22	20
		2050	67	67	66

Table 60 - Groningen Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to central scenario

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	148	148	148
		2030	35	35	42
		2050	48	50	44
	≥ 56 dB(A) L_{den}	2017	5	5	5
		2030	2	2	2
		2050	2	2	2
Severely annoyed	≥ 48 dB(A) L_{den}	2017	99	99	99
		2030	24	24	32
		2050	32	33	31
	≥ 56 dB(A) L_{den}	2017	7	7	7
		2030	2	2	2
		2050	2	2	2

Table 61 - Lelystad Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to central scenario

Aspect	Contour level	Year	Reference baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning state (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	31	31	31
		2050	51	51	50
	≥ 56 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	2	2	2
		2050	7	7	7
Severely annoyed	≥ 48 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	72	72	69
		2050	101	100	100
	≥ 56 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	29	28	23
		2050	62	62	61

The counts of the number of houses and severely annoyed people of the reference baseline scenario show that the noise impact, in terms of number of houses and severely annoyed people, remains relatively unaffected by implementing either the worst- or best-case CO_2 ceiling policy.[73] This is mainly the result of the traffic output from the AEOLUS model, which shows that the total amount of movements does not differ significantly between the reference baseline scenario and its worst- and best-case CO_2 ceiling scenarios. The distribution of movements over the technology classes from Table 54 remains relatively

[73] It needs to be noted however that the noise impact presented for Lelystad Airport underestimates the real impact that would arise when special flight procedures for this airport are considered (refer to section 0 for further details). The real influence of implementation of a CO_2 ceiling policy on the noise impact is therefore expected to be different from what is computed and presented here.

constant as a result from implementation of one such CO_2 ceiling. These technology classes define the noise impact to a large extent and since the CO_2 ceiling policies do not cause significant adjustments in the compositions of the fleets being operated at the various airports, no significant affects in terms of noise impact are identified.

The trends over time, as shown in Table 57 to Table 61, do however indicate that the noise impact in research year 2050 will reduce in comparison to the situation in year 2017. This reduction in noise impact is achieved despite an increase in the number of movements and is therefore a direct result from the introduction of quieter aircraft types, which are modelled through the newly introduced technology classes (discussed in Subsection 5.8.2).

5.8.4 Results in other baseline scenarios

The extreme baseline scenario, which is baseline Scenario 6 in Figure 20 has the highest projected baseline emissions and is discussed here.

The score function discussed in Subsection 5.8.2 showed that the best- and worst-case CO_2 ceiling policy for this baseline scenario are different as compared to the central baseline scenario . Analysis of the fleet compositions being operated at each airport. as specified by the AEOLUS model. shows that implementation of these CO_2 ceiling policies limits the total amount of flights.

The effects of the CO_2 ceiling policies of the extreme scenario on the noise impact at each airport, shown in Annex H.3, are not consistently worse or better in comparison to the noise impact related to the CO_2 ceiling policies of the central baseline scenario. This fluctuation is the result of the interactions between number of flights. aircraft types. aircraft technology classes and the flight destinations.

The effect of implementation of either the worst or best-case CO_2 ceiling policy compared to the extreme baseline scenario also can vary, Generally, it does not significantly influence the number of houses and severely annoyed people within the 48, 56 and 70 dB(A) L_{den}-contours. Although there are significant differences in some specific cases. The cause of these differences besides the combination of aircraft numbers and technology classes is the geographical relation between these contours and urban areas.

Overall. it shows that introduction of quieter aircraft in 2030 and more in 2050 affects the noise impact positively.

Based on the observed impacts of the CO_2 ceiling policies related to the central baseline and to baseline Scenario 6 (presented in Annex H.3), it is expected that implementation of a CO_2 ceiling policy in a baseline scenario where the emissions remain below the ceiling does not significantly affect the noise impact compared to a baseline without a CO_2 ceiling policy implemented.

6 Social impacts and safety

6.1 Introduction

This chapter presents the social and safety impacts of the CO_2 ceiling for Dutch aviation. It starts with an assessment of the impacts on external safety in Section 6.2, followed by an analysis of the impacts on employment in the aviation sector in Section 6.3.

6.2 External safety

6.2.1 Introduction

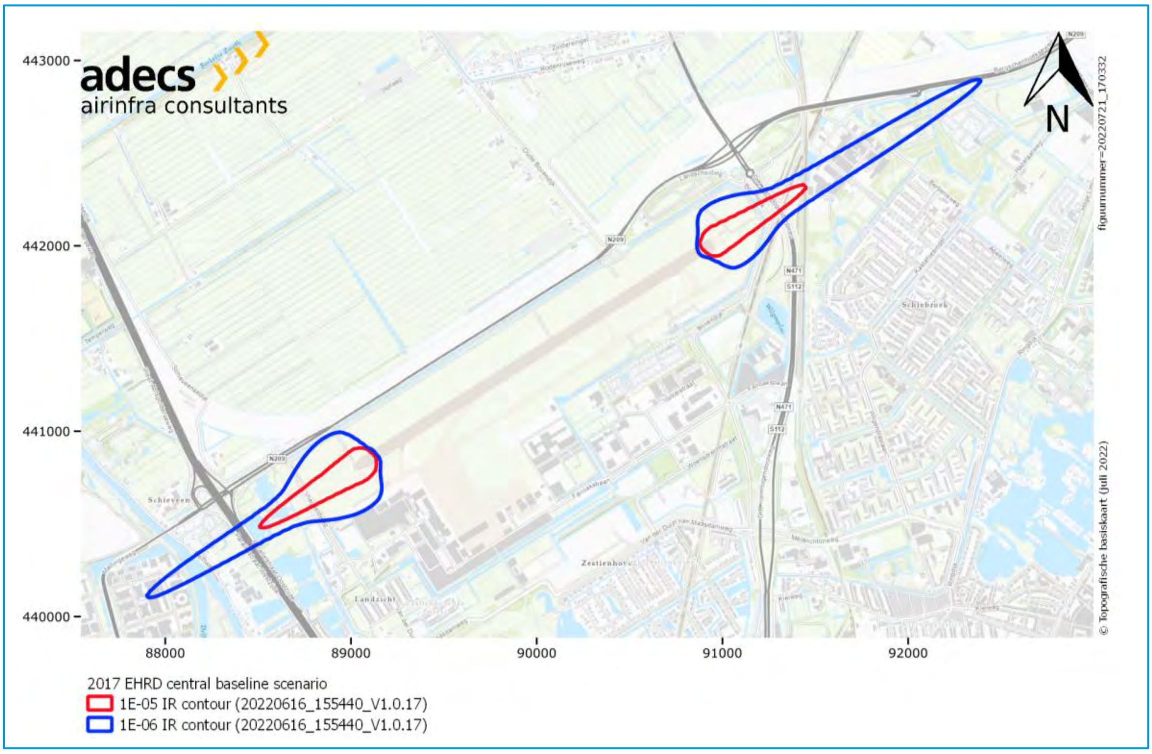
In this section we analyse how the implementation of a CO_2 ceiling influences the external safety and its resulting impact on the environment of the airports under consideration. This impact is a function of the fleet composition being operated at these airports.[74] The external safety is quantified through the individual risk (IR) using the prescribed calculation methods and the GEVERS model (RIVM, 2010). The effects are analysed by counting the number of houses within the legally defined IR-contours. (RIVM, 2010), which was developed for the Ministry of Infrastructure and Water Management. The effects are analysed by counting the number of houses within the legally defined IR-contours.

6.2.2 Methodology

The latest version (2.2) of the GEVERS calculation model is used to compute the IR at both the regional airports and at Schiphol Airport for all three research years. The effects of the CO_2 ceiling policies within the 10^{-5} and the 10^{-6} IR-contours are analysed, since these IR-contours are legally defined in the licence 'Besluit burgerluchthavens'. The uncertainty in the expected runway usage as a consequence of the weather is taken into account by considering a 20% surcharge in the number of movements for the 10^{-5} IR-contour, which is in accordance with the Dutch decree 'Regeling burgerluchthavens'. Figure 68 provides an example of the relative locations of such IR-contours at Rotterdam The Hague Airport and visualises their position relative to other infrastructure such as houses.

[74] The assumptions about aircraft technology improvements and fleet composition are in line with the WLO assumptions (CPB & PBL, 2016).

Figure 68 - IR-contours at Rotterdam The Hague Airport for 2017 of the reference baseline scenario



Computation of these IR-contours relies on the accident probabilities. The currently applicable accident probabilities, both for the regional airports and Schiphol, are used to quantify the IR-contours in research year 2017. The accident probabilities that are applicable to generation 3 and 4 aircraft are updated in order to quantify the environmental effects for research years 2030 and 2050 more accurately. This allows for consideration of safety improvements within the aviation industry to be taken into account in quantifying the environmental impact due to external safety. The accident probabilities for the regional airports (Maastricht. Eindhoven. Groningen. Lelystad and Rotterdam) are therefore updated in accordance with Table 62 (NLR, 2021). Similarly, the accident probabilities currently used at Schiphol are based on RANI-2010 (NLR, 2019). These are therefore updated to the RANI-2018 accident probabilities (NLR, 2019) to compute the impact safety in research years 2030 and 2050.

Table 62 - Accident probabilities for generation 3 and 4 aircraft

Aircraft Generation	Flight Type	Accident Type	Regional Airports		Schiphol Airport	
			Current (2017)	New values (2030 and 2050)	RANI-2010	RANI-2018
3	Take-off	Run	0.000007%	0.000002%	0.000001%	0.000001%
4		Run	0.000007%	0.000002%	0.000001%	0.000001%
3		Shoot	0.000003%	0.000002%	0.000004%	0.000003%
4		Shoot	0.000003%	0.000002%	0.000004%	0.000003%
3	Landing	Run	0.000073%	0.000060%	0.000015%	0.000010%
4		Run	0.000073%	0.000060%	0.000015%	0.000010%
3		Shoot	0.000017%	0.000008%	0.000007%	0.000006%
4		Shoot	0.000017%	0.000008%	0.000007%	0.000006%

For other aircraft generations (1 and 2), the default accident probabilities provided by GEVERS version 2.2 are used (see Table 63), because this is the most current data available. Using this older data gives a worst-case impact, since it is more likely that accident rates for future years shall be lower. In addition, these aircraft generations contribute to only a small portion of today's aircraft traffic.

Table 63 - Default accident probabilities for generation 1 and 2 aircraft as provided by GEVERS version 2.2

Aircraft Generation	Flight Type	Accident Type	Accident probability
1	Take-off	Run	0.000105%
2		Run	0.000007%
1		Shoot	0.000003%
2		Shoot	0.000003%
1	Landing	Run	0.000366%
2		Run	0.000090%
1		Shoot	0.000524%
2		Shoot	0.000195%

The computation of the IR-contours also relies on the traffic distribution over the runways and flight routes. We here used the same distribution as we used to compute the noise impact for the regional airports (see Section 5.8). A different approach was used to determine an up-to-date distribution at Schiphol, since the required data could not be provided by the AEOLUS model. The traffic distribution that lies at the basis of the MER NNHS 2020, which consists of an expected 500.000 movements in 2020 without consideration of the COVID-19 pandemic (Advanced Decision Systems Airinfra BV & To70 BV, 2020) was therefore used to determine the relative amount of flights utilising each of Schiphol's runways and flight routes. The traffic data for Schiphol that is provided by the AEOLUS model is therefore distributed over the runways and flight routes in accordance with the distribution found in the Schiphol MER NNHS 2020.

The resulting traffic distributions provided the input for the GEVERS calculation model, such that the IR-contours could be computed. The impact on the environment is quantified by computing the number of houses within the 10^{-5} and 10^{-6} IR-contours. These results are presented for each regional airport, as well as for Schiphol, in the next section.

6.2.3 Results

The results of the external safety calculations, in terms of the number of houses within the 10^{-5} and 10^{-6} IR-contours, are presented in Table 64 to Table 69.[75] The results for the central scenario are presented for each airport separately, such that insight into the local effects, resulting from implementation of the worst- and best-case CO_2 ceiling policy (see Table 55), is provided. We only present the results for 2017, 2030 and 2050 in this section.

[75] The external safety results were obtained with an older version of the AEOLUS model. The same AEOLUS model version was used to quantify the impacts regarding airport noise and external safety. Analysis of the newer AEOLUS version outputs showed that the changes in traffic composition, relative to these outputs obtained with an older version of AEOLUS, were such that the traffic compositions can be considered to be equal. No significantly different effects are to be expected in terms of external safety impact as a result from relying on a different AEOLUS model version to quantify these effects. The currently presented results are therefore considered to be accurate.

Table 64 - Rotterdam The Hague Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	4	4	4
		2030	2	2	3
		2050	4	4	4

Table 65 - Maastricht Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	96	96	96
		2030	75	74	75
		2050	85	85	85

Table 66 - Eindhoven Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	1	1	1
		2030	0	0	0
		2050	0	0	0

Table 67 - Groningen Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
	≥ 10^{-6}	2017	0	0	0
		2030	0	0	0
		2050	0	0	0

Table 68 - Lelystad Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	≥ 10^{-5}	2017	N/A	N/A	N/A
		2030	0	0	0
		2050	0	0	0
	≥ 10^{-6}	2017	N/A	N/A	N/A
		2030	0	0	0
		2050	1	1	1

Table 69 - Schiphol Airport - Absolute results of number of houses within IR-contours related to the central scenario

Aspect	Contour level	Year	Reference baseline scenario	Fuel supplier/airline - auctioning state (lowest improvement in external safety)	Airport - soft allocation (largest improvement in external safety)
Houses	≥ 10^{-5}	2017	2	2	2
		2030	2	2	1
		2050	2	2	2
	≥ 10^{-6}	2017	645	645	645
		2030	633	562	471
		2050	594	594	590

Table 64 to Table 68 show that the effect in terms of external safety, as a result from implementation of a CO_2 ceiling policy, is little to insignificant. Since the aircraft generations in the AEOLUS output are mainly of generation Type 3, these IR-contours become a function of mainly the MTOW of the aircraft being operated. This aspect, as well as the amount of movements, remains relatively unaffected and therefore results in the absence of significant effects as a result from implementation of de CO_2 ceiling policy in terms of external safety.

Additionally, adjustment of the accident probabilities, prevents that the amount of houses within the IR-contours increases in the future, as would be expected from the increase in traffic volume at these airports.

6.2.4 Results in other baseline scenarios

The extreme baseline scenario, which is baseline scenario 6 in Figure 20, has the highest projected baseline emissions and is discussed here.

The score function discussed in Subsection 5.8.2 showed that the best- and worst-case CO_2 ceiling policy for this extreme baseline scenario are different as compared to the central scenario (see Table 55). Analysis of the fleet compositions being operated at each airport, as specified by the AEOLUS model, shows that implementation of these CO_2 ceiling policies limits the total amount of flights.

The result for this extreme baseline scenario regarding external safety are presented in Annex H.4. These show that, despite an increase in traffic relative to the central scenario, the 10^{-5} and 10^{-6} IR-contours remain such that no significant amount of houses are located within these contours. Additionally, implementation of the CO_2 ceiling policies does not alter this result despite the influence of implementation on the amount of flight movements. These CO_2 ceiling policies limit the amount of movements significantly such that the emission remain below the ceiling.

At Schiphol, implementation of either CO_2 ceiling policy does significantly alter the impact on external safety (see Annex H.4). Implementation of the worst- and best case CO_2 ceiling policy related to this baseline scenario affects the aircraft movements differently, therefore resulting in a significantly different impact on external safety. The differences in amount of movements is the main contribution that causes these effects.

Based on the observed impacts of the CO_2 ceiling policies related to the central baseline and to the baseline scenario with the highest projected baseline emission, it is expected that implementation of a CO_2 ceiling policy in a baseline scenario where the emissions remain below the ceiling does not significantly affect the impacts related to external safety.

6.3 Jobs in the Dutch aviation sector

6.3.1 Introduction

In this section we analyse and discuss the impact of the CO_2 ceiling on the level of employment in the Dutch aviation sector. We calculate the change in employment in the aviation sector as a result of changed volume of air transport operations in the Netherlands in the CO_2 ceiling options and compare the figures to employment figures in the baseline.

6.3.2 Methodology

We perceive number of flight movements as the primary indicator for the volume of economic activity in the aviation sector, for which we assume flight movements and gross output of the aviation sector has a constant linear relation. Therefore, we calculate the impact of the CO_2 ceiling on the number of jobs in the aviation sector as a result of change in the number of flights.

The gross output used in analysis is the total value of services and products provided by a sector. We use the gross output of the sector in 2016 from the CBS input-output tables, which is the most recent data available for sectoral input-output figures (CBS, 2017). Consequently, we calculate the gross output of the sector in 2017 using the change in the number of jobs in the aviation sector between 2016 and 2017 (CBS & Decisio, 2019).

Using the change in the number of flight movements (from the modelling results) and consequent change in gross output of the aviation sector in a year, we calculate the change in gross output of the aviation sector in 2030, 2040 and 2050 for the baseline and the options. Assuming a similar constant linear relation between gross output of a sector and the volume of employment in the sector, we calculate the change in employment volume following changes in gross output of the aviation sector in the options compared to the baseline.

The employment in the aviation sector is defined as the economic activities involved in air transport. That is, all employment involved in and around servicing air transport activities. From CBS we obtained the number of full time equivalent employed (fte[76]) directly involved with the provision of air transport and surrounding services at Amsterdam Schiphol Airport (CBS & Decisio, 2019).
This comprises staff employed in:
- airport operations (facility management, air traffic control, slot coordination);
- airline operations (in-flight, ground handling and aircraft maintenance for both pax and cargo airlines);
- air cargo activities (transport, storage/warehousing);
- airport facilities (security, cleaning services);
- retail, hospitality, catering, other services related to air transport operations.
  - The number of fte at Schiphol is scaled to the number of employment in the entire Dutch aviation sector by the number of flights at AMS and the other national airports.

We do not estimate the impact on the long-term employment and higher order employment effects due to the presence of air transport (so called catalytic employment effects of aviation). This is because of the following reasons and assumptions:
- the job market is assumed to become in balance at the long-term;
- there are issues with assigning changes in employment in the regional economy to aviation, as the majority of literature shows a correlation, rather than a cause-and-effect relationship.
- there are many other factors in play determining the volume of employment in third and higher order effects, that the impact of air transport activities becomes uncertain.77
- Nevertheless, we are aware that certain economic activities in regions with airports are located in these regions because of the presence of air transport.

6.3.3 Results

The results of the calculation of aviation employment impact under the CO_2 ceiling options are presented in Table 70. The number of fte are rounded at ten. In the second column, total employment in the aviation sector is indicated in fte per year. The employment in the projected future years is estimated by the changes in total volume (number of flights) of Dutch aviation in the baseline.

76 Fte is defined as 40 work hours per week.

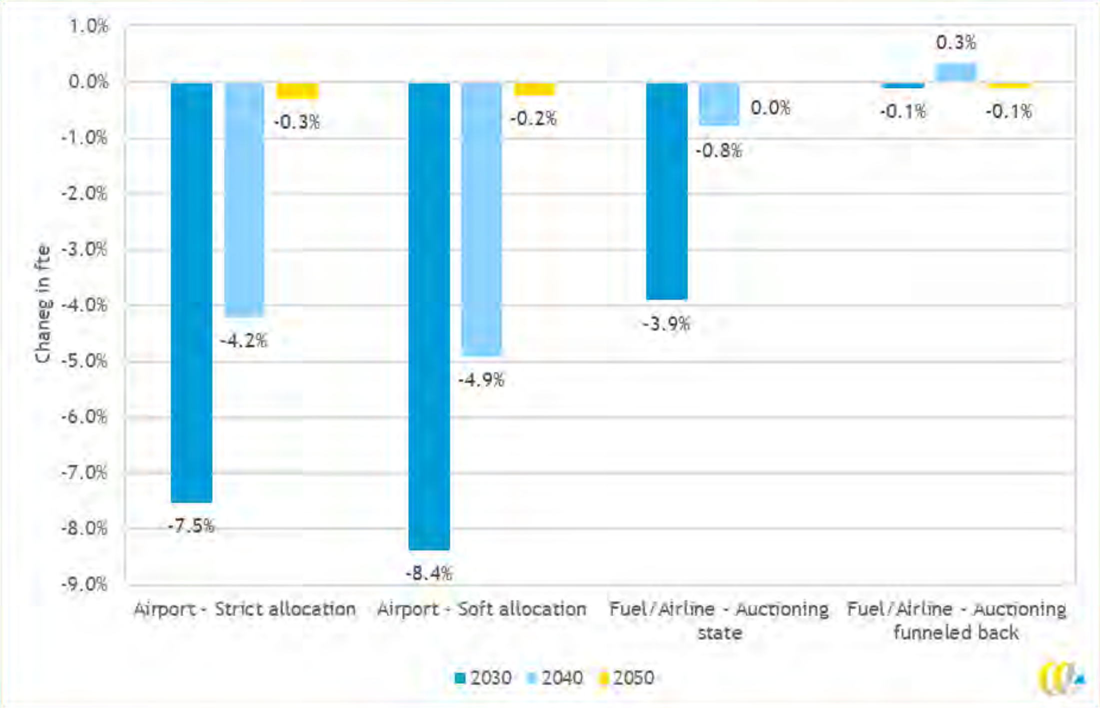
77 It is very difficult to state about the employment for retail businesses in e.g. *Hoofddorp* where a relative high number of employees from firms involved in air transport activities may be located. To some extent one can predict household expenses from these employees in local shops, however, many other factors are in play determining the volume of regional economic activities (e.g. attractiveness, accessibility, local rules, etc.).

Table 70 - Baseline employment volume and change of employment n the aviation sector, fte per year

Year	Baseline	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
2017	65,030	0	0	0	0	0	0	0	0
2030	65,456	-4,930 (-6,670 to -4,930)	-4,930 (-6,920 to -4,930)	-5,490 (-7,200 to -5,490)	-2,560	-70	-2,560 (-2,740 to -2,370)	-2,560	-70
2040	70,197	-2,960 (-6,270 to -2,960)	-2,960 (-6,560 to -2,960)	-3,450 (-6,730 to -3,450)	-560	230	-560 (-750 to -380)	-560	230
2050	79,060	-240 (-6,850 to 620)	-240 (-6,280 to 560)	-190 (-6,800 to 610)	-30	-90	-30 (-3,070 to 590)	-30	-90

We observe the substantial decrease of flights in the airport options has a strong downward effect on the growth of employment in the sector. The level of employment only shows an absolute decrease in 2030 compared to employment in 2017. In 2040 and 2050, the employment grows (decade-on-decade), but only at a slower pace than in the baseline. The changes in employment by the options are indicated in Figure 69.

Figure 69 - Relative changes in employment in the Dutch aviation sector (fte per year) relative to the baseline



6.3.4 Results in other baseline scenarios

In scenarios in which emissions remain below the ceiling, we expect no significant effects to the level of jobs in the Dutch aviation sector compared to the baseline.

In the scenario with the highest projected baseline emissions (baseline Scenario 6 from Figure 20) the impacts are higher. Due to higher expected baseline growth of flights,[78] the number of jobs in the aviation sector in the baseline of Scenario 6 is estimated at a similar higher level (see Annex H.4). The CO_2 ceiling is an absolute norm, which implies there is no adjustment of the maximum level of emissions allowed depending on the actual growth scenario. In the extreme scenario, the number of flights to be reduced or SAF necessary to comply is several times higher compared to the necessary reduction in the central scenario. Therefore the changes in total number of jobs in the CO_2 ceiling options are also more significant.

The number of jobs lost in the aviation sector as a consequence of the CO_2 ceiling is the highest in the airport options. This is mainly due to the restriction in the number of flights. while in other CO_2 ceiling options the number of flights is more or less maintained while using other emission reduction techniques. Be aware the baseline jobs in the aviation sector are higher than the above presented figures from the central scenario. In the Fuel

78 The number of flights is compared to the abovementioned central baseline scenario.

supplier/Airline *funnelled back* options the number of jobs may increase slightly due to a small increase of the number of flights to and from Dutch airports.

See the exact impact figures on employment in the aviation sector in the other scenarios Annex H.

7 How do the options compare?

7.1 Introduction

This chapter presents a multicriteria analysis of the different policy options of the CO_2 ceiling, as introduced in Section 2.6. This multicriteria analysis compares the different options in a structured way.

Section 7.2 presents and defines the criteria, which are scored for each of the suboptions in the subsequent Sections 7.3 through 7.8.

7.2 Criteria for comparison

We have defined five criteria to compare the options against, some of which have several subcriteria. A distinction should be made between criteria which are related to the main objective of the CO_2 ceiling (to safeguard that the CO_2 emissions targets for Dutch aviation, set by the Government, are not exceeded) and criteria that are related to other effects of the policy choice (effects on the aviation sector, environment, economy and safety).

All criteria are scored on a five point scale, ranging from -- (very negative) to ++ (very positive) with 0 meaning (almost) no impact. How these are exactly defined differs per criterion. A detailed explanation of the choices is in included in Annex E.

We did not rank the different criteria on importance. This is because the relative importance of the different criteria is a political choice that should not be made by the research team. For the different subcriteria that together form a main criterion, we did make an aggregation: this unavoidably involves assigning weights.

Below we introduce the different criteria and subcriteria. Also, Figure 70 provides a schematic overview of the criteria and subcriteria.

The first criterion is defined as 'certainty about the impact on aviation CO_2 emissions'. This criterion is directly related to the aim of the CO_2 ceiling. The criterion has four components:
1. Control which regulated entities have over CO_2 emissions.
2. Predictability of CO_2 emissions.
3. Feasibility of implementation.
4. The international acceptance of the measure which also relates to the risk of retaliation.

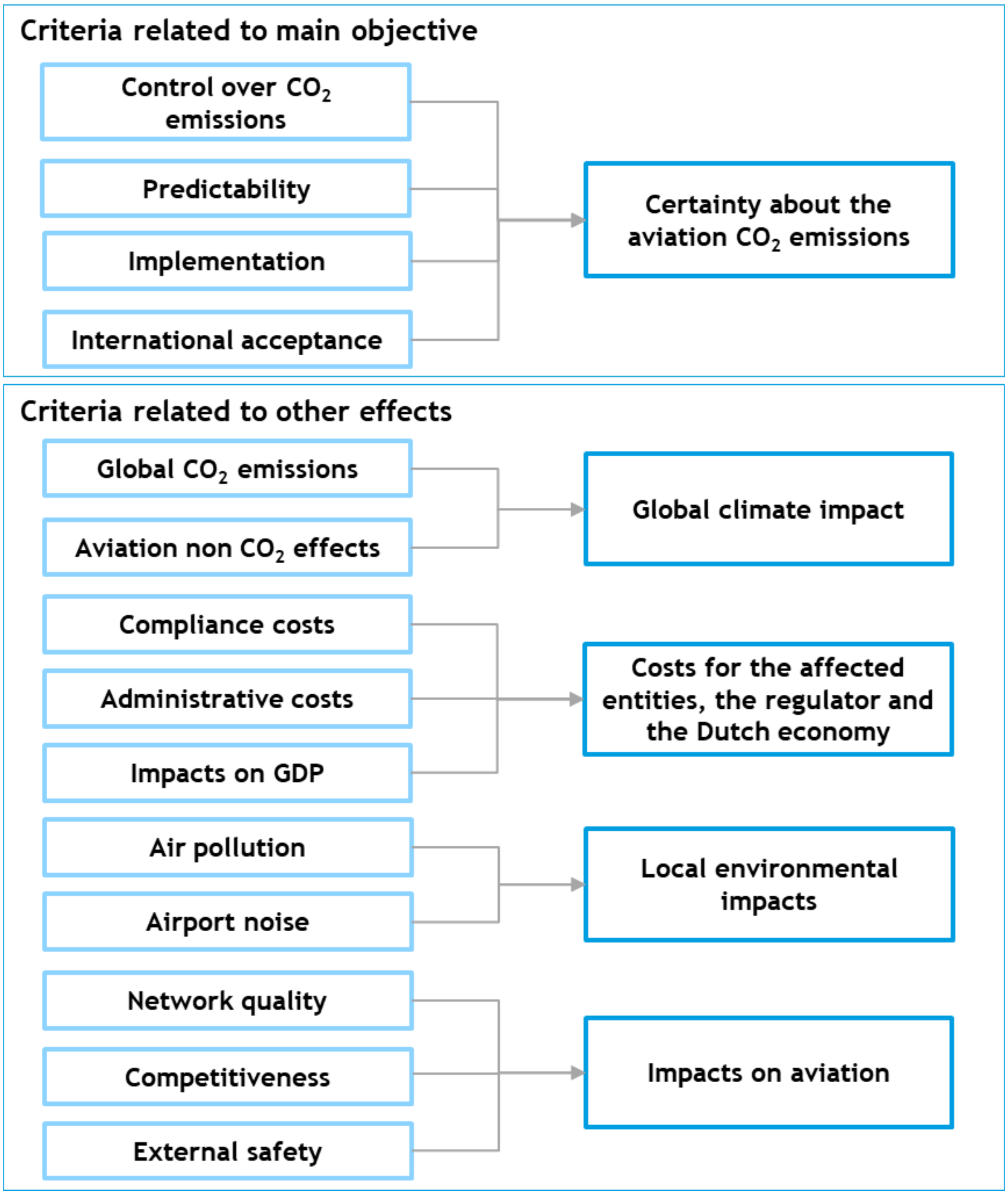
As the CO_2 ceiling is a climate measure, the impacts on GHG emissions, both in the aviation sector and in other sectors, as well as the change in non-CO_2 climate impacts from aviation are also relevant. The 'global climate impact' therefore constitutes the second criterion.

The third criterion is the 'cost of the measure' for both the affected entities, the regulator and the Dutch economy. This is translated into the following three subcriteria:
1. The compliance costs.
2. The administrative costs.
3. The state revenues.

The final two criteria are directly taken from the Dutch aviation white paper 'luchtvaartnota', which defines public interests of aviation (next to the interest of reducing the climate impact of aviation). The fourth criterion comprises the 'local environmental impacts: airport noise and LTO emissions of air pollutants'.

The fifth criterion comprises the 'impacts on aviation: network quality, level playing field and aviation safety'. This criterium also consists of three subcriteria: network quality, competitiveness and external safety.

Figure 70 - Schematic overview of the criteria and subcriteria



7.3 Certainty about aviation CO_2 emissions - main objective

The CO_2 ceiling aims to provide assurance that the CO_2 targets described in the aviation white paper are met. This depends on:
- the control which regulated entities have over the CO_2 emissions, so that they can effectively and accurately reduce them;
- the predictability of the policy option without which regulated entities and emitting entities cannot take appropriate action;
- the feasibility of implementation which determines whether the policy option can be implemented and the effort required; and
- the international acceptance, without which it would be harder to ensure compliance of all emitting entities.

7.3.1 Control over CO_2 emissions

The control over CO_2 emissions of the regulated entity of a policy option is defined as the extent to which these entities can control the amount of CO_2 emissions on international commercial flights departing from the Netherlands. The more control they have, the lower the risk that the emissions go above the ceiling for reasons outside of control of the regulated entity.

The airport option would entail that airports include emission estimates in their capacity declaration. Airports control their capacity in terms of the number of available slots (for departure and arrival of aircrafts). At coordinated airports, the slot coordinator issues a number of slots based on the capacity declaration. Slots represent rights to use a runway at a given time. They are not restricted by aircraft type or destination. This is a free choice of the airlines. Hence, the CO_2 emissions per slot vary and change over time if airlines decide to change operations. There is no way for airports to enforce the choices of airlines. This is comparable to the way in which the Netherlands currently regulates noise and air quality. As discussed in Section 2.6, the average CO_2 emissions per aircraft movement have decreased by about 6% at Schiphol between 2015 and 2019, and increased by about 10 and 30% at Eindhoven and Rotterdam, respectively, in the same period. The main reasons are developments in aircraft technology (new efficient aircrafts replace older less efficient aircrafts) leading to an decrease of emissions per movement and changes in flight destinations and aircraft size (longer distances and larger aircrafts leading to more emissions per movement).

In addition to the control over the number of slots, airports may be able to influence CO_2 emissions by inducing airlines to reduce emissions voluntarily in order to maintain airport capacity and to a very limited amount by differentiation in airport charges.

In the fuel supplier option, fuel suppliers are not allowed to sell more fossil fuel than they have allowances. Depending on whether baseline emissions would be below or above the ceiling, the auction could result in cost increases of fossil fuels sold at Dutch airports. When the cost increase is larger than the price difference between SAF and fossil fuels plus kerosene related taxes (EU ETS, CORSIA, ETD), it becomes attractive to blend in more SAF.

Fuel suppliers do not control the choice of aircraft type or destinations, nor can they influence operational decisions which impact emissions, ranging from the loading of an aircraft to the amount of fuel tankered. All these choices are made by the airlines. However, the price signal provided by the option would provide an incentive to airlines to change their emissions if necessary to stay below the ceiling. Therefore, we consider the control of fuel suppliers over emissions to be more direct than the control of airports.

In the airline option, airlines cannot create more emissions than they have emission allowances for. Of the three regulated entities, airlines (as the emitting entities) have the most direct control over emissions. They can, in principle, adjust their route network, their aircraft fleet, and take operational measures to reduce emissions. Therefore, we consider the control of airlines over emissions to be more direct than the control of fuel suppliers.

Conclusion

Within each policy option, regulated entities have control over at least some factors determining the amount of CO_2 emissions. Therefore, all scores are positive or zero. As described above, airlines have control over most, if not all, factors that determine the amount of CO_2 emissions of the flights they execute and a finite amount of emission allowances will ensure that overall emissions remain below the ceiling. Therefore, we assign a score of ++ to the airline options. Fuel suppliers control fewer factors, but in addition to their control, the price of fuel influences other factors under the control of airlines. Like the airline option, the allowance system ensures that the overall emissions remain below the ceiling. Therefore, we assign a score of + to the fuel supplier options. Of all potential regulated entities, airports control the fewest factors that determine the amount of CO_2 emissions of flights departing from their airport. Therefore, we assign a score of 0 to the airport options.

Table 71 presents the evaluation of the control which regulated entities have over CO_2 emissions.

Table 71 - Evaluation of the control which regulated entities have over CO_2 emissions within the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Control of the regulated entity over CO_2 emissions	*0*	*0*	*0*	+	+	+	++	++

7.3.2 Predictability

The predictability of the policy option is defined as the extent to which regulated and emitting entities can make accurate estimates of the emissions and how they compare to the CO_2 ceiling, so that they can take action if needed. The better the predictability, the more commensurate action will be, and the lower the unintended impacts will be.

The airport option would entail that airports include emission estimates in their capacity declaration. They will likely do so on the basis of historical data, input from airlines about planned flight schedules and SAF blending as well as modelling of emissions. This means that the emission forecasts are as accurate as the flight plans (including destinations and aircraft types) and the modelling. In cases where the projected emissions exceed the ceiling, airports could liaise with airlines in order to agree on voluntary means to reduce emissions, such as increased SAF use or increased tinkering.[79] It is, however, not certain that airlines would be willing to engage in such negotiations. Even if they would agree to

[79] If modelled data instead of tanked fuel are used to determine the CO_2 emissions the options of tankering does not apply.

voluntarily reduce emissions, it is uncertain whether they would honour their commitments, because not doing so would not be penalized. When voluntary action is not successful, airports would have to reduce their capacity declaration, and the slot coordinator would reduce the number of slots.

In the three year compliance cycle, airports have more time to build up experience and to take past responses to capacity changes into account than in a one-year compliance cycle. Hence, a three year compliance cycle would have a better predictability of emissions over the entire cycle than the one year compliance cycle. It should be noted that a three year compliance cycle consists of six IATA seasons. Therefore, in practice there are six cycles that can be used to determine the right amount of slots such that the CO_2 ceiling is not surpassed. To safeguard that emissions stay below the ceiling, the safety margin that airports apply should be larger for a one year compliance period than in a three year period.

Because the predictability does not relate to the level of the emissions ceiling, there is no difference between the allocation options.

The fuel supplier option would entail that fuel suppliers buy allowances at the auction/allowance market. Price setting at the auction works best if fuel suppliers can accurately project fuel consumption. Fuel suppliers will in general not have access to flight schedules, like airports, so they cannot forecast kerosene demand in detail. They would probably forecast demand based on long-term supply contracts they have and on information about emissions in the past, regulatory changes, and the business cycle. When demand for allowances is not accurately predictable, their prices may be volatile, which could trickle down to airlines and aviation demand. Volatility offers the possibility for speculations possibly leading to higher fuel prices for airline. The volatility will be larger, and consequently the predictability lower, in the suboption without a market stability mechanism than in the option with a market stability mechanism.

Airlines have established ways of dealing with unpredictable fuel prices, which may be expected to apply to allowance prices, so the impact of this uncertainty on demand and ultimately on emissions can be expected to be limited. A volatile price may also result in volatile demand for additional SAF to be blended in. Depending on the versatility of SAF producers, this may lower predictability of prices and effect emissions.

The airline option would require airlines to buy emission allowances at the auction. We consider that airlines do not have perfect information about the flights that other airlines plan to execute. This may result in volatile allowance prices, especially when emissions are close to the ceiling. When emissions end up just above the ceiling, the only short-term actions which airlines could take would be to increase SAF use or to scrap flights. This could result in relatively high allowance prices. However, if emissions are at or below the ceiling, the allowances have no short-term value.

Conclusion

We consider that emissions are more predictable in the airport option than in other options, because airports have ex-ante information about the flights which airlines plan to execute. Options with longer compliance cycles or market stability mechanisms are more predictable than other options.

Table 72 summarises the evaluation of the predictability of CO_2 emissions in each of the policy options.

Table 72 - Evaluation of the predictability of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Predictability of emission volumes	+	*0*	+	*0*	*0*	-	*0*	*0*

Note: A more detailed description of the meaning of the scores is included in Annex E.

7.3.3 Feasibility of implementation

The feasibility of implementation is defined as the effort required to implement a policy option. This comprises the legislative effort (whether or not an option can be legislated by amending existing legislation or requires new legislation), and setting up monitoring and enforcement schemes. This evaluation assumes that amending existing legislation requires less effort than adopting new legislation. This assumption should be revisited in a more comprehensive legal analysis.

The airport option envisages that the CO_2 ceiling is included in existing airport permits: the Luchthavenverkeersbesluit (in case of Schiphol) or Luchthavenbesluit (in case of the regional airports). These currently also regulate external safety, airport noise and emissions of air pollutants. This implies that the legislative effort would consist of amending the Aviation Law (Wet Luchtvaart) and the permits. The Aviation Law would need to state that there are limit values for CO_2 emissions and what those limits are, as well as provisions for monitoring compliance and enforcement. Monitoring compliance could entail setting up systems to gather empirical data (building, for example, on proposed European legislation) or modelling rules - see Section 4.3. The permits would set the limit values for all airports from which international commercial flights are operated. In addition, methods would have to be agreed on how to calculate CO_2 emissions.

There is no difference in the feasibility of implementation of the suboptions of the airport option.

The fuel supplier option envisages establishing a system for fossil fuel supply rights. This would be a new piece of legislation. Potentially, it could use provisions from the coming ETS RTB (EC, 2021c) which would require fuel suppliers to monitor and report fuel supplies to road transport. The monitoring and reporting system, however, would need to be set up from scratch and enforcement mechanisms would have to be agreed on.

In addition to the new regulation described above, the suboption in which the auctioning revenues would be funnelled back would require a decision on the criteria and rules as well as an organisation to implement them. The agreements that would have to be made about the funnelling back of auctioning incomes would deviate from the normal system for budget allocation, which makes this particularly complex to implement.

The airline option would set up a closed emissions trading scheme for aircraft operators executing international commercial flights operating from Dutch airports. This requires new legislation. It could be inspired by the EU ETS but with important differences, notably that it is a closed system. The option funnelling back revenues would require additional legislation and organisational changes.

Conclusion

The legislative effort required for implementing the CO_2 ceiling would be least for the airport options, because existing legislation could be amended. Therefore, we score this as relatively positive: +. However, it has to noted that for airports it might be more challenging than it seems at first glance to take this additional rule into account in the capacity declaration. The other options require new legislation. Because funnelling back revenues requires additional rules and monitoring systems, we score these options worst: --. The other options are scored -.

Table 73 summarises the evaluation of the feasibility of implementation of the policy options.

Table 73 - Evaluation of the feasibility of implementation of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Feasibility of implementation	+	+	+	-	--	-	-	--

Note: a more detailed description of the meaning of the scores is included in Annex E.

7.3.4 International acceptance/risk of retaliation

A lack of international acceptance could undermine the certainty which the CO_2 ceiling provides, especially when airlines refuse to participate or are prohibited to participate by their administering State. This risk is higher when airlines are directly affected, and lower when they are indirectly affected. Historically, the acceptance of the inclusion of aviation in the EU ETS has encountered stronger international resistance than airport capacity limits or aviation taxes. This means that the international acceptance of the airline options is lower than the acceptance of the other options. A detailed discussion about retaliation was included in Section 3.9.

Conclusion

Airlines are not directly affected as regulated entity in the airport and fuel supplier options. Therefore, we score this as neither positive nor negative: 0. Because airlines the regulated entities in the airline options, we score this option as negative: -.

Table 74 summarises the evaluation of the international acceptance of the policy options.

Table 74 - Evaluation of the international acceptance of the policy options

	Airport - Strict allocation (3-yearcycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
International acceptance/risk of retaliation	*0*	*0*	*0*	*0*	*0*	*0*	-	-

Note: a more detailed description of the meaning of the scores is included in Annex E.

7.3.5 Conclusion

Table 75 recapitulates the evaluation of the different elements of the certainty about aviation CO_2 emissions and adds an overall score for each option. If all elements are given equal weight, the airport options with a 3-year compliance cycle score best, followed by the airport option with a 1-year compliance cycle and the fuel supplier auction in which revenues are fiscal income.

Table 75 - Evaluation of the certainty about aviation **CO_2** emissions of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Control of the regulated entity over CO_2 emissions	0	0	0	+	+	+	++	++
Predictability	+	0	+	0	0	-	0	0
Feasibility of implementation	+	+	+	-	--	-	-	--
International acceptance/risk of retaliation	0	0	0	0	0	0	-	-
Certainty about aviation **CO_2** emissions	+	0	+	0	0	0	0	0

Note: a more detailed description of the meaning of the scores is included in Annex E.

7.4 Total climate impacts

Reduction of CO_2 emissions is not the aim of the CO_2 ceiling. However, if the ceiling prevents emissions from surpassing the limits, there is a relevant global climate impact. Therefore, as a climate policy instrument, the total climate impacts are a relevant criteria. In most scenarios, the impacts are zero because the business as usual emissions remain below the CO_2 ceiling. The impacts of all policy options on tank-to-wing CO_2 emissions of commercial international flights departing from Dutch airports is approximately the same (see Section 5.2). However, the emission reductions in the ceiling per airport options are slightly higher, because the ceiling may be met at individual airports before the total ceiling is reached. Different options have different impacts on total global tank-to-wing CO_2 emissions of aviation, on well-to-tank emissions of aviation fuels, on emissions in other sectors and on non-CO_2 impacts. In addition, there may be impacts resulting from increased tankering. Together, these constitute the impact on global CO_2 emissions.

As shown in Section 5.5, the total global emission reduction brought about by the fuel supplier and airline options are the largest. These options have a lower total impact in case revenues are funnelled back to the sector. The impact of the airport options on global CO_2 emissions is the smallest of all options. (When airlines take voluntary action to reduce emissions in the airport options, and when they maximise tankering in all options, the impacts on global CO_2 emissions are comparable to the other options).

The impact on non-CO_2 emissions scores best in the fuel supplier and airline options as well.

7.4.1 Conclusion

All options reduce overall emissions if the ceiling is restrictive. Therefore, we score them as 0, + and ++ according to the order in which emissions are reduced, as described above.

Table 76 summarises the evaluation of the total climate impacts of the policy options.

Table 76 - Evaluation of the total climate impacts of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Total Global CO_2	++	++	++	++	++	++	++	++
Aviation non-CO_2	+	+	+	++	++	++	++	++
Total climate impacts	++	++	++	++	++	++	++	++

Note: a more detailed description of the meaning of the scores is included in Annex E.

Note: in most scenarios, there are no climate impacts. This evaluation assumes that baseline emissions are above the ceiling. In addition, this evaluation assumes that airlines will not voluntarily reduce emissions in the airport options.

7.5 Costs and economic impacts

The costs which are considered in this multicriteria analysis comprise of the compliance costs, which are the costs that regulated entities and emitting entities have to make to comply with the regulation, and the administrative costs, which regulators and regulated entities have to make to demonstrate compliance. The compliance costs are presented in Section 4.2. In contrast to the criteria assessed hitherto, the compliance costs depend on the emissions in the baseline scenario and the level of effort required. The administrative costs are independent of the baseline scenario and have been presented in Section 4.3. The impacts on the Dutch economy have presented in Section 4.7. These take into account that costs for some actors (e.g. auctioning costs) are benefits for others (in this case: fiscal income).

7.5.1 Compliance costs

In most scenarios, compliance costs are zero because baseline emissions remain below the ceiling (see Section 2.2). When emissions are below the ceiling, no costs have to be made to reduce them. When baseline emissions are higher than the ceiling, the *level* of the costs vary, but the order of the costs across the variants is the same. The main components of the compliance costs are the fuel costs (in most cases a benefit because fewer long-haul flights mean less fuel, which in turn mean lower fuel costs) and the auctioning costs (in policy options in which the revenues are added to government coffers).

Conclusion

Table 77 presents the evaluation of compliance costs in cases where baseline scenarios project that CO_2 emissions are higher than the ceiling, based on Section 4.2. Lower compliance costs imply that a policy is more cost-effective (for the aviation sector), the policy options with the lowest compliance costs score best: ++. The options in which the costs increase are the options in which the auction revenues are retained by the State; these score worst: --.

Note that this evaluation assumes that airlines will not take collective voluntary action in the airport options. If they would voluntarily act to avoid a reduction in airport capacity, the compliance costs of the airport options would be the same as for the fuel supplier and airline options in which auctioning revenues are funnelled back (i.e. somewhat higher, implying a less cost-effective policy and a lower score).

Table 77 - Evaluation of the compliance costs of the policy options when baseline emissions exceed the **CO_2** ceiling

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Compliance costs	++	++	++	--	+	--	--	+

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, compliance costs are zero. This evaluation assumes that baseline emissions are above the ceiling. In addition, this evaluation assumes that airlines will not voluntarily reduce emissions in the airport options. Also note: a more positive (+) score for compliance costs means less compliance cost (cost reduction).

7.5.2 Administrative costs

In contrast to the costs of compliance, administrative costs are independent of how the baseline emissions relate to the CO_2 ceiling. As shown in Section 4.3, the administrative costs depend on whether or not the Fit for 55 proposals are implemented as proposed by the Commission. If they are, some of the administrative tasks have to be performed to comply with EU law, and these tasks would therefore not be additional tasks of the CO_2 ceiling. The evaluation below assumes that the Fit for 55 proposals are indeed adopted and implemented. If this is not the case, additional costs would need to be made.

Table 78 presents the evaluation of administrative costs associated with the different policy options. As with the costs of compliance, administrative costs are always considered negative. The higher the costs, the more negative the score.

Table 78 - Evaluation of the administrative costs of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Administrative costs	-	-	-	-	-	-	--	--

Note: a more detailed description of the meaning of the scores is included in Annex E.

7.5.3 Impacts on the Dutch economy

The impacts on the Dutch economy, assessed here as impacts on GDP, have been presented in Section 4.7. the impacts stem from changes in consumer spending: residents who cancel their travels altogether will spend additional money in the Netherlands, while non-residents who cancel their trip to the Netherlands will not spend money in the Netherlands. Here we evaluate the net effect of this consumer spending on GPD. In most scenarios, the GDP effect of consumer spending are negligible because the implementation of the CO_2 ceiling does not require aviation to change when baseline CO_2 emissions are below the ceiling. In other scenarios, the fuel supplier and airline options in which auctioning revenues are retained by the State have the most positive impacts. This is mainly because there is little evasion here, therefore Dutch passengers who cancelled their trip will now mostly spend their money in the Netherlands. Conversely, when auctioning revenues are funnelled back to the sector, we see a slight increase of the number of passengers who fly, therefore people have less money to spent in the Dutch economy leading to a negative impact on GDP. The airport options have a small positive impact. Table 79 provides an overview.

Table 79 - Evaluation of the impacts of the policy options on Dutch GDP

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Impacts on GDP	+	+	+	++	--	++	++	--

Note: in most scenarios, there are no impacts on GDP. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.
Note: a more detailed description of the meaning of the scores is included in Annex E.

7.5.4 Conclusion

In the evaluation of overall costs, compliance costs dominate because they are an order 1,000 larger than administrative costs. However, compliance costs are only relevant in a minority of the scenarios, while administrative costs are relevant in any scenario. Therefore we assign equal weights to all cost items, and also to the impacts on GDP.

The fuel supplier option in which revenues are funnelled back score and the airline options worst on this criteria. Options in which revenues are funnelled back have a negative impact on GDP, and the airline options have relatively high administrative costs. The scores of the other options are very close to each other. Table 80 presents the overall evaluation.

Table 80 - Evaluation of the overall costs of the policy options

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Compliance costs	++	++	++	--	+	--	--	+
Administrative costs	-	-	-	-	-	-	--	--
Impacts on GDP	+	+	+	++	--	++	++	--
Overall costs	0	0	0	0	-	0	-	-

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, compliance costs and impacts on GDP are zero. This evaluation of compliance costs assumes that baseline emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.6 Local environmental impacts of Dutch aviation

The local environmental impacts of Dutch aviation comprise airport noise and LTO emissions of air pollutants.

7.6.1 Airport noise

In most baseline scenarios, implementation of any policy variant will not have a material impact on aviation and hence there will not be an impact on airport noise. The impacts on airport noise in a baseline scenario in which action is required to remain below the ceiling have been presented in Section 5.8. The impact on airport noise stems predominantly from the change in the number of flights. However, it does matter which flights are cancelled. Therefore, there is no linear relation between the reduction of flights and the effects on airport noise. As such, the reduction in airport noise is larger for the airport options, in which the number of flights is reduced, than for the fuel supplier and airline options, in which long-haul flights are replaced by short-haul flights. When the auctioning revenues are funnelled back in the sector, the number of flights could even increase in some years, increasing airport noise. However, these increases are relatively small and do not occur for all years. Therefore, we expect the effects on airport noise to be negligible. Table 81 presents the evaluation of this criteria.

Note that this evaluation assumes that airlines will not take collective voluntary action in the airport options. If they would voluntarily act to avoid a reduction in airport capacity, the impact of the airport options on airport noise would be the same as for the fuel supplier and airline options.

Table 81 presents the evaluation of airport noise associated with the different policy options.

Table 81 - Evaluation of the impacts of the policy options on airport noise

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Airport noise	++	++	++	+	*0*	+	+	*0*

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, there are no impacts on noise. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.6.2 LTO emissions of air pollutants

In most baseline scenarios, none of the policy options will have an impact on LTO emissions of aviation because the CO_2 emissions remain the ceiling, and consequently the number of flights, types of aircraft and destinations remain the same.

The impacts of the policy options on LTO emissions in a scenario in which action is required to remain below the ceiling are presented in Section 5.7. Like the impacts on noise described above, the number of flights is a major driver of LTO emissions. LTO emissions are reduced in all options, but more so in the airport options where the number of flights is reduced, and less so in the airline and fuel supplier options in which long-haul flights are substituted by short-haul flights.

Note that this evaluation assumes that airlines will not take collective voluntary action in the airport options. If they would voluntarily act to avoid a reduction in airport capacity. The impact of the airport options on airport noise would be the same as for the fuel supplier and airline options.

Because LTO emissions are reduced in all options, sores are positive or neutral. Table 82 presents the evaluation of LTO emissions associated with the different policy options.

Table 82 - Evaluation of the impacts of the policy options on aviation LTO emissions

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
LTO emissions of air pollutants	++	++	++	+	+	+	+	+

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, there are no impacts on LTO emissions. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.6.3 Conclusion on local environmental impacts

In most baseline scenarios, there are no impacts on the local environment of either options. When the baseline emissions are higher than the CO_2 ceiling, the impacts are presented in Table 83. In the airport option the reductions are mainly caused by a reduction in the number of aircraft movements. The smaller reduction in the fuel supplier and airline option are mainly caused by an incentive for fleet renewal and a change in aircraft types used caused by a shift from long-haul to short-haul destinations.

Table 83 - Evaluation of the impacts of the policy options on the local environment of airports

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctionin g state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Airport noise	++	++	++	+	*0*	+	+	*0*
LTO emissions of air pollutants	++	++	++	+	+	+	+	+
Overall impact on the local environment of airports	++	++	++	+	+	+	+	+

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, there are no impacts. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.7 Impacts on aviation

7.7.1 Network

In most baseline scenarios, CO_2 emissions of international commercial flights departing from Dutch airports remain below the CO_2 ceiling. Consequently, aviation activity will be equal to the baseline and there will be no impacts on the network.

In scenarios where the CO_2 ceiling has an impact, the amount of distance travelled by air is significantly reduced in all options. However, the exact way in which this is done differs between the policy options. The reduction in total distance travelled by airplanes is mostly obtained by reducing the number of flights in the airport options. In the fuel/airline options, the number of flights is not reduced as much, because a shift from longer to shorter flights is realized and efficiency improvements are incentivized (which reduces the need to change the network). This is discussed in detail in Section 3.4. When the number of flights to a region is reduced, either the frequency to a specific airport or the number of destinations within that region have to be reduced, or both. This means that the quality of the network is reduced to some extent. This means that in all options, the intercontinental network quality reduces. In the fuel supplier and airline options, the quality of the intra-European network either reduces slightly (when auctioning revenues are added to government coffers) or improves (when revenues are funnelled back to the aviation sector).

Note that if airlines were to take voluntary action to safeguard airport capacity in the airline option, the impacts of the airport options would be the same as for the fuel supplier and airline options in which auctioning revenues are funnelled back.

Table 84 presents the evaluation of the impacts on network quality associated with the different policy options.

Table 84 - Evaluation of the impacts of the policy options on aviation network quality

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Network quality (intra-EEA)	-	-	-	-	+	-	-	+
Network quality (intercontinental)	-	-	-	-	-	-	-	-
Overall impact on network quality	-	-	-	-	0	-	-	0

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, there are no impacts. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.7.2 Competitiveness/level playing field

In the majority of scenarios, implementation of any policy option does not affect the competitiveness of Dutch airports or airlines. Only in scenarios where baseline CO_2 emissions exceed the CO_2 ceiling, impacts could occur.

In a restrictive scenario, the CO_2 ceiling could affect the competitiveness of Dutch airports and the competitiveness of Dutch airlines.

The competitiveness of airports is indicated by the amount of evasion of passengers and freight. A share of the decrease in passengers and freight at Dutch airport will evade to competing airports in other countries. Also a share of passengers who would transfer at Schiphol to a connecting flight in baseline will now fly via another hub, when the CO_2 ceiling is implemented and the emissions would rise above the ceiling. Section 3.2 shows that the number of passengers is reduced to a larger extent in the airport options than in the fuel supplier and airline options, and that the options in which revenues are funnelled back to the sector have the lowest impact (see Table 85). Note that the evaluation of the airport options assumes that airlines will not take collective voluntary action in the airport options. If they would voluntarily act to avoid a reduction in airport capacity, the impacts of the airport options on airport competitiveness would be the same as for the fuel supplier and airline options in which auctioning revenues are funnelled back.

Table 85 - Evaluation of the impacts of the policy options on airport competitiveness

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Airport competitiveness	--	--	--	-	0	-	-	0

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios, there are no impacts on airport competitiveness. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

An indicator of the competitiveness of Dutch airlines is the relative change in the number of passengers flying with a member of the SkyTeam alliance, of which KLM is a partner. In the airline options and the options in which auctioning revenues are retained by the State, SkyTeam is the second worst affected airline grouping in our model (the other groupings are Star Alliance, OneWorld, unaffiliated full service carriers, and low cost carriers). When auctioning revenues are funnelled back, SkyTeam benefits of the growing number of passengers, but other groupings (except for one) benefit more. Table 86 presents the evaluation.

Table 86 - Evaluation of the impacts of the policy options on airline competitiveness

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Airline competitiveness	-	-	-	-	--	-	-	--

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios. There are no impacts on airline competitiveness. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

Table 87 presents the evaluation on overall competitiveness of the Dutch aviation sector, if all elements have the same weight.

Table 87 - Overall evaluation of the impacts of the policy options on competitiveness of the aviation sector

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Airport competitiveness	--	--	--	-	0	-	-	0
Airline competitiveness	-	-	-	-	--	-	-	--
Competitiveness of aviation sector	-	-	-	-	-	-	-	-

Note: a more detailed description of the meaning of the scores is included in Annex E.
Note: in most scenarios. There are no impacts on airline competitiveness. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.7.3 Aviation external safety

The impacts on aviation safety are always positive, even when the baseline CO_2 emissions are far above the CO_2 ceiling, as shown in Section 6.2. We estimated the effects on external safety for the suboptions that have not been analysed in Section 6.2 based on the effects on the number of flights per subvariant.

Table 88 presents the evaluation on external safety of the Dutch aviation sector.

Table 88 - Evaluation of the impacts of the policy options on aviation external safety

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
External safety	++	++	++	+	0	+	+	0

Note: a more detailed description of the meaning of the scores is included in Annex E.

7.7.4 Conclusion on impacts on aviation

Table 89 summarises the subsections above as it evaluates the impacts of the policy options on the public goals of the aviation sector as described in the civil aviation policy memorandum. The impacts on network quality and competitiveness of the aviation sector are all given three times more weight compared to external safety (see Annex E).

Table 89 - Evaluation of the impacts of the policy options on Dutch GDP

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Network quality	-	-	-	-	*0*	-	-	*0*
Competitiveness of aviation sector	-	-	-	-	-	-	-	-
External safety	++	++	++	+	*0*	+	+	*0*
Impacts on aviation sector	-	-	-	-	0	-	-	0

Note: a more detailed description of the meaning of the scores is included in Annex E.

Note: in most scenarios, there are no impacts on airline competitiveness. This evaluation assumes that baseline CO_2 emissions are above the ceiling and that airlines will not voluntarily reduce emissions in the airport options.

7.8 Conclusions

Table 90 gives an overview of the scores of the different suboptions for the different criteria.

When comparing how the options score with respect to the main objective of the CO_2 ceiling (see Table 75), it first of all can be concluded that all policy options are suitable to achieve these goals. The total scores of the subcriteria are roughly equal. However, the airport options with a 3-year enforcement cycle score slightly better than the other options. This is mainly because the implementation is reasonably simple (because the legislation can be added to an existing legal framework) and the risk of international retaliation is comparably low (it is widely accepted that states have the right to determine airport capacity). However, the regulated entities have less direct control over CO_2 emissions than fuel suppliers and airlines. Because of the limited flexibility the airport option with a one year enforcement cycle scores lower than the airport options with strict allocation.

When comparing the options with respect to the other effects, it becomes clear that different suboptions perform well on different criteria. All suboptions perform well on total global climate effects. However, the ceiling per airport suboptions score well local environmental impacts compared to the other options. Furthermore, there are differences between the suboptions where the auctioning income is for the state versus the suboptions where the income is funnelled back: the latter scores better on impacts on the aviation sector, whereas it scores lower on the impacts on the Dutch GDP. All suboptions score equally well on the total costs, because costs made by the aviation sector are for the largest part income for the government.

However, it should also be noted that in the majority of baseline scenarios the emissions never reach the ceiling. In those scenarios, only the feasibility of implementation, and the administrative costs are relevant. Only if the ceiling is reached, then the other factors become of significance.

In this study we did not define a preferred policy option, since this implies that relative weights are given to the different criteria. This is a political decision that should not be made by the research team. As we explained above, the different suboptions all have relative strengths and weaknesses. The right policy choice depends on the relative importance that is assigned to these criteria.

Table 90 - Comparison of all the criteria in the multicriteria analysis

	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation (3-year cycle)	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
Certainty about aviation CO_2 emissions	+	0	+	0	0	0	0	0
Total climate impacts	++	++	++	++	++	++	++	++
Overall costs	0	0	0	0	-	0	-	-
Overall impact on the local environment of airports	++	++	++	+	+	+	+	+
Impacts on aviation sector	-	-	-	-	0	-	-	0

8 Conclusions

The aim of the CO_2 ceiling is to safeguard that the CO_2 emissions targets for Dutch aviation, set by the Government in the aviation white paper 'luchtvaartnota', are not exceeded. Apart from this main aim, the CO_2 ceiling could also affect the aviation sector, the economy, the environment and external safety.

Could a CO_2 ceiling effectively ensure that the emission targets are not exceeded?

A large set of plausible baseline scenarios have been developed to take into account socio-economic and policy uncertainty (airport capacity, European and national climate politics). They show that in the majority of plausible scenarios (38 out of 54), CO_2 emissions will not exceed the targets. However, there are other equally plausible scenarios in which emissions would exceed the targets. This is more likely in scenarios with high economic growth (WLO high scenario) in combination with moderate climate politics and high airport capacity.

Therefore, it can be concluded that, without government action, aviation emissions could exceed the CO_2 targets, even when the proposals of the Fit for 55 package are implemented as proposed. This would go against the policy goals as stated in the Civil Aviation Policy Memorandum and undermine the credibility of the Dutch efforts.

Ensuring that the CO_2 emissions of Dutch aviation do not exceed the ceiling provides certainty to market actors with regards to supply and demand of sustainable aviation fuels and aircraft innovation. It also provides clarity to the aviation sector about the limits within which growth is possible according to the policy framework set by the Dutch government.

For these reasons, it can be concluded that a national CO_2 ceiling for aviation could be an effective instrument to ensure that the agreed CO_2 emission limits are not surpassed.

Different policy options for the CO_2 ceiling

There are various choices that can be made when designing the CO_2 ceiling. The most important choice is which entity is regulated: the airports, the fuel suppliers or the airlines. We defined those as our main policy options. Furthermore, a range of more detailed choices need to be made. In our analysis we distinguished eight suboptions.

For the option where airports are the regulated entity we defined three suboptions:
1. Strict allocation of the CO_2 budget to airports; 3-year compliance cycle.
2. Strict allocation of the CO_2 budget to airports; 1-year compliance cycle.
3. Soft allocation of the CO_2 budget to airports; 3-year compliance cycle.

For the option where fuel suppliers are the regulated entity we defined three suboptions:
1. Auctioning revenues are retained as fiscal income for the state; a market stability mechanism is introduced.
2. Auctioning revenues are funnelled back to the aviation sector; a market stability mechanism is introduced.
3. Auctioning revenues are retained as fiscal income for the state; there is no market stability mechanism.

For the option where airlines are the regulated entity we defined two suboptions:
1. Auctioning revenues are retained as fiscal income for the state.
2. Auctioning revenues are funnelled back to the aviation sector.

Impact of the CO_2 ceiling if it is not restrictive

In most baseline scenarios, CO_2 emissions of commercial international flights departing from Dutch airports will remain below the CO_2 ceiling. In those scenario's, there are no impacts other than the implementation of the system, administrative costs and the risk of retaliation from the international community.

Impacts of the CO_2 ceiling if it is restrictive

In some scenarios, business as usual scenarios exceed the CO_2 ceiling. In those cases, regulated entities need to take action to reduce emissions to the level of the ceiling, with impacts on aviation, the environment and the economy. In this study, we compare the effects of the CO_2 ceiling compared to the baseline. Therefore, when we speak of negative effects we mean that the effects are negative in comparison to the baseline.[80]
Here we give a short summary of these impacts:

- Impacts on the aviation sector are that airlines will either have to fly less or fly in a more sustainable manner. Both options would likely lead to an increase in ticket prices and freight rates because of increased scarcity and additional costs (for example extra use of SAF) made by the airlines. Also, a restrictive ceiling would be a driver for additional fleet renewal towards a more efficient fleet. Impacts on fuel consumption would be that either less fuel is used (reduction of flights or shorter flights) or a shift from fossil kerosene to SAF is made. If the total number of flights is reduced to prevent surpassing the ceiling, there are negative effects on both the European and intercontinental network quality. If the total number of flights stays equal but additional costs are made (for example because of the use of extra SAF) then a shift in the network is observed: the intercontinental network becomes smaller due to more emissions per passenger, whereas the European network improves.
- The economic impacts of the CO_2 ceiling consist of compliance costs, administrative costs, auctioning revenues, fiscal impacts, cost of enforcement as well as upstream and downstream effects. Of these, the impacts of compliance costs are most significant. The compliance costs - specifically the fuel costs - in most policy options actually decrease due to the decrease in number of flights or increased share of shorter (EEA) flights. For the options where regulated entities have to buy CO_2 certificates and the revenues go to the state, the compliance costs can be relatively high. The allowance revenues for the state are therefore a positive fiscal impact. The administrative costs and enforcement costs are negligible compared to the compliance costs.
- The environmental impacts are in general positive if the number of flight decreases: less aviation means lower climate impacts (both from CO_2 and non-CO_2 effects), less local air pollution and less noise in the surrounding of airports. For the CO_2 emissions, a significant share of the emissions that are reduced by the Dutch aviation sector are still emitted elsewhere due to evasion of flights to foreign airports, a shift to land transport or additional emissions in other EU ETS sectors. Still, a net positive effect remains. If

[80] Note that in the reference scenario and most other scenario's, the number of flights can keep growing compared to current levels in all subvariants. Therefore, if we speak of negative effects on the aviation sector, these should be interpreted as negative in comparison to the baseline. In absolute terms the network quality and other aspects do still improve compared to the current situation.

the emission reduction is used by means of SAF blending instead of reduction of the aviation volumes, this does not cause evasion. Therefore, the net climate effects are larger if this happens. Also, some positive effects on air pollution are obtained by blending SAF. However, this would not significantly reduce airport noise.

- Social impacts and safety was in this study defined as the impacts on external safety and jobs in the Dutch aviation sector. The impacts on external safety are positive if the number of flights decreases, since this reduced the accident risks. The effects on jobs in the Dutch aviation sector are small in all policy options. In 2030 when the CO_2 ceiling is most restrictive, in the airport options the employment in the sector might be up to 8% lower compared to the volume of employment in the baseline. The negative impact on employment decrease over time as the ceiling is less restrictive. In the fuel supplier and airline options with funnelling back of allowance revenues the impacts on employment are negligible.

In this study, we have tried to account for the uncertainty of future developments by defining 54 different distinct baseline scenarios. Each presents a unique possible future. However, even these baseline scenarios do not cover all possible developments.[81] Two important aspects that might influence the results are:

1. More ambitious international climate policy for the aviation sector. In our analysis we defined different scenarios for EU and Dutch climate policy. However, in all scenarios it is assumed that outside of the EU the ambitions are limited. If other blocs in the world (such as the USA or China) or the international community agree on stricter climate policy for aviation, the level playing field is less disturbed by a Dutch CO_2 ceiling.
2. CO_2 ceilings, other climate measures or reduced airport capacities in neighbouring countries. If neighbouring countries also limit the amount of aviation (by additional taxes, capacity restrictions, …), the possibility for evasion would be reduced. Therefore, the net climate effects would benefit from such developments.

How do the options compare?

The main objective of the CO_2 ceiling is to safeguard that the emission limits which were set by the Dutch government are not surpassed. In general, all suboptions are able to meet this requirement. However, the airport option with a 3-year enforcement cycle (either soft- or strict allocation) scores slightly better compared to the alternatives on this point in the multicriteria analysis. This is mainly because the implementation is reasonably simple (within the existing airport permits) and the risk of international retaliation is comparably low. In addition, the number of regulated entities (Dutch airports) is small (compared to the airlines in the airline option) and all entities are situated in the Netherlands. However, the regulated entities have less direct control over CO_2 emissions than fuel suppliers and airlines. Because of the limited flexibility the airport option with a one year enforcement cycle scores lower than the airport options with strict allocation.

The CO_2 ceiling is designed to achieve its main objective, but by doing so it also causes other effects. When comparing the options with respect to the other effects, it becomes clear that different suboptions perform well on different criteria. All options lead to a significant overall CO_2 reduction. In the airport option this is mainly achieved by a reduction in the number of aircraft movements at Dutch airports, whereas in the fuel supplier option

[81] The decrease of the annual capacity at Schiphol from 500,000 aircraft movements to 440,000 is outside the range of the baseline scenario's. The scenarios with reduced capacity assume a linear decrease in capacity to 440,000 movements in 2050, but not in 2024.

and the airline option blending additional SAF and contributes significantly to the additional CO_2 reduction. The ceiling per airport suboptions score well on overall costs and local environmental impacts. Furthermore, there are differences between the suboptions where the auctioning income is for the state versus the suboptions where the income is funnelled back: the latter scores better on overall costs and impacts on the aviation sector. Also the impacts on the Dutch GDP are negative for these suboptions. It is important to consider that the state revenues that are generated in suboptions of the fuel supplier and the airline option can be used for other purposes, for instance to subsidize the development of sustainable aviation or contribute to other benefits for the society.

A fundamental difference between the options is who benefits from measures that decrease CO_2 emissions. In the airport option the benefits are collectively distributed, which means that more slots become available for the collective of airlines operating at Dutch airports. In the fuel supplier and airline options airlines are individually stimulated to decrease emissions, because additional costs are attached to CO_2 emissions. In case the collective stimulus would lead to unintended reactions of the airlines, the Dutch government could decide to implement additional measures to correct for this.

It should also be noted that in the majority of baseline scenario's the emissions never reach the ceiling. In those scenario's, only the feasibility of implementation, administrative costs and the risk of retaliation are relevant. Only if the ceiling would be surpassed in the baseline, the CO_2 ceiling has additional impacts on the aviation sector, the environment and the economy.

In this study we did not determine a preferred policy option, since this implies that relative weights are given to the different criteria. This is a political decision that should not be made by the research team. The main arguments for the airport option are the rather straight forward implementation in the existing airport permits and the relatively low risk of international retaliation. The main argument for the fuel supplier and the airline option are that the regulated entities have better possibilities to control over the CO_2 emissions and that airlines are individually stimulated to reduce their CO_2 emissions.

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A Stakeholder consultation

During this project two general stakeholder meetings have been organized and a third is planned around the publication date of the report. The first stakeholder meeting took place on 24 March 2022 as a hybrid event in Zzin in The Hague and online. The second stakeholder meeting was held as an online session on 30 June 2022. The purpose of these meetings was to inform the stakeholders on the development of the study and to present and discus intermediate results. The following organisations have been invited to the meetings.

Core team	
	KLM
	Royal Schiphol Group
	easyJet
	VNPI
	SkyNRG
Supervisory committee	
	Ministry of Economic Affairs
	Ministry of Finance
	PBL
	KiM
Advisory group	
	LVNL
	NLR
	TU Delft
	Boeing
	Climate Neutral Group
Stakeholders	
	Maastricht Aachen Airport
	Twente Airport
	Rotterdam The Hague Airport
	Eindhoven Airport
	Lelystad Airport
	ACN
	TUI
	Ryanair
	IATA
	Airports Council International
	NVL
	Transavia
	Corendon
	BARIN
	Neste
	Shell
	BP
	Airbus
	Boeing
	ANVR
	AOPA
	DNATA

	Embraer
	EvoFenedex
	GKN Fokker
	KNVVL
	VNO NCW
	NAG
	GKN Fokker
	LRN
NGOs	
	Greenpeace
	Natuur & Milieu
	Milieu en Natuurfederatie Noord-Holland
	Milieudefensie
	EDF
	RGO
	AEF
	Transport & Environment
Other organisations	
	Europese Commissie
	TU Delft
	ICAO/ECAC
	CBS
	NEa
	ILT
	Min. FIN

In addition three specific stakeholder sessions have been organized on March 11th 2022 with members of the possible regulated entities (Airports, Fuel Suppliers and Airlines). The purpose was to discuss the policy options and suboptions in detail and to obtain specific information on for instance implementation, regulation and administrative costs. The following table summarizes the participants of the online events.

Airport stakeholders	Fuel Supplier stakeholders	Airline stakeholders
Schiphol	VNPI	KLM
Maastricht Airport	Shell	Easyjet
Eindhoven Airport	Neste	Transavia
Groningen Airport	SkyNRG	Barin
Lelystad Airport	KLM	TUI
Twente Airport		ACN
Rotterdam The Hague Airport		
ACI Europe		
NVL		

To better understand the strategic responses to the CO_2 ceiling by important players, we interviewed the following airports and airlines in a confidential one-to-one setting:
- KLM;
- Transavia;
- Easyjet;
- Schiphol Airport;
- Rotterdam The Hague Airport.

B Baseline scenarios

CE Delft
Committed to the Environment

1 Introduction

This Appendix contains the 'Task Report Proposal Selection Baseline Scenarios'. The document has been shared with the supervisory committee of this study and comments of the members have been addressed. Therefore, the text has not been adjusted in this Appendix. Since the moment when the Task Report has been written the terminology in the project has evolved. Therefore, this appendix is not fully consistent with the main part of this report. These changes should not lead to problems understanding the context of this appendix. In addition, in the section 'Modelled scenarios' a part of the original Task Report has been left out since the results of the modelling have been updated. All results are presented in the main part of this report. The place is marked in the text.

This memo contains a proposal for the selection of baseline scenarios for the impact assessment of the national aviation CO_2 ceiling. It builds upon a task report which presents the scenarios and which has been disseminated amongst stakeholders. Section 2 has been altered and Section 8 presents the proposal for selection.

2 General considerations

Impact assessments for the Dutch government generally use two baseline scenarios, labelled WLO Low and WLO High and representing a future with low economic growth, loose environmental regulation and low innovation; and a future with high economic growth, more stringent environmental regulation and high innovation, respectively.

The WLO scenarios for aviation have been defined in 2015 (CPB & PBL, 2016) and updated in 2018 (SIGNIFICANCE & To70, 2019). They do not take into account more recent developments, especially with regards to airport capacity, Fit for 55 combined with the Dutch SAF blending, and COVID-19. For the Impact Assessment of the National CO_2 Ceiling for Aviation, new baseline scenarios have been developed which include these recent developments. The basis for the new scenario is provided in Table 1

Table 1 - Overview of current, proposed and announced policies for the Dutch aviation sector and their implementation in AEOLUS

		Current policy	Proposed policy	Announced policy	*Implementation of base scenario of Impact Assessment CO_2 ceiling in AEOLUS*
Airport Capacity restrictions	Amsterdam Schiphol	500,000	No proposed changes	No announced changes	*2018-2050: 500.000*
	Lelystad	No commercial air traffic	25,000 in 2030.	No announced changes	*2017-2022: 0* *2023: 4,000* *2030: 25,000* *2050: 45,000* *(linear interpolation)*
	Eindhoven	2030: 41,500 2050: 41,500	Remain within noise contours. ASSUMPTION max. capacity: 55,000	No announced changes	*2017-2030: 41,500* *2050: 55,000* *(linear interpolation)*

		Current policy	Proposed policy	Announced policy	*Implementation of base scenario of Impact Assessment CO_2 ceiling in AEOLUS*
	Rotterdam	2030: 22,000 in LOW and 25,000 in HIGH 2050: no limit	No proposed changes	No announced changes	*2030: 22,000 (LOW)/25,000 (HIGH)* *2031-2050: no limit (capacity determined by demand)*
	Maastricht	2030: 17,500 2050: no limit	No proposed changes	No announced changes	*2030: 17,500* *2031-2050: no limit (capacity determined by demand)*
	Groningen	2030: 17,500 2050: no limit	No proposed changes	No announced changes	*2030: 17,500* *2031-2050: no limit (capacity determined by demand)*
Tax	Taxes	Aviation tax € 7,845 per departing OD passenger, adjusted for inflation	Fit for 55 (energy tax	Threefold increase aviation tax	*Aviation tax € 23,535 per departing OD passenger (= 3 x € 7,845)* *Energy tax on intra-EU flights of EUR 0.90 per GJ of kerosene*
Climate policy	SAF blending	No policy	Increased blending of SAF and RFNBO with targets as in ReFuelEU en REDIII	National blending targets: 14% in 2030 and 100% in 2050	*Flights departing from NL airports:* *2030: 14%* *2050: 100%* *Pathway 2020-2050: curve with constant growth rate* *Flights departing from other EEA airports:* *2030: 5%* *2050: 63%* *Pathway 2020-50 as in ReFuelEU*
	Action Programme for Hybrid Aviation (AHEV)	-	-	100% electric taxiing in 2030 100% electric flying under 500 km in 2050	*Not in AEOLUS. Post processing. Introduction electric flying from 2041.*
	Emissions trading and carbon pricing	EU ETS (intra-EU flights) CORSIA (international flights)	Fit for 55: revised EU ETS	N/A	*Ticket prices include EU ETS and CORSIA prices.*
	Induced innovation in aviation sector				*Impact of price incentives from AERO-MS*
COVID-19	Recovery and long-term effects				*Follow climate and energy outlook 2021 PBL*

For three additional dimensions, namely 1) the airport capacity, 2) European climate policy (Fit for 55) and 3) national climate policy (Dutch SAF blending), three options have been defined, low, middle and high. In addition, a COVID-19 correction has been defined and applied to all baseline scenarios. This results in a total of 54 possible scenarios.
Table 2 presents an overview. Scenarios 20 and 23 correspond to the definition in Table 1 and are the central scenarios. During the impact assessment a selection of these baseline scenarios will be considered. Scenarios in which the CO_2 ceiling is not restrictive will not be studied further, since there will be no impacts from applying the ceiling other than administrative tasks and costs.

Table 2 - Overview of possible baseline scenarios

	National SAF blending	WLO Low with COVID-19 recovery			WLO High with COVID-19 recovery		
		Airport Capacity Low	Airport Capacity Middle	Airport Capacity High	Airport Capacity Low	Airport Capacity Middle	Airport Capacity High
Fit for 55 reduced	Reduced ambition	1	2	3	4	5	6
	As proposed	7	8	9	10	11	12
	Increased ambition	13	14	15	16	17	18
Fit for 55 as proposed	Reduced ambition	19	20*	21	22	23*	24
	As proposed	25	26	27	28	29	30
	Increased ambition	31	32	33	34	35	36
Fit for 55 increased ambition	Reduced ambition	37	38	39	40	41	42
	As proposed	43	44	45	46	47	48
	Increased ambition	49	50	51	52	53	54

* Central scenarios.

3 Airport capacity restrictions

Three levels have been defined for airport capacity restrictions. For Rotterdam, Groningen and Maastricht the capacity restrictions are the same in all three levels. For the airports of Amsterdam, Lelystad and Eindhoven the combined capacity in the base scenario is 600,000 aircraft movements in 2050. The high variant assumes maximum use of the capacity at Amsterdam within the current operational and safety constraints. This results in an increase of 130,000 flights in 2050 (Ministerie van Infrastructuur en Waterstaat, 2020). A low variant has been defined which mirrors this by reducing the combined capacity at Amsterdam, Lelystad and Eindhoven by 130,000. The capacity reduction has been divided over these three airports by assuming that Lelystad will not open, in conformity with current policy (see Table 1), and that the capacity at Eindhoven will be restricted to 30,000 flights in order to achieve a 30% reduction in noise, in conformity with the result of the stakeholder consultation (To70, 2019).

For the largest airport, Amsterdam, capacity is fixed at the current level of 500,000 aircraft movements per year in the base scenario. The low and high scenario respectively envisage a gradual reduction to 440,000 aircraft movements per year in 2050 or a gradual increase to 630,000 aircraft movements per year in 2050. In the low scenario, Lelystad is not open, whereas in the base and high scenario, its capacity increases from 25,000 aircraft movements per year in 2030 to 45,000 aircraft movements per year in 2050. Eindhoven has a capacity of 41,500 aircraft movements per year in 2030 in both the base and high scenario, increasing to 55,000 in 2050. In the low scenario, the capacity is 38,000 movements in 2030 reducing to 30,000 in 2050. The capacity of Rotterdam The Hague is fixed at

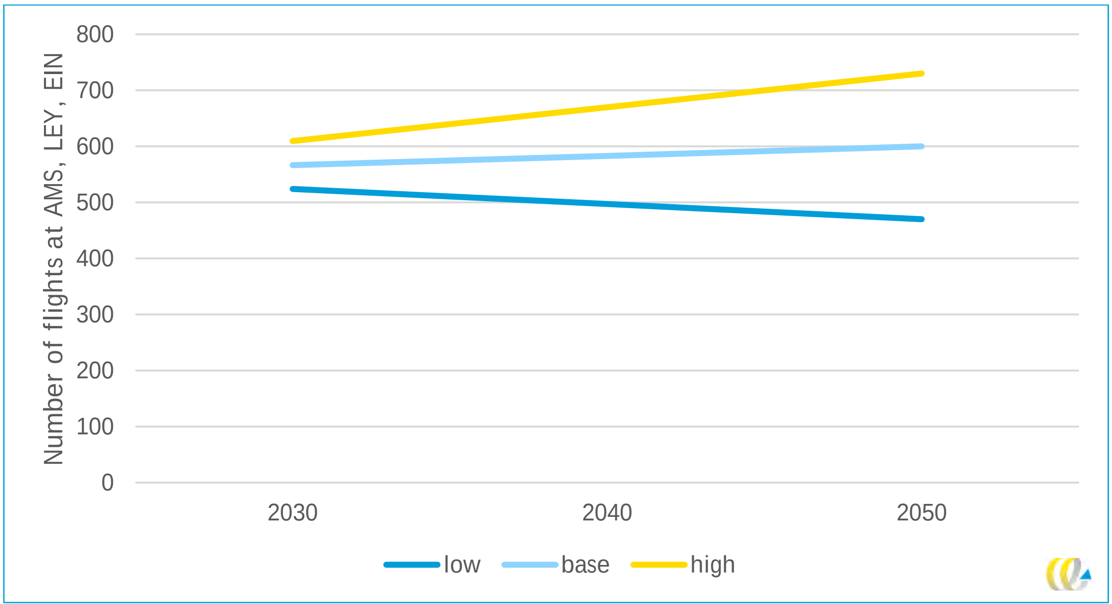
25,000 movements in 2030 and determined by demand in the later years in the base and high scenario (note that this does not result in a larger number of flights in the base scenario). In the low scenario, the capacity in 2040 is 40,000 aircraft movements. Both Maastricht Aachen and Groningen Eelde have a capacity of 18,000 in 2030 in all scenarios and 30,000 in the low scenario in 2040. In all other scenarios, the number of aircraft movements in 2040 and 2050 is determined by demand. Table 3 provides an overview and Figure 1 provides the combined capacity at Amsterdam, Lelystad and Eindhoven.

Table 3 - Airport capacity restrictions scenarios (1,000 movements)

	2030			2040			2050		
	Low	Base	High	Low	Base	High	Low	Base	High
Amsterdam	486	500	543	463	500	587	440	500	630
Lelystad	0	25	25	0	35	35	0	45	45
Eindhoven	38	41.5	41.5	34	48	48	30	55	55
Rotterdam - The Hague	22/25	22/25	22/25	*	*	*	*	*	*
Maastricht Aachen	17.5	17.5	17.5	*	*	*	*	*	*
Groningen Eelde	17.5	17.5	17.58	*	*	*	*	*	*

Note: * means that the capacity is determined by demand. For Rotterdam/The Hague the capacity limit for 2030 is slightly different in the WLO Low (22k) and in the WLO High scenarios (25k).

Figure 1 - Combined capacity limit at Amsterdam, Lelystad and Eindhoven (*1,000)



4 Fit for 55

Three Fit for 55 scenarios have been developed. In the main scenario, all proposals are adopted as proposed by the Commission on 14 July 2021. In a reduced scenario, the blending obligation of ReFuelEU Aviation is halved and the energy tax on aviation fuels is not implemented. In an increased ambition scenario, the blending obligation of ReFuelEU Aviation is increased by 50%. Table 4 presents an overview.

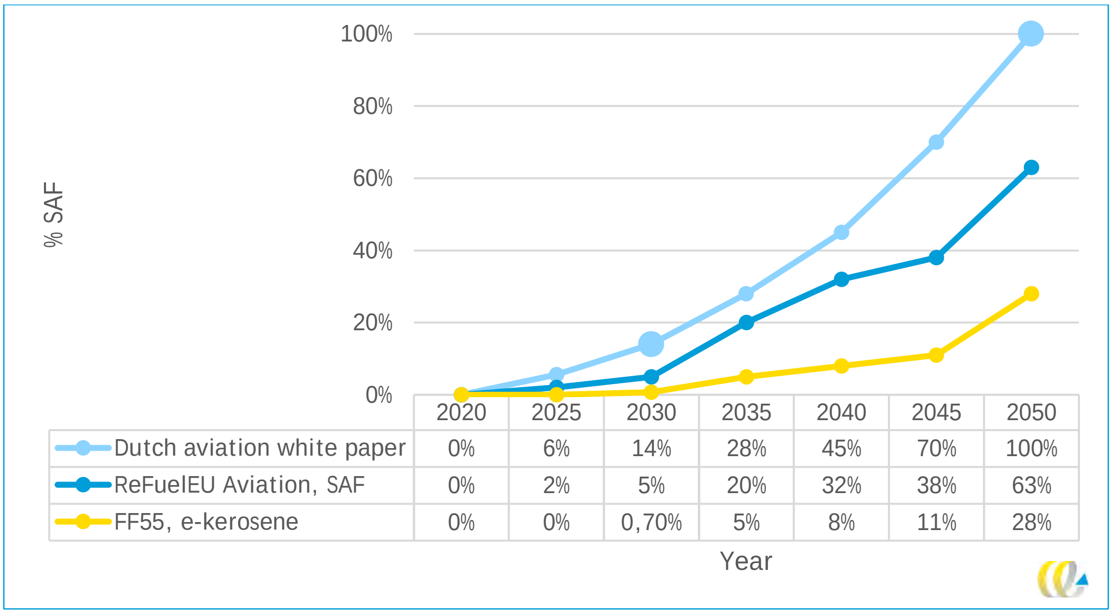
Table 4 - Fit for 55 scenarios

	EU ETS	CORSIA	ReFuelEU Aviation	ETD
Fit for 55 reduced	As proposed by the Commission	As currently agreed by ICAO	50% of the blending volumes proposed by the Commission	No energy tax on aviation fuels
Fit for 55 proposed	As proposed by the Commission	As currently agreed by ICAO	As proposed by the Commission	As proposed by the Commission
Fit for 55 increased ambition	As proposed by the Commission	As currently agreed by ICAO	150% of the blending volumes proposed by the Commission	As proposed by the Commission

5 National SAF blending

The Dutch white paper on aviation (Luchtvaartnota) contains the aim to blend 14% SAF in 2030 and 100% in 2050. Interpolation between 2020 and 2030, and between 2030 and 2050 with a constant annual growth rate yields a blending curve that is more stringent than the proposed blending mandate of ReFuelEU Aviation, as shown in Figure 2 (a curve rather than a linear increase represents the gradual increase in production capacity over time). Low national SAF blending requires blending in line with ReFuelEU; high SAF blending 23% in 2030 and 100% from 2041 onwards.

Figure 2 - SAF blending and blending mandates



6 Dutch aviation tax

In line with the Coalition Agreement, the Dutch aviation tax is increased to $€_{2017}$ 25.49 from 2023 onwards (the price level in AEOLUS is 2017, this corresponds to $€_{2022}$ 27.19).

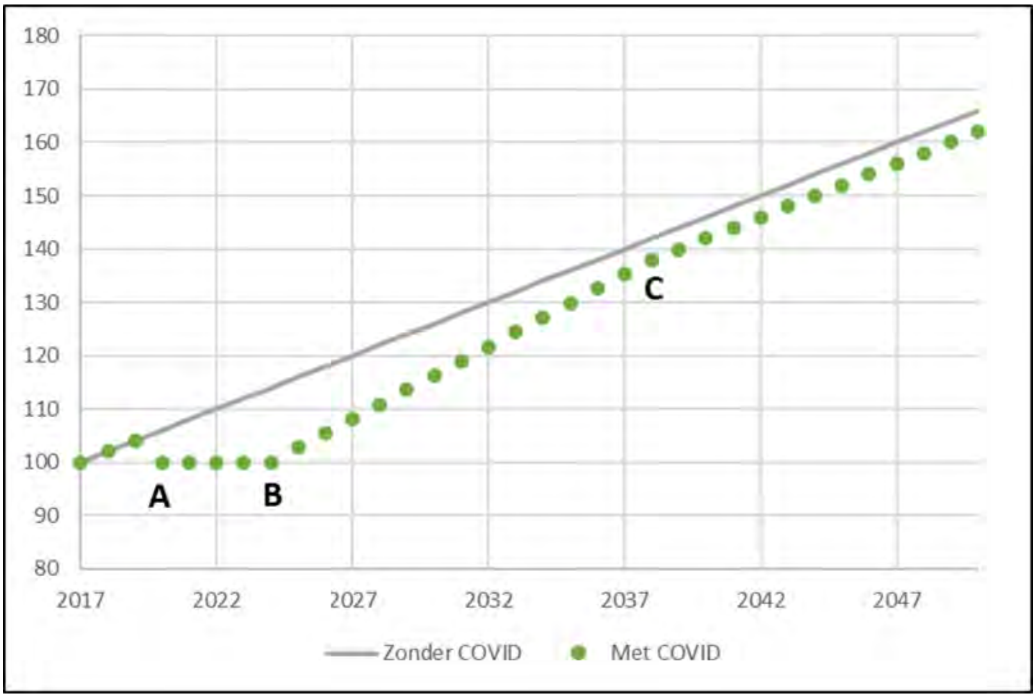
7 COVID-19 recovery

In line with the Climate and Energy Outlook 2021 (KEV2021) of the Dutch Environmental Assessment Agency (PBL), the COVID recovery entails:

1. Overall leisure demand returns to 2019 levels by 2024; Business demand is reduced by 5% (B in Figure 3).
2. Ticket prices are 3% higher between 2024 and 2030 in order for airlines to pay back emergency loans (Bouwer, et al., 2021).
3. Accelerated growth rates between 2024 and 2038 so that by 2038, leisure demand is back on its pre-COVID path and business demand is 5% lower (dotted line between B and C in Figure 3).

Figure 3 presents how demand recovers between 2024 and 2050.

Figure 3 - Recovery of demand after COVID-19



Source: Significance Memo, June 2022.

8 Modelled scenarios

In a number of scenarios, the projected CO_2 emissions of Dutch aviation stay below the CO_2 ceiling. Modelling the policy variants in these scenarios does not yield information about their impacts (other than administrative costs). In other scenarios, the exceedance of the ceiling is similar, which also results in similar impacts when modelled. Hence, the total number of 54 scenarios (Table 2) can be reduced. This section explains which scenarios have been selected.

Here a part of the Task Report has been left out since the results of the modelling have been updated. All results are presented in the main part of this report.

From the scenarios, we propose to select only scenarios that project emissions above the CO_2 ceiling for at least ten years, in order to have two data points (the impacts are assessed for every fifth year (the impacts of scenarios that have emissions above the ceiling for a few years can be inferred from the assessment of the scenario which is closest by in terms of emissions. Applying this criteria eliminates all scenarios with increased Fit for 55 ambition[1] or increased national SAF blending ambition, as well as WLO laag scenarios with Fit for 55 as proposed, as well as Scenarios 28, 29, and probably Scenarios 1 and 7. A second selection criterion is to select scenarios that vary on one important aspect from other modelled scenarios, so that the differences can be attributed transparently. Starting from the modelled central Scenario 23, this results in selecting at least Scenarios 5 and 24. Finally, from the remaining scenarios we select scenarios that are sufficiently different from each other. In combination with the second criteria, this results in the following selection:

The two central scenarios, as defined in Table 1:
1. WLO Low, Fit for 55 as proposed, no additional national SAF blending, airport capacity middle.
2. WLO High, Fit for 55 as proposed, no additional national SAF blending, airport capacity middle (23).

Only central Scenario 2 will be modelled, as emissions in central Scenario 1 remain below the CO_2 ceiling for most years.

Five additional scenarios that will be modelled:
1. WLO High, Fit for 55 reduced, no additional national SAF blending, airport capacity middle (5).
2. WLO Low, Fit for 55 reduced, no additional national SAF blending, airport capacity middle (2).
3. WLO High, Fit for 55 as proposed, no additional national SAF blending, airport capacity high (24).
4. WLO High, Fit for 55 reduced, no additional national SAF blending, airport capacity high (6).
5. WLO High, Fit for 55 reduced, additional national SAF blending, airport capacity high (12).

Note that the selection is skewed towards scenarios with high demand for aviation (WLO Hoog), high supply (airport capacity high) and climate policies which are less ambitious than currently proposed by the European Commission and in the Luchtvaartnota and the Coalition Accord. The reason is that the emissions remain below the ceiling in most scenarios with low demand for aviation (WLO laag), climate ambition in line with the Luchtvaartnota and the Coalition Accord, and current or restricted airport capacity.

Table 5 presents the scenarios that will be modelled.

[1] We still need to check whether scenarios with an increased airport capacity in WLO hoog (especially 42 and 48) also stay below the ceiling.

Table 5 - Overview of possible baseline scenarios

		WLO Low with COVID-19 recovery			WLO High with COVID-19 recovery		
	National SAF blending	Airport Capacity Low	Airport Capacity Middle	Airport Capacity High	Airport Capacity Low	Airport Capacity Middle	Airport Capacity High
Fit for 55 reduced	Reduced ambition	1	2†	3	4	5†	6†
	As proposed	7	8	9	10	11	12†
	Increased ambition	13	14	15	16	17	18
Fit for 55 as proposed	Reduced ambition	19	20*	21	22	23*†	24†
	As proposed	25	26	27	28	29	30
	Increased ambition	31	32	33	34	35	36
Fit for 55 increased ambition	Reduced ambition	37	38	39	40	41	42
	As proposed	43	44	45	46	47	48
	Increased ambition	49	50	51	52	53	54

* Central scenarios.

† Scenarios that will be modelled.

9 References

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C Design of options and suboptions

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1 Introduction

This Appendix contains the 'Task Report Policy Options'. The document has been shared with the supervisory committee of this study and comments of the members have been addressed. Therefore, the text has not been adjusted in this Appendix. Since the moment when the Task Report has been written the terminology in the project has evolved. An example is the 'airline option' which is called 'national ETS' option in this Appendix. These changes should not lead to problems understanding the context of this appendix.

This Task Report is a part of the impact assessment of the Dutch national CO_2 ceiling. It results from Task 1, the definition of options and suboptions for the design of a ceiling, of which the impacts will be assessed.

The relevance of this Task Report in the wider impact assessment is that the impact assessment will assess all relevant impacts of all options and suboptions against a series of baseline scenarios. The study will compare the impacts of the different variants in order to provide decision makers with the best possible information. The memo has been drafted by CE Delft and was reviewed by the ministry of I&W and the supervisory committee for the impact assessment.

In Chapter 2 we discus some general considerations. Afterwards we give an overview of all possible dimensions to define the suboptions (Chapter 3). Chapter 3.1 looks into the general dimensions which are common for all main options. In Chapter 5 we present the specific dimensions per main option. In these parts we list all theoretical options per dimension. From those we selected the preferred options and give a prediction of the difference in modelled effect. Below the tables brief argumentation is given for the preferred options. In the last part (Chapter 4) we list first suggestions for possible suboptions.

2 General considerations

In this chapter we give a short recap on the approach to define the suboptions as presented in our proposal, summarize the most relevant findings in relation to the suboptions from the preparatory assessments and shortly reflect on the coalition agreement from December 2021.

2.1 Proposal

The study will analyse two to five suboptions per main option (ceiling per airport, national ETS, fossil fuel ceiling) with a maximum of ten suboptions. These suboptions will be evaluated for a number of baseline scenarios. In addition, sensitivity analysis will be carried out to determine the impacts of potential external trends or events and additional (national) policies, for instance the market recovery from COVID-19.

The method for the definition of the suboptions consists of the following steps:
- Make use of preparatory analyses of To70, NLR and CE Delft.
- Explore all possible design dimensions and options (see Chapter 3).
- Narrow down per dimension and per main option (see Chapter 4).
- Take into account preferences of I&W and supervisory committee.

2.2 Preparatory assessments and coalition agreement

Coalition agreement

The coalition agreement states that the government is planning to introduce a CO_2-ceiling per airport[1]. This can be interpreted as a preference for the main option ceiling per airport. Indeed, the minister has informed Parliament on previous occasions that the working hypothesis of the government is that the ceiling per airport is the most viable option. The comparison with other options in this study will inform whether this hypothesis needs to be revised. After consultation with the ministry of I&W it has been clarified that the formulation in the coalition agreement has no impact on the definition of the suboptions for this study.

Future Lelystad unclear

The coalition agreement states that a decision about the possible opening of Lelystad airport for civil aviation will be made in 2022[2]. Since the decision about the opening of Lelystad airport is potentially very relevant for the outcomes of the impact assessment, we recommend considering both possible options within this study. However, we suggest not to consider the 'open' and 'closed' option for all combinations of suboptions and baseline scenarios. The reason is that this distinction would require two model runs and impact estimations for each of these combinations and hence result in a reduction of possible options that can be studied by a factor of two.

Instead, for the baseline scenario we propose to analyse a situation in which Lelystad airport will be opened before the implementation of the CO_2 ceiling in 2024. Since the formal decision to open Lelystad is under review but has not been revised, we consider opening of Lelystad as the status quo in this study. This is in line with the assumptions in the AEOLUS model update[3]. The effects of a situation without Lelystad airport will be taken into account in alternative scenarios.

For the ceiling per airport option, it has to be decided on which basis a CO_2 budget will be allocated to Lelystad airport, since it has no historical emissions. Either the budget can be created by decreasing the budget of all other airports or by transferring the budget from Schiphol. This aspect will be discussed in more detail in Chapter 0. In the other main options, the allocation of rights is either for fuel related parties or airlines. In these cases, the budget is not directly linked to specific airports.

The legal uncertainty of ETS option

During the preparatory analyses of CE Delft[4] and the legal assessment of the ministry of I&W, it became obvious that the introduction and enforcement of the ETS option is much more challenging than the other two main options. Given this uncertainty we recommend selecting a maximum of only two suboptions for the ETS option and focusing with the remaining maximum of eight suboptions on the fossil fuel ceiling and the airport option. An additional argument is that we foresee many similarities in

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1 'We zetten de voorstellen voor verduurzaming uit de Luchtvaartnota 2020-2050 'Verantwoord vliegen naar 2050' (2020) door, waaronder emissie plafonds per luchthaven.'

2 'Dit vraagt om een integrale oplossing die zekerheid en perspectief biedt voor zowel de hub functie van Schiphol als de omgeving van de luchthaven. Het kabinet zal hierover in 2022 besluiten en hierbij de opening van vliegveld Lelystad betrekken en hierbij ook de laagvlieg routes in ogenschouw nemen.'

3 AEOLUS update January 2022, private communication with Significance, not published yet.

4 'Taak 4 - Internationale effecten van de verschillende varianten' and 'Taak 5 - Beleidsadvies over de internationale inzet'.

the behavioural reactions of airlines and passenger in the ETS and the fossil fuel option. Although there might be small differences, the implementation in AEOLUS for the model estimations will take into account the effects of ticket price increases on the passenger choice and on the strategic choices of airlines on fleet usage/renewal, fuel blending and potential adjustments of destinations in the same way. Both of these main options have in common that they lead to additional costs in that the CO_2-ceiling introduces a capacity restriction at Dutch airports. For the ceiling per airport option, such a restriction is introduced as well, but airlines do not face additional costs due to the CO_2-ceiling (due to the lack of auctioning in this option). This situation (scarcity of slots and no extra costs) enables airlines to increase their prices and increase profits per unit. In the fossil fuel ceiling option and the national ETS option revenues from the auctioning of rights are for the state (but could be used to stimulate sustainability projects in aviation). The similarities between the ETS and national fuel ceiling option implies that impacts on the demand for ETS suboptions can probably be deduced quite well from comparable fossil fuel options.

3 Overview of dimensions

In Table 1 a preliminary overview of all possible dimensions is presented. We distinguish dimensions that are the same for all main options and dimensions that are specific for the three main options. For the definition of each suboption a specific design option has to be chosen per dimension. The individual suboptions will be distinct in at least one of the dimensions.

Table 1 - Overview of the potential dimensions that must be defined for the individual suboptions

Dimensions for suboptions in all main options	**Dimensions for 'ceiling per airport'** option	**Dimensions for 'fossil fuel ceiling'** option	**Dimensions for 'national ETS'** option
Emission contribution SAF	Regulated entity	Regulated entity	Regulated entity
Measuring method CO_2 emission	Ceiling system	Ceiling system	Ceiling system
Reference period for allocation or limit	Budget Lelystad Airport	-	-
Definition cumulative CO_2 budget	Allocation between airports	Initial allocation of rights	Initial allocation of rights
Moment of definition pathways	Addressees pathway	Regulation point in value chain	Auctioning method 1
Banking	-	Auctioning method	Auctioning method 2
Monitoring and enforcement	-	Limit on purchase or possession	Improved grandfathering
Compliance period	-	Timing of auctions	Timing of auctions
-	-	Secondary market	Secondary market
-	-	Market stability mechanism	Market stability mechanism

3.1 General dimensions for all main options

In Table 2 the general dimensions for all main options are listed. The first two columns number and state the particular dimension. The third column lists all the theoretical options found for this dimension. In the fourth column we picked from the theoretical options the preferred one(s), with argumentation for these choices given see Table 2. In the fifth column we propose whether this dimension should be constant or variable in the suboptions used for the model calculations.

Table 2 - List of dimensions, theoretical options, preferred options, whether the dimension is a constant or variable in the suboptions and expected model effects for all main options

N	Dimensions	Theoretical options	Preferred options	Constant/variable in suboptions
1	Emission contribution SAF	0% or based on LCA	0%	Constant
2	Measuring method CO_2 emission	Realized transport data, realized fuel data, tanked fuel, modelled CO_2-emission	1. Modelled CO_2-emission 2. Tanked fuel	Constant
3	Reference period for allocation or limit	2005, 2014-2019, 2017-2019, 2019, etc.	2017-2019	Constant
4	Definition cumulative CO_2 budget	Linear, demand driven or accelerated	Linear	Constant
5	Moment of definition cumulative CO_2 budget	Pre-defined or in steps	Pre-defined	Constant
6	Banking	Yes or no	Yes	Constant
7	Monitoring and enforcement	ILT, MLA, NEa	ILT (Ceiling per airport); Nea (other main options)	Constant
8	Compliance period	Yearly, every 2-years, every 3-years, every 5-years, etc.	Every 3-years	Constant

1. 0% Emission contribution SAF: SAF has much lower but still positive total lifecycle emissions compared to fossil kerosine (about 70-100% reduction). When SAF is counted as 0% contribution to the emission budget the Scope 3 emissions are not regulated within the CO_2 ceiling and airlines are less stimulated to use the most sustainable fuels (this also depends on the allowed SAFs; when - as in EU ETS - only high greenhouse gas saving biofuels are allowed, airlines are still stimulated). An alternative option is to determine the SAF-emissions with a LCA approach, such as is used by the EU Renewable Energy Directive or by ICAO in the context of CORSIA, resulting in approximately 20% residual emissions (ICAO, 2021). However, this LCA approach is not in line with the provisions of the EU's Emissions Trading Scheme. If choosing an LCA approach, then fossil fuel emissions should be calculated with the same approach for consistency reasons. This implies that emissions are calculated for the whole chain, raising the attributable emissions from Dutch aviation. By taking into account the emissions of earlier steps in production we would either burden the aviation sector with emissions from other sectors and double count the emissions. Both options seem unwanted. Also, this method may become very complex, because upstream emissions may vary over the source from which the crude is extracted, the refinery, the way in which the fuel is transported, and many other variables. Aligning with ReFuelEU Aviation and the revision of the EU ETS within the Fit for 55 proposals seems logical here. In these policies all sustainable aviation fuels which meet the requirements of the RED will probably be counted with a 0% CO_2 contribution.[5,6] Note, that also the contribution of alternative aircraft propulsion (electric, hydrogen) must be taken into account. In our suggestion they are also considered with a 0% contribution.

[5] Page 23, 'Omgang met duurzame brandstoffen', Taak 3 (CE Delft, 2021).
[6] Page 6, 'Duurzame brandstoffen', Kamerbrief (Ministerie van Infrastructuur en Waterstaat, 2021).

CE Delft

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- CE Delft will make a separate analysis for the possible changes in the well-to-wing emissions for other economic sectors, as well as the non-CO_2 climate effects of aviation.

2. Modelled CO_2 emissions or monitored fuel use or uplift as the measuring method for CO_2 emissions: An accurate option would be to align with the method of the EU ETS, where the realized fuel data are calculated by fuel measurements before and after flight. However, it seems that this data is not usable for a Dutch CO_2 ceiling, given the differences in geographical scope. Also, for ETS as well as CORSIA, the Dutch authorities primarily process global CO_2 data from Dutch airlines instead of emissions from all airline departing the Netherlands. Foreign airlines could object to supply their fuel data.[7] Modelled CO_2 emissions has the current preference as it is an accurate method, but could lead to discussions about the model. Monitored fuel uplift has the second preference due to tankering risks, but becomes the preferred option in the future, if the Refuel EU Aviation initiative is implemented. This will include the requirement to tank on average at least 90% of the fuel at the departing airport and obligate parties to report detailed fuel data. Realized transport data have no direct link to CO_2 emission and should not be used.[8] Note that the reference year for the cumulative CO_2 budget is 2005. The chosen measuring method has also to be applied on the available data of this year to determine the reference value of the CO_2 ceiling. For the realized fuel data this is not directly possible since aviation was included in 2012 in the EU ETS.
   - A policy decision about the measuring method will be made later, in the phase of the legislative proposal.
   - For the purpose of this study tanked fuel will be used as information source to determine the total (available) CO_2 budget. This also aligns with the 'Luchtvaartnota' and the letter to parliament. CE Delft and Significance will analyse in which way this information source influences the modelling for each of the main options.
   - CE Delft will analyse the administrative burdens of the different monitoring options, independently of the main option.
   - Current estimates are that 5% of the tanked fuel in the Netherlands is due to outbound tankering. CE Delft and Significance will perform an analysis of the possible behavioural reactions, including tankering (Peeters, et al., 2021).

3. Reference period of 2017-2019: All options need a reference period for either their allocation of budget (Ceiling per airport option), allocation of rights by grandfathering (option in National ETS option) or when introducing a limit on the purchasing of rights (option in Fossil fuel and National ETS options). Choosing a year close to 2005 could result in a distorted allocation since the amount of emissions and market shares have changed since then. Also, from 2005 onwards traffic volumes have grown faster at the regional airports than at Schiphol. Therefore, including years too close to 2005 would lead to too tight a budget for regional airports for the Ceiling per airport option. More recent years such as 2020 and 2021 are not representative due to the COVID-19 situation. 2019 is the most recent representative year but a period of one year does not take into account the fluctuations of traffic over the years. The most equally distributed period for the Ceiling per airport option seems to be 2017-2019.[9] For the other options more research would be needed to make an informed decision for the reference period. For now, a similar period seems appropriate and consistent.

7 Page 11, 'Bepaling van de CO_2-uitstoot', Taak 2 (CE Delft, 2021).

8 Page 13, 'Verdeelsleutel: verdelen op basis van welke parameter(s)?', (To70, 2021).

9 Page 22, 'Verdeelsleutel: bepalen referentieperiode', (To70, 2021).

3. Linearly reducing pathway to determine cumulative CO_2 budget: To determine the cumulative CO_2 budget we need to draw a line through the reduction target of the 'Luchtvaartnota'. This line could have various shapes resulting in different CO_2 budgets. One option is a demand driven pathway, this pathway follows the technological innovation but can lead to a postponement of reduction measures and overall, more emissions. An accelerated pathway would stimulate sustainability measures the most but brings the risk of reaching the CO_2 ceiling at an early stage and is less cost efficient since innovations need time. Also the demand driven and accelerated pathways will become quite complex, and illogical, if they have to fulfil the reduction targets of 2030 and 2050. A linear pathway would result in the average cumulative CO_2 budget, and therefore is the best compromise.[10] Also note that all options have flexibility built in, therefore none of them have to strictly follow the exact line of the cumulative CO_2 budget.
   The advised choices for the general dimensions result in a proposed cumulative CO_2 budget, which can be seen in Figure 1. Since there is no policy for what the ceiling until 2030 is supposed to look like, we have worked out a practical proposal. For the purpose of this impact assessment we assume an introduction of the National CO_2 ceiling in 2024. According to the Eurocontrol base scenario the flight level will approximately recover in 2024 from the COVID-19 pandemic to the 2019 level (Eurocontrol, 2021). We suggest using the 2019 emissions as the initial point to define the cumulative CO_2 budget from 2024 onwards. This supposes that there are no efficiency improvements between 2019 and 2024. In reality, the emissions in 2024 are very likely to be lower, giving the sector some more space and softening the effects of the introduction of the ceiling. The proposed cumulative CO_2 budget results in a pathway with an average reduction of 163 kt/year for the period 2024 to 2030, and 276 kt/year for the period from 2030 to 2070.

[10] Page 21, 'Reductiepad', Taak 2 (CE Delft, 2021).

Figure 1 - CO_2-emissions on the basis of tanked kerosine in the Netherlands[11]; the proposed cumulative CO_2 budget is shown in green

4. Pre-defined CO_2 budget: Defining the CO_2 budget in parts - for limited amounts of time - could add flexibility for periodically taking into account trends and developments in the sector. However, it also creates a recurring process of research, license applications, checks and commitments. It could lead to recurring discussions instead of being a clear guideline. Therefore, a pre-defined national cumulative CO_2 budget is advised, providing predictability and stimulus for future reduction policies:[12]
   - Cumulative CO_2 budget needs to be defined for the model estimations of the impact assessment. The effect of adding flexibility can only be assessed qualitatively during this study.

5. Banking system to save rights or budget Allowing parties to save their left over rights (or left over CO_2 budget in the ceiling per airport option) adds more flexibility. When it is expected that prices will increase, parties could stock up rights leading to smoother pricing. The option of stocking up rights (or saving left over budget) also adds certainty of having enough rights (budget) for next year's emissions.[13] In the ceiling per airport option the flexibility can also be achieved by defining a step-size of the cumulative CO_2 budgets of several years. Monitoring and enforcement would be

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11 Historic CO_2-emissions are based on tanked kerosine in the Netherlands (CBS, 2021) multiplied by the emission factor used by EU ETS of 3,15 (To70, 2021).

12 Page 33, 'Volledig vastleggen of in meerdere stappen', (To70, 2021).

13 Page 17, 'Veilingontwerp en de secundaire markt', Taak 3 (CE Delft, 2021).

implemented on the same multiannual period. This approach has the advantage that - in the case of a ceiling per airport - no system for trading or bookkeeping of rights has to be implemented.

4. Monitoring and enforcement: For the 'Ceiling per airports' option the most logical choice for the monitoring authority is the 'Inspectie Leefomgeving en Transport (ILT)" as they are already the environmental supervisor for national airports. Eindhoven airport is an exemption due to its military function. Therefore, it is supervised by the 'Militaire Luchtvaart Autoriteit (MLA)'. Placing the monitoring and enforcement under one organisation seems practical.[14] For the other options the NEa would be the logical choice - as the NEa already fulfils a similar function for the EU ETS, CORSIA and sustainable fuels. The exact instruments for enforcement still have to be worked out. These will be designed such that undermining (by for example in a business decision taking a small fine for granted) of the ceiling is not possible.[15] [16]

Compliance period of 3-years: Monitoring and enforcing of the CO_2-ceiling on too short a period has the disadvantage that airports (and airlines/fuel sellers) do not have enough flexibility to react to unforeseen external effects and the shock-wise introduction of technologies or SAF factories. These parties also have too little time to react to the adjusted usage of slots by airlines (since the airport has no control over changes in aircraft and destination choice for the slot usage and thus on the CO_2 emissions). This can lead in single IATA seasons to emissions that are slightly higher or lower than originally expected. Too long a period however might result in too high emissions during the first years requiring a sharp decrease of aircraft movements at the end of the period. Although we estimate that this risk is low, the impact could be very large. By having an enforcement term of three years (and thus six IATA seasons) we create enough flexibility for airports to adjust for unforeseen changes. The main instrument for airports will be the capacity declaration, however there are also opportunities in (existing) airport charges and SAF subsidies.

3.2 Dimensions per main option

The Ceiling per Airport

The 'Ceiling per airport' option concerns a ceiling which allows a maximum of CO_2 emissions per airport. In Table 3 the dimensions of this option are presented.

Table 3 - List of dimensions, theoretical options, preferred options, whether the dimension is a constant or variable in the suboptions and expected model effects for the 'Ceiling per airport' option.

N	Dimensions	Theoretical options	Preferred options	Constant/variable for suboptions
1	Regulated entity	Entire sector, airport groups, airports, airlines	Airports	Constant
2	Ceiling system	Norm, rights	Norm	Constant
3	Budget Lelystad airport	Reserved beforehand, transferred from Schiphol,	Transferred from Schiphol	Constant

[14] Page 38, 'Bouwblok 4: Monitoring en handhaving', (To70, 2021).
[15] Page 25, 'Monitoring en handhaving', Taak 2 (CE Delft, 2021).
[16] Page 27, 'Monitoring en handhaving', Taak 3 (CE Delft, 2021).

N	Dimensions	Theoretical options	Preferred options	Constant/variable for suboptions
		transferred from all Dutch airports		
4	Allocation between airports	Strict, soft, combination of strict and soft	Strict and soft	Variable
5	Addressees pathway	Generic, airport-specific	Airport-specific	Constant

1. Individual airports are regulated entities: Making individual airports the regulated entity has the advantage that the CO_2 budget can be aligned with other restrictive rules (for instance on noise emissions, air quality, etc.) defined in the luchthaven(verkeers)besluiten (LVB). Airports are already familiar with monitoring and enforcement of environmental aspects. The fact that CO_2 emissions are global is a fundamental difference with the other aspects, but is not necessarily an argument to address it at a different level. The CO_2 budget would be an additional norm to the existing ones.[17] Addressing airport groups would give the Schiphol group more flexibility in its operations (other airports are not affected, due to the fact that they are not part of a group) but the downside is that monitoring and enforcement would be more challenging as it would be at a different level, and some airports would benefit more from this flexibility than others. Establishing a system in which the budget between the individual airports is allocated every few years for an upcoming period can in fact guarantee the same flexibility without the mentioned disadvantages. However, this flexibility could lead to a perverse effect. Airports that have realized a larger CO_2 reduction in the previous period could be allocated a smaller budget in the next period and those airports that have achieved less CO_2 reductions could be allocated more. Addressing the whole sector makes enforcement very challenging and applying it to airlines is better covered in the ETS option.

2. Norm as ceiling system: The ceiling can either be regulated by setting a norm or introducing rights. A rights system (allocated by historical emissions) could allow for trading of rights between airports. However, this requires to set up a whole trading system for a small number of players. Also, the idea behind this specific design option is to align with the luchthaven(verkeers)besluiten (LVB). In this way the government can weigh all factors (noise, CO_2, nitrogen, etc.) in its decision for setting the capacity for each airport. Therefore a norm is the preferred option.

3. Budget Lelystad airport is either reserved beforehand or later transferred from Schiphol: When the budget is reserved beforehand this results in a decrease in CO_2 budget for all airports of about 3.4%. When transferred from Schiphol only the budget of Schiphol is decreased by ~3.7%. Since Lelystad airport is the intended overflow airport for Schiphol it makes sense to transfer the budget from Schiphol.[18] There is an option that Lelystad airport will not be opened at all. This variable will be taken into account in the design of the various scenarios for this impact assessment.

4. Strict and soft allocation between airports: The basis for the allocation are the historic emissions according to the measuring method for CO_2 emissions. However, combining this with soft allocation gives flexibility for the ambitions and circumstances of the airports, and it also enables the government to be more consistent with previous considerations for permits (such as noise norms). This will be especially important for Groningen and Maastricht airport with their left-over capacity under the noise norms, it will be hard for them to make a business case with strict allocation only

17 Page 6, 'Verdeelsleutel: verdelen onder welke partijen?', (To70, 2021).
18 Page 17, 'Lelystad airport', (To70, 2021).

based on historic CO_2 emissions. Adding soft allocation also makes room for new market entrants. However, since this is a small and predictable market, sudden changes in the composition of airports is not expected. Moreover, the government has a say in this. The extra flexibility of soft allocation could however have a downside in reducing the support from airports when the established allocation is less based on clear numbers.[19] A combination of strict and soft elements where the historic share in CO_2 emissions is corrected by the capacity in noise norms (with clear and transparent rules) is advised. Note that due to uncertainties in airports closing (or new airports opening) it is recommended to evaluate the budget allocation every five years.

5. A generic pathway: In a generic pathway for the cumulative CO_2 budget the path is chosen for the whole sector, giving the government a central role. This central approach has a clear process where the different airports are directly and jointly controlled. Airport-specific enables, comparable with the 'luchthavenbesluit', airports themselves to make a proposition for a pathway and report the probable outcomes through an environmental impact assessment, or 'milieueffectrapportage (MER)'. This enables customization for the individual challenges of the airports and is consistent with the current approach for noise norms. Note this is only for the distribution among the airports, all airports together still have to meet the targets of the overall cumulative CO_2 budget. The downside of an airport-specific pathway is that it makes the process longer and more complicated.[20] We also think the flexibility for this option is sufficiently guaranteed by the three years compliance period and soft allocation.

3.3 The Fossil fuel ceiling

The 'Fossil fuel ceiling' option concerns a ceiling which sets a maximum on the amount of tanked fossil fuels in the Netherlands to a level corresponding to the cumulative CO_2 budget.

Table 4 - List of dimensions, theoretical options, preferred options, whether the dimension is a constant or variable in the suboptions and expected model effects for the 'Fossil fuel ceiling' option

N	Dimensions	Theoretical options	Preferred options	Constant/variable for suboptions
1	Regulated entity	Fuel sellers, fuel service providers or fuel producers	Fuel sellers	Constant
2	Ceiling system	Fuel rights (both sellers as service providers), taxes (only fuel sellers) or none	Fuel rights	Constant
3	Initial allocation of rights	Auction (only fuel sellers) or sale at a fixed price (both sellers as service providers)	Auction (only fuel sellers)	Constant
4	Regulation point in value chain	Production, first sale to airport or tanking	First sale to airport	Constant
5	Auctioning method	Single-round sealed bid uniform price, else	Single-round sealed bid uniform price	Constant
6	Limit on purchase or possession	Purchase, possession or none	Purchase	Constant
7	Timing auctions	Yearly, monthly, weekly	Weekly or monthly	Constant

19 Page 19, 'Op basis van een bredere afweging ('zachte' verdeelsleutel)', (To70, 2021).

20 Page 32, 'Generiek of luchthaven-specifiek reductiepad', (To70, 2021).

N	Dimensions	Theoretical options	Preferred options	Constant/variable for suboptions
8	Secondary market	Open, closed or none	Closed or none	Constant
9	Market stability mechanism	Quantity, price or none	Quantity	Variable

1. Fuel sellers as regulated entity: There are three possible regulated entities: fuel sellers, fuel service providers or fuel producers. Regulating fuel producers seems complex since they can be located in different jurisdictions and even when they are based in the Netherlands their products can be supplied both in the Netherlands and in other countries.. Also, it would be legally challenging to regulate foreign producers. Both fuel sellers and fuel service providers are viable options regarding their Dutch jurisdiction. AFS, the fuel service provider of Schiphol for storage, is a small company with only 30 employees. Small companies often have limited liquidity and execution power. For regional airports fuel service providers can differ between producers, airlines or a distinct party. Fuel sellers are mostly large multinationals. Regarding feasibility fuel sellers seem the preferred option.[21]

2. Preventing windfall profits with fuel rights system: When regulating fuel sellers or fuel service providers scarcity could be created (in case the ceiling is restricting aviation growth) for the Dutch fossil-kerosine market, leading to increased prices and therefore windfall profits for the fuel sellers. This can be seen as contravening the 'polluters pay' principle. Therefore, we would advise taking measures to prevent windfall profits. This can be done by introducing a fuel rights system, where the fuel sellers have to hand in fuel rights for every tonne of fuel they either sell or transport/store. Fuel rights are sold by a national authority leading to revenues for the Dutch state. The price should match the price increase following from supply restrictions. This can for instance be achieved by auctioning of rights. Another option would be to only regulate fuel sellers and introduce a separate tax for windfall profits. However, since this tax should be variable and exactly match the price increase due to supply restrictions, this would require detailed predictions for the future and implementing it could be difficult in practice.[22] It is also important to consider how the revenues from auctions are used. They could for instance be added to increase the general revenues of the state, to compensate the aviation tax or be used to as subsidies to stimulate sustainable aviation projects. In this study no choices are made for the usage of these revenues, however to compare this option with the Ceiling per airport option there will be a suboption with revenues funnelled back to the sector.

3. Auctioning to fuel sellers as initial allocation of rights: In this initial allocation method fuel sellers bid against each other in auctions to gain rights. Fuel sellers have the price insights and know which price raise they can ask airlines taking into account possible constraints of the ceiling. The other method would be to sell fuel rights at a fixed price. Here the government sells fuel rights either to fuel sellers or fuel service providers at a fixed price. To prevent windfall profits this price needs to be variable over time and has to match the price rise resulting from supply restrictions as closely as possible. This method seems uncertain since fuel sellers and airlines have to cooperate intensely for accurate price information and it could be difficult to make accurate price projections.[23]

21 Page 10, 'Wie is de normadressaat?', Taak 3 (CE Delft, 2021).

22 Page 12, 'De normadressaat in een systeem zonder windfall profits', Taak 3 (CE Delft, 2021).

23 Page 13, 'De normadressaat in een systeem zonder windfall profits', Taak 3 (CE Delft, 2021).

4. Single-round sealed bid uniform price auctioning method: There are multiple possible auctioning methods. Aligning with EU ETS using single-round, sealed bid, uniform price seems best. Here participants cannot see each other's bids and all bids should be made within a certain time horizon. After the auction the clearing price is determined: this is the price where supply and demand of rights meet. All bids above the clearing price are accepted, and all contestants pay the same clearing price per right. The upside of this blind auctioning method is that it is harder for sellers to just go above the competitor's price, and therefore discourages abuse of the system.[24]

5. First sale of fuel to a Dutch airport as regulation point in value chain: In early points of the value chain, close to production, it is uncertain whether the fuel will end in a wing of an aircraft departing from a Dutch airport (and hence be counted within the CO_2 ceiling). The best option seems to regulate at the point where it is clear that fuel is going to a Dutch airport. Here the fuel seller who is selling fuel for the first time to a customer at a Dutch airport has to hand in the fuel rights. There is a theoretical risk of the fuel being resold for tankering purposes. This is unlikely when the CO_2/fuel rights are already attached to the fuel. In that case 'too much' fuel would be regulated and the CO_2 ceiling will likely result in a higher price at Dutch airports, this situation seems unlikely.[25]

6. Limit on purchasing rights: A fuel seller could for strategic reasons try to buy up all of the rights. Next to being unwanted for competitive reasons, this could also result in the creation of 'dry' fuel sellers (without rights) resulting in specific airlines not having enough fuel for their flights. Note a mitigating reaction of airlines could be to contract multiple fuel sellers. To prevent fuel sellers from buying up all the rights a limit can be introduced. There can either be a limit on possession of rights or buying of rights. A limit on possession would be most direct but can be practically and legally challenging for foreign fuel sellers. A limit on purchasing of rights is preferred. Here every fuel seller has a limit as to how many rights they can buy at an auction. The limit should be based on historical sales data with a markup to allow growth (representing for example 1.5 times last year's sales). The downside of a limit would be decreased flexibility for fuel sellers to buy strategically or buffer.[26]

7. Weekly or monthly timing of auctions: A concern would be fuel sellers buying and using so many rights at the start of the year that their collective fuel rights are all used before the end of the year. Natural spreading over the year with weekly or monthly auctions can prevent this.[27]

8. A closed or no secondary market: On the one hand an open secondary market where investors can speculate is undesirable, on the other hand, investors can provide liquidity to markets and offer financial products tied to allowances, such as futures and options. Investors could retain a large share of the rights because they expect price increases on the long term, with the purpose to harm the Dutch aviation sector or for other strategic reasons. In the meantime, the lower number of available rights would lead to less flights. A closed secondary market can add flexibility to the system, but since there are only a limited number of fuel sellers (that are also direct competitors) the question is whether there will be enough trade to have an added value.[28] In the closed case a

[24] Page 16, 'Veilingontwerp en de secundaire markt', Taak 3 (CE Delft, 2021).
[25] Page 14, 'De normadressaat in een systeem zonder windfall profits', Taak 3 (CE Delft, 2021).
[26] Page 18, 'Gelijke toegang voor airlines en luchthavens', Taak 3 (CE Delft, 2021).
[27] Page 19, 'Een natuurlijke spreiding over het jaar', Taak 3 (CE Delft, 2021).
[28] Page 16, 'Veilingontwerp en de secundaire markt', Taak 3 (CE Delft, 2021).

specific supplier could not be able to deliver additional fuel and an airline would be required to purchase it from a different supplier. However, in the long run (especially with frequent auctions, see dimension 7) the first supplier will probably try to acquire more rights for the next period.

6. Market stability mechanism on quantity: There are multiple reasons for surpluses or shortages on the market: think of the COVID-19 crisis or a broken factory at a large SAF-producer. A market stability mechanism (MSR) can be introduced to limit the volatility of the price of a right. When the number of rights is too large, less rights are being auctioned and the non-auctioned rights are being saved in a market stability reserve. When there are too few rights, the rights saved in the reserve are brought back into the system by additional auctioning. Compared to the other measures that give flexibility to the system, the main goal of the MSR is to prevent extreme prices in both directions. There is the option of coupling the MSR directly to the price, however it seems rather hard to establish an initially right price. Therefore, coupling to quantity seems best.[29]

3.4 The National ETS

The 'National ETS' option concerns a national emissions trading system for airlines operating flights from the Netherlands. This would be a closed system only for airlines to ensure the in-sector CO_2 targets from the 'Luchtvaartnota'.

Table 5 - List of dimensions, theoretical options, preferred options and expected model effects for the 'National ETS' option

N	Dimensions	Theoretical options	Preferred options	Constant/variable for suboptions
1	Initial allocation of rights	Auctioning and/or grandfathering	Auctioning	Variable
2	Auctioning Method 1	Pre-sale, ceiling, expiration or none	Pre-sale or ceiling	Constant
3	Auctioning Method 2	Single-round sealed bid uniform price, else	Single-round sealed bid uniform price	Constant
4	Improved grandfathering	New entrants budget, benchmark or none	New entrants budget and benchmark	Constant
5	Timing of auctions	Yearly, monthly, weekly	Weekly	Constant
6	Secondary market	Open, closed or none	Closed	Constant
7	Market stability mechanism	Quantity, price or none	Quantity	Constant

1. Auctioning as initial allocation of rights: For allocation through auctioning, airlines have to bid against each other to receive rights. This allocation method prevents airlines from receiving windfall profits. The auctioning income could through subsidies be funnelled back to the sector for sustainable technologies or fuels, otherwise they are revenues for the state. A downside of this method is that it is possible for an airline to strategically buy up most of the rights, making it harder for competitors to fly. Initial allocation of rights by grandfathering means that the government gives rights away for free to airlines, based on historical emissions. This could lead to windfall profits for airlines, which can be seen as unwanted due to the 'polluters pay' principle. Another downside of grandfathering is it could lead to accusations of protectionism, and it could limit new market entrants, because they have no historic emissions and therefore no allocated rights. Another option would be a hybrid allocation model where a part of the rights is grandfathered and the rest auctioned. In the EU ETS 82% of the aviation rights are grandfathered,

[29] Page 24, 'Een marktstabiliteitsmechanisme', Taak 2 (CE Delft, 2021).

15% is auctioned and the remaining 3% is reserved for new entrants. In addition, the aviation sector is a net buyer from other sectors. The freely allocated rights were originally meant to get the EU-ETS going and prevent leakage effects. Since the system appeared to function properly and the leakage effects seemed limited, the proportion of grandfathered rights (and the free rights) has been slowly decreasing, such that by 2026 rights will only be auctioned.[30] Therefore auctioning as allocation of rights would align with the future form of the EU ETS.

2. A pre-sale of rights or a limit to purchase rights improves allocation by auctioning: Allocation by auctioning can be improved by preventing airlines from strategically buying up most of the rights. One method is by offering a pre-sale, where the largest players can buy in line with their historic emissions a part of the rights for a fixed price. The rest of the rights will be auctioned after, where also the smaller players can buy rights. This could however lead to accusations of protectionism or discrimination between airlines, given the high market share of KLM in the Netherlands. A counter argument would be that KLM compared to foreign competitors bears most of the costs of the measure incurred in their national market. Another method to improve auctioning would be to set a limit to the number of rights an airline can buy per auction. Proportionally to their historic emissions and limit it at say 1.5 times the amount of rights handed in last year or the amount of last year plus a fixed number of rights to allow small airlines to grow. Another method would be to let rights that are not used expire after a certain amount of time. This could incentivise airlines to only buy rights for own use. A downside is that it limits flexibility. This hinders well-meant strategic choices, such as airlines buffering up rights when prices are low. Also it limits the planning certainty of airlines, which seems unwanted.[31]

3. Single-round sealed bid uniform price auctioning method: Same argumentation as in the 'Fossil fuel ceiling' option dimension 7.[32]

4. New entrants budget and benchmark to improve grandfathering: To also include new entrants in the grandfathering allocation system, a new entrants budget can be introduced. A downside of this new entrants budget could be that if there are no new market entrants the total budget is (by a small amount) structurally decreased. In the EU ETS this is done by reserving 3% of the yearly rights for new entrants. Common criticism on grandfathering is that it rewards polluters instead of punishes. This is due to the fact that airlines that historically have taken little measures to reduce emissions will have large emission budgets. They get many freely allocated rights and will have a limited incentive to take sustainability measures. Within the EU ETS this is tackled by limiting the freely allocated rights to a benchmark. This benchmark is a measure for the carbon efficiency of airlines expressed in CO_2 per tonne-kilometre. Efficient airlines which emit less CO_2 per tonne-kilometre get more free rights than less efficient airlines. By reducing the benchmark yearly airlines are further stimulated to take emission reducing measures.[33]

5. Weekly timing of auctions: Same argumentation as in the 'Fossil fuel ceiling' option dimension 8.[34]

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[30] Page 13, 'Allocatie van rechten', Taak 2 (CE Delft, 2021).

[31] Page 17, 'Manieren om toch vast te houden aan veiling van rechten', Taak 2 (CE Delft, 2021).

[32] Page 18, 'Veilingsmechanisme', Taak 2 (CE Delft, 2021).

[33] Page 18, 'Grandfathering', Taak 2 (CE Delft, 2021).

[34] Page 19, 'Een natuurlijke spreiding over het jaar', Taak 3 (CE Delft, 2021).

6. Closed secondary market: The presence of a secondary market offers participants more flexibility and leads to more accurate CO_2 pricing. The question is whether the added value is large enough with possibly a small number of active participants, which also are direct competitors (and can strengthen their position by acquiring rights and by not selling any), to justify the government spending needed for such a system. Note, that when using existing trade platforms of third parties (similarly as the trade of nitrogen rights in the Netherlands) the government spending should be limited. An option would be to have an open secondary market. But this could lead to investors buying up large parts of the rights, resulting in airlines potentially having to decrease their number of flights.[35]
   - No difference in model effect expected

7. Market stability mechanism on quantity: Same argumentation as in the 'Fossil fuel ceiling' option dimension 9.[36]

4 Suboptions

In this Chapter the suboptions are listed. The starting point for the suboptions are the logical choices following from the preliminary studies. Therefore if in the tables for the general dimensions and option-specific dimensions there is one preferred option, this will be the basis for the suboptions.
We will vary the suboptions for dimensions which reflect important policy choices or make the main options more comparable. Note that the suboptions are defined based on distinction in policy. If from a modelling point of view not all suboptions are different, we will review the effect differences qualitatively.

The given suboptions follow from the 'Constant/variable for suboptions' column of the table per main option. In this approach we define:
- three suboptions for the ceiling per airport option;
- three suboptions for the fossil fuel ceiling option;
- two suboptions for the national ETS option;
- (two sensitivity analyses).

4.1 General remarks

National cumulative CO_2 budget

In 2005, $3.51*10^6$ kg kerosene[37] has been delivered to the Dutch airports. This corresponds to an emission of 1.,06 Mton CO_2 (applying an emission factor of 3.15 kg CO_2/kg kerosene).
The ceiling for 2030 is equal to the emissions of 2005. From this year onwards the average reduction path is linear until 2070, when zero emissions has to be realized (note that the same approach is taken in the EU ETS). For the period 2024 - 2029 the reduction path is based on the expected emissions in 2024 and a linear reduction until 2030. An overview of the annual emission for selected years and the cumulative emissions over the entire period is given in Table 6.

35 Page 20, 'De secundaire markt', Taak 2 (CE Delft, 2021).
36 Page 24, 'Een marktstabiliteitsmechanisme', Taak 2 (CE Delft, 2021).
37 https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/uitstoot-en-brandstofverbruik/brandstofverbruik-luchtvaart

Table 6 - Emissions pathway and the resulting cumulative CO2 budget

Year	2024	2030	2040	2050	2060	2070	2024 - 2029	2030 - 2050	2050 - 2070
CO_2 [Mton]	12,03	11,06	8,29	5,53	2,76	0,00	69,76	168,61	58,05

4.2 Ceiling per airport (three suboptions)

In the ceiling per airport option the national budget is distributed based on the realized emissions in the period 2017-2019 or based on the historic emissions corrected with the left over capacity in noise norms.

Table 7 - Used capacity within the noise norms for each airport

Year	Schiphol	Rotterdam	Eindhoven	Maastricht	Groningen
2017	99%	92%	85%	69%	60%
2018	99%	100%	90%	90%	83%
2019	99%	95%	96%	73%	61%
2017-2019	99%	96%	90%	77%	68%

Table 8 - Allocation between airports based strictly on realized emissions in 2017-2019 or allocation based on historic emissions corrected for the left over capacity in noise norms

Method	Schiphol	Rotterdam	Eindhoven	Groningen	Maastricht
Share of national CO_2 ceiling per airport based on actual emissions 2017-2019	94.27%	1.17%	3.04%	0.17%	1.35%
Share of national CO_2 ceiling per airport taking into account unused airport capacity 2017 - 2019	93.34%	1.20%	3.30%	0.22%	1.95%

Table 9 - Suboptions for the 'Ceiling per airport' main option

Suboptions	Explanation
Strict allocation, flexible	Allocation of CO_2 budget is strictly on basis of realised fuel data (2017-2019). Sufficient flexibility with an enforcement term of 3-years.
Strict allocation, not-flexible	Allocation of CO_2 budget is strictly on basis of realised fuel data (2017-2019). Insufficient flexibility due to a too short enforcement term of 1-year.
Soft allocation, flexible	Allocation of CO_2 budget is based on historic emissions corrected for complete filling of the noise capacity. Sufficient flexibility with an enforcement term of 3-years.

4.3 Fossil fuel ceiling (three suboptions)

The airport option does not generate fiscal revenue. In the Fossil fuel and National ETS option the auctioning of allowances generates fiscal revenue. To guarantee comparability between the main options we create at least one suboption in the Fossil fuel and ETS options defined by no net income for the state.

Table 10 - Suboptions for the 'Fossil fuel ceiling' main option

Suboptions	Explanation
Auctioning income for the state	Initial allocation of rights by auctioning. Government income made from auctioning is for the state.
Auctioning income is funnelled back	Initial allocation of rights by auctioning with a limit to purchase rights. Government income made from auctioning is funnelled back into the sector.
Auctioning income for the state, no stability mechanism	Initial allocation of rights by auctioning. Government income made from auctioning is for the state. No stability mechanism.

4.4 National ETS (two suboptions)

Table 11 - Suboptions for the 'National ETS' main option

Suboptions	Explanation
Auctioning	Initial allocation of rights by 100% auctioning.
Grandfathering	Initial allocation of rights by mostly grandfathering.

5 References

CBS, 2021. *Levering in Nederland van kerosine aan internationale luchtvaart, per jaar.* [Online] Available at: https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/uitstoot-en-brandstofverbruik/brandstofverbruik-luchtvaart
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D Input data modelling and impact assessments

This annex includes the input data for the calculations of the modelling and the impact assessment. The data used in the AEOLUS scenario modelling of the CO_2 ceiling variants is stated in Section E.1. In Section E.2 we outline the input data used for the calculations of the impacts.

D.1 Data AEOLUS modelling

The data input and assumptions that are general for the modelling of the extreme scenario and the extreme scenario are included here.

D.1.1 Fuel properties and fuel blending rates

Energy density

The emission factors of kerosene as well as the different SAF alternatives are described in Subsection 5.2.2 and Subsection 5.7.2. Therefore, these are not repeated here. The assumed energy densities are shown in Table 91.

Table 91 - Energy density of aviation fuels. GJ per tonne

Kerosene (Jet-A1)	HEFA	Gas. + FT	ATJ	RFNBO
43.5	43.5	44	43.5	42.7

Source : (CE Delft, 2021; Bauen, et al., 2020).

Aviation fuel blends

The aviation fuel blending rates applied at Dutch airports used are indicated in the following tables. The blending requirements are based on the proposals for the Renewable Energy Directive III as well as ReFuelEU Aviation (European Commission, 2021; European commission, 2021b). Note that in the different CO_2 ceiling options, airlines may choose to blend more than the required percentages which are shown here. The detailed shares of SAF blending rates (HEFA, GAS +FT, ATJ and RFNBO) are based on the impact assessment of ReFuelEU Aviation (European Commission, 2021) and shown in the section 'SAF shares'.

The blending requirements in the reference scenario is shown in Table 92. The blending requirements in the extreme scenario is shown in Table 93. Note that the 2030 SAF blending requirements are equal in both cases (although the specific synthetic SAF requirements are not equal). This is because the reduced ambition assumes that the ReFuelEU Aviation blending requirements are reduced, whereas the RED III requirements for 2030 are not reduced.

Table 92 - Blending requirements per year in the reference scenario

Blending requirement (% of energy)	2017	2025	2030	3035	2040	2045	2050
General SAF blending requirement	0.0%	2.0%	9.0%	20.0%	32.0%	38.0%	63.0%
Specific synthetic SAF requirement	0.0%	0.0%	0.7%	5.0%	8.0%	11.0%	28.0%

Table 93 - Blending requirements per year in the extreme scenario

Blending requirement (% of energy)	2017	2025	2030	3035	2040	2045	2050
General SAF blending requirement	0.0%	1.0%	9.0%	10.0%	16.0%	19.0%	31.5%
Specific synthetic SAF requirement	0.0%	0.0%	0.4%	2.5%	4.0%	5.5%	14.0%

SAF shares

The aviation fuel blending rates applied for scenarios with the Fit for 55 blending obligations as proposed are listed in Table 94. These are used for the analysed reference scenario (Scenario 23).

Table 94 - Aviation fuel blend rates as the proposed Fit for 55 without Dutch blending obligation

Year	Kerosene (Jet-A1)	HEFA	Gas. + FT	ATJ	RFNBO
2030	91.0%	3.9%	0.0%	4.4%	0.7%
2040	68.0%	4.6%	9.9%	9.6%	8.0%
2050	37.0%	5.0%	16.8%	13.2%	28.0%

The aviation fuel blending rates applied for scenarios with the Fit for 55 blending obligations with reduced ambition and no additional Dutch blending obligation are listed in Table 95. These are used for the extreme scenario (Scenario 6). We assumed reduced ambition is a 50% reduction of the obligatory blending targets in the years 2040 and 2050 (e.g. 8% RFNBO in 2040 becomes 4% in the reduced ambition variant).

Table 95 - Aviation fuel blend rates of Fit for 55 reduced ambition without Dutch blending obligation

Year	Kerosene (Jet-A1)	HEFA	Gas. + FT	ATJ	RFNBO
2030	91.0%	3.9%	0.0%	4.4%	0.7%
2040	84.0%	2.3%	4.9%	4.8%	4.0%
2050	68.5%	2.5%	8.4%	6.6%	14.0%

D.1.2 Fuel cost and taxes

Fuel prices

We assumed fuel cost increases due to the various different policy proposals which are part of the Fit for 55 package. However, the airlines do not necessarily need to increase the costs of individual tickets proportionally to the costs made. For example, airlines may choose to increase costs more on flights with relatively less competition compared to highly competitive routes in order to avoid losing passengers to the competition. For the most part, it was not possible to model such dynamics. However, we did choose to assume:

- The ticket price increases for business class passengers are 10% higher than what you would expect based on the costs for the airline and ticket price increases are about 8% lower for non-business class passengers (because the price elasticity is lower for business class).
- The ticket price increases for direct full service carrier flights are 10% higher compared to what you would expect based on the costs for the airline and ticket price increases are about 11% lower for indirect flights (because the price elasticity is lower for direct flights).

Both these effects are modelled such that in total, the ticket price increases equal the cost increases for the airlines. The precise cost assumptions are specified below.

The fuel cost assumptions, which are shown in Table 96, are based on the values used in the ReFuelEU Aviation proposal. These prices reflect the cost price of SAF production. When there is significant demand due to the blending obligations, the market price will be determined by the price of SAF that is used with the highest marginal costs. We assumed that this is ATJ for normal SAF and PTL/RFNBO for the specific blending requirements of RFNBO.

Table 96 - Fuel price assumptions per year (EUR per kg fuel)

Year	Kerosene (Jet-A1)	HEFA	Gas. + FT	ATJ	Synthetic SAF - PTL/RFNBO
2030	€ 1.05	€ 1.01	€ 2.06	€ 2.09	€ 2.97
2040	€ 1.19	€ 1.04	€ 2.04	€ 2.16	€ 2.31
2050	€ 1.33	€ 1.05	€ 2.09	€ 2.16	€ 1.93

Source: (European Commission, 2021).

ETD - Fuel excise duty

The ETD revision proposes an excise duty for aviation fuels in the commercial sector. The tax for aviation fuel will be introduced gradually (starting in 2023) before reaching the final minimum rate after a transitional period of ten years (2033). The proposal suggests a yearly increase of $1/10^{th}$ of the full minimum rate. Therefore. The fuel excise duty in the year 2030 deviates from the figure in 2040 and 2050. The SAF types are subject to fuel tax as well. However. Lower minimum rates apply. Moreover. Fuel excise duty is charged on the SAF types only from the start of 2033. Meaning these type of fuels are not subject to the tax in the transitional period. In Table 97 the fuel excise duty rates per tonne fuel are outlined.

Table 97 - Fuel excise duty as proposed by the ETD. In EUR per tonne fuel

Year	Kerosene (Jet-A1)	HEFA	Gas. + FT	ATJ	RFNBO
2030	€ 374.10	€ 0	€ 0	€ 0	€ 0
2040	€ 467.63	€ 234.03	€ 236.72	€ 234.03	€ 6.41
2050	€ 467.63	€ 234.03	€ 236.72	€ 234.03	€ 6.41

Source : (European Commissions, 2021b) (CE Delft, 2021; EC, 2021).

The assumed EU ETS and CORSIA prices are shown in Table 98[82].

[82] The current CORSIA system has only been defined until 2035. However, we consider it very likely that the system will persist after 2035. Therefore, we assumed that the CORSIA system wil be continued until 2050 with increasing CO_2-offsetting prices. The assumptions that we made are in line with (CE Delft, 2021).

Table 98 - EU ETS and CORSIA cost per tonne **CO_2**

Year	ETS	CORSIA
2030	€ 85	€ 13
2040	€ 200	€ 87
2050	€ 315	€ 160

Source: (CE Delft, 2021; EC, 2021).

D.2 Data impact assessment analysis

The data input and assumptions for the impact analyses are presented in this section. The data applies for all scenarios, unless stated otherwise. For example, the fuel blending rates are one of the determining factors for the differences of the scenarios, therefore these are different per scenario.

D.2.1 Fuel cost and taxes

Fuel cost and taxes used in the impact analyses are equal to the figures used in the scenario modelling (see Section E.1.2).

D.2.2 Data employment

In Table 99 the data input is presented used for the estimation of the aviation employment effect under the policy options.

Table 99 - number of FTE in the Dutch aviation sector

Baseline FTE (x 1,000)	Scope	Source
58.12	Aviation sector AMS	CBS & Decisio (2017)
65.03	Entire Dutch aviation sector	Calculated using volume total Dutch aviation operations

E Details of multicriteria analysis

The multicriteria analysis in Chapter 7 scores the different suboptions on six criteria, which themselves consist of subcriteria. All criteria are scored on a five point scale, ranging from -- (very negative) to ++ (very positive) with 0 meaning (almost) no impact. In this Annex we describe how we scored the different subcriteria and how we combined the subcriteria into the overall criteria score.

For some subcriteria, a quantitative approach could be used (for example, for global CO_2 emissions, a scale based on the absolute CO_2 emission reduction could be made). For other subcriteria, such as 'control of the regulated entity over CO_2 emissions', a qualitative approach had to be chosen.

Table 100 to Table 104 explains for each of the six criteria:
- What choices were made for the five point scale for the subcriteria;
- How we aggregated the subcriteria to the overall criteria score.

Table 100 - Certainty about aviation CO_2 emissions

	--	-	0	+	++
Control of the regulated entity over CO_2 emissions	*The regulated entity is not in control of the CO_2 emissions*	*The regulated entity can control the CO_2 emissions to some extent*	*The regulated entity can control the CO_2 emissions reasonably well*	*The regulated entity has indirect control of the CO_2 emissions*	*The regulated entity is in full control of the CO_2 emissions*
Predictability	*The regulated entity is unable to predict the CO_2 emissions*	*The regulated entity cannot predict the CO_2 emissions well*	*The regulated entity can predict the CO_2 emissions reasonably well*	*The regulated entity can predict the CO_2 emissions well*	*The regulated entity can predict the CO_2 emissions perfectly*
Feasibility of implementation	*Particularly complex new legislation must be made for this policy*	*Completely new legislation must be made for this policy*	*The policy can reasonably conveniently be implemented in existing policy frameworks*	*The policy can be conveniently implemented in existing policy frameworks*	*No significant effort is required*
International acceptance/risk of retaliation	*Strong retaliation is expected*	*It is reasonably likely that there will be retaliation, because airlines are directly affected*	*It is uncertain whether there will be retaliation, since airlines are indirectly affected*	*There is limited risk of retaliation*	*There is no risk of retaliation*
How did we combine the subcriteria?	For this criterion, we chose to give all subcriteria an equal weight. The first two are of importance because these are directly related to the goal of the **CO_2** ceiling. The latter two are importance because they together determine the practical feasibility of the implementation of the policy.				

Table 101 - Total climate impacts

	--	-	0	+	++
Global CO_2	*Emission growth of more than 0.4 million tonnes in 2030 in the reference scenario*	*Emission growth of between 0.1 and 0.4 million tonnes in 2030 in the reference scenario*	*No significant emission reduction or growth (between 0.1 and -0.1 million tonnes) in 2030 in the reference scenario*	*Emission reduction of between 0.1 and 0.4 million tonnes in 2030 in the reference scenario*	*Emission reduction of more than 0.4 million tonnes in 2030 in the reference scenario*
Aviation non-CO_2	*Emission growth of more than 0.4 million tonnes in 2030 in the reference scenario*	*Emission growth of between 0.1 and 0.4 million tonnes in 2030 in the reference scenario*	*No significant emission reduction or growth (between 0.1 and -0.1 million tonnes) in 2030 in the reference scenario*	*Emission reduction of between 0.1 and 0.4 million tonnes in 2030 in the reference scenario*	*Emission reduction of more than 0.4 million tonnes in 2030 in the reference scenario*
How did we combine the subcriteria?	These factor are weighted equally, because both are expressed in the same unit of CO_2-eq. emissions.				

Table 102 - Costs: compliance costs, administrative costs and government incomes

	--	-	0	+	++
Compliance costs	*The compliance costs increase significantly (more than 5%)*	*The compliance costs increase (less than 5%)*	*No change of compliance costs*	*The compliance costs decrease (less than 5%)*	*The compliance costs decrease significantly (more than 5%)*
Administrative costs	*Administrative costs increases are higher than € 2 million*	*Administrative costs increases are lower than € 1 million*	*No administrative costs*	*Decrease in administrative costs of more than € 1 million*	*Decrease in administrative costs of more than € 2 million*
Impacts on GDP	*Decreasing effect on GDP of more than € 100*	*Decreasing effect on GDP of more than € 25*	*No significant effect on GDP (-€ 25 to +€25)*	*Increasing effect on GDP of more than € 25*	*Increasing effect on GDP of more than € 100*
How did we combine the subcriteria?	Compliance costs and GDP are both given equal weight. They are both weighted 3x more than administrative costs because they are about an order 1,000 higher. Since compliance costs and government income are not relevant for the non-restrictive scenarios, while administrative costs are always relevant we think some weight for administrative costs is still appropriate.				

Table 103 - Local environmental impacts of Dutch aviation

	--	-	0	+	++
LTO emissions of air pollutants	*The air pollutant emissions in the reference scenario in 2030 are increased significantly (NO_x more than 7,5%)*	*The air pollutant emissions in the reference scenario in 2030 are somewhat increased (NO_x between 2,5 and 7,5%)*	*The air pollutant emissions in the reference scenario in 2030 are not significantly changed (NO_x between -2.5 and +2.5%)*	*The air pollutant emissions in the reference scenario in 2030 are somewhat reduced (NO_x between 2,5 and 7,5%)*	*The air pollutant emissions in the reference scenario in 2030 are reduced significantly (NO_x more than 7,5%)*
Airport noise[83]	*The number of houses within the 56/58 db Lden-contour in the reference scenario in 2030 increases with more than 500*	*The number of houses within the 56/58 db Lden-contour in the reference scenario in 2030 increases with between 250 and 50*	*The number of houses within the 56/58 db Lden-contour in the reference scenario in 2030 does not change significantly (between -250 and +250)*	*The number of houses within the 56/58 db Lden-contour in the reference scenario in 2030 decreases with between 250 and 500*	*The number of houses within the 56/58 db Lden-contour in the reference scenario in 2030 decreases with more than 500*
How did we combine the subcriteria?	We gave both criteria equal weight, since there is no reason to assume that one is more important than the other.				

Table 104 - Impacts on aviation

	--	-	0	+	++
Network quality	*The number of flights decreases with more than 10%*	*The number of flights decreases with between 2 and 10%*	*The number of flights stays equal (between -2 and +2%)*	*The number of flights increases with between 2 and 10%*	*The number of flights increases with more than 10%*
Competitiveness of the aviation sector	*More than 50% of the decrease in passengers goes to other airports*	*Less than 50% of the decrease in passengers goes to other airports*	*No significant change in passengers*	*Less than 50% of the increase in passengers goes to other airports*	*More than 50% of the Increase in passengers goes to other airports*
External safety	*The number of houses within the 10^{-6} safety*	*The number of houses within the 10^{-6} safety*	*There is no impact on the number of houses*	*The number of houses within the 10^{-6} safety*	*The number of houses within the 10^{-6} safety*

83 Because a 56 dB contour was calculated for the regional airports and a 58 dB contour for Schiphol, these can not precisely be compared. However, we still chose to do as this is the most practical way to obtain a reliable score based on the available data.

	--	-	0	+	++
	contour level in the reference scenario in 2030 increases more than 100	*contour level in the reference scenario in 2030 increases by 25 to 100*	*that is within the 10^{-6} safety contour level (.. to ..)*	*contour level in the reference scenario in 2030 decreases by 25 to 100*	*contour level in the reference scenario in 2030 decreases more than 100*
How did we combine the subcriteria?	We gave ‘network quality’ and ‘competitiveness of the aviation sector’ triple weight compared to ‘external safety’, since the accident rates of aviation are very low.				

F Fluctuations and the AEOLUS output

F.1 Introduction

The AEOLUS runs which were made for this study form the basis of our quantitative analysis. However, the AEOLUS model does not account for fluctuations (such as fluctuations in demand due to economic conditions) that can affect the working of the CO_2 ceiling. For this reason, additional analysis was done to estimate the effect of fluctuations such in four suboptions:[84]

- Ceiling per airport - strict allocation (3-year cycle).
- Ceiling per airport - strict allocation (1-year cycle).
- Ceiling per airport - soft allocation (3-year cycle).
- Fuel supplier - no stability mechanism.

F.2 Historic fluctuations

Our analysis of historic fluctuations is based on the kerosene sales in the Netherlands in the period 1990-2020 (CBS, 2021). We chose this variable since it is closely related to the CO_2-emissions of flights departing from the Netherlands. This also is in line with the CO_2-emission measurement method as chosen in this study.

Figure 71 shows the historic kerosene sales in the Netherlands compared to a quadratic trend line.[85] Figure 72 shows the same data expressed as yearly fluctuations from this trend line. From this data, we can conclude that:

- historically, fluctuations in demand are common;
- the periods of above average/below average demand usually last about 6 years (for example 1990-1994; 1995-2001; 2003-2008; 2009-2015);
- fluctuations of up to 10% compared to the trend line are not uncommon. Due to the coronavirus, extreme downward fluctuations were seen in 2020.

[84] The fluctuations which we here consider could also affect the other suboptions. However, since for these suboptions the effects of fluctuations on the impact of the CO_2 ceiling are most relevant, we only performed this additional analysis for these.

[85] The year 2020 was excluded from the dataset on which the trend line was based.

Figure 71 - Historic kerosene sales in the Netherlands and a quadratic trend line

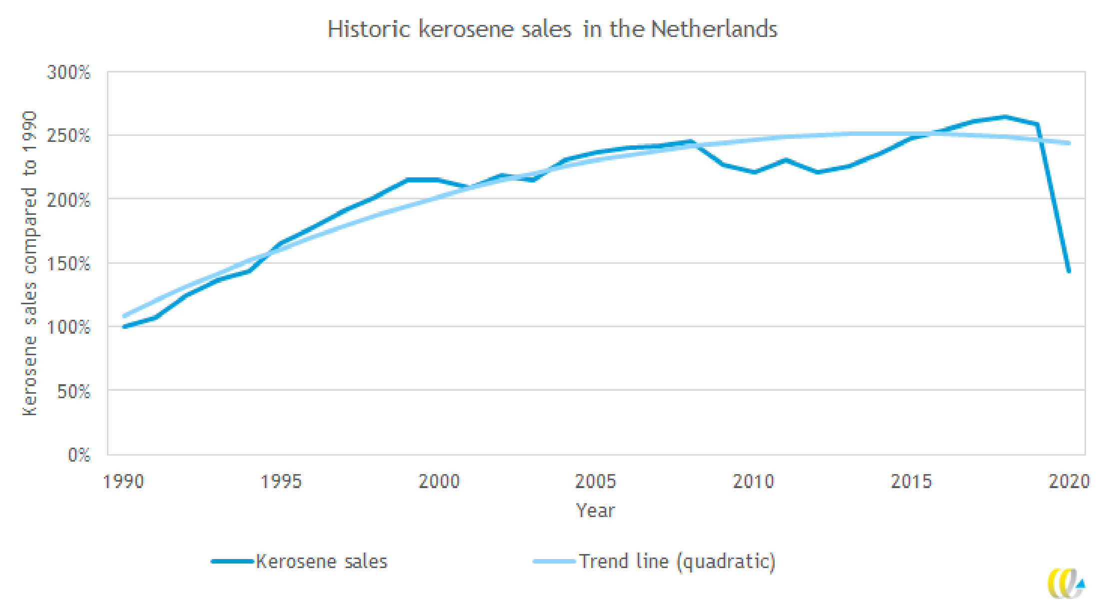
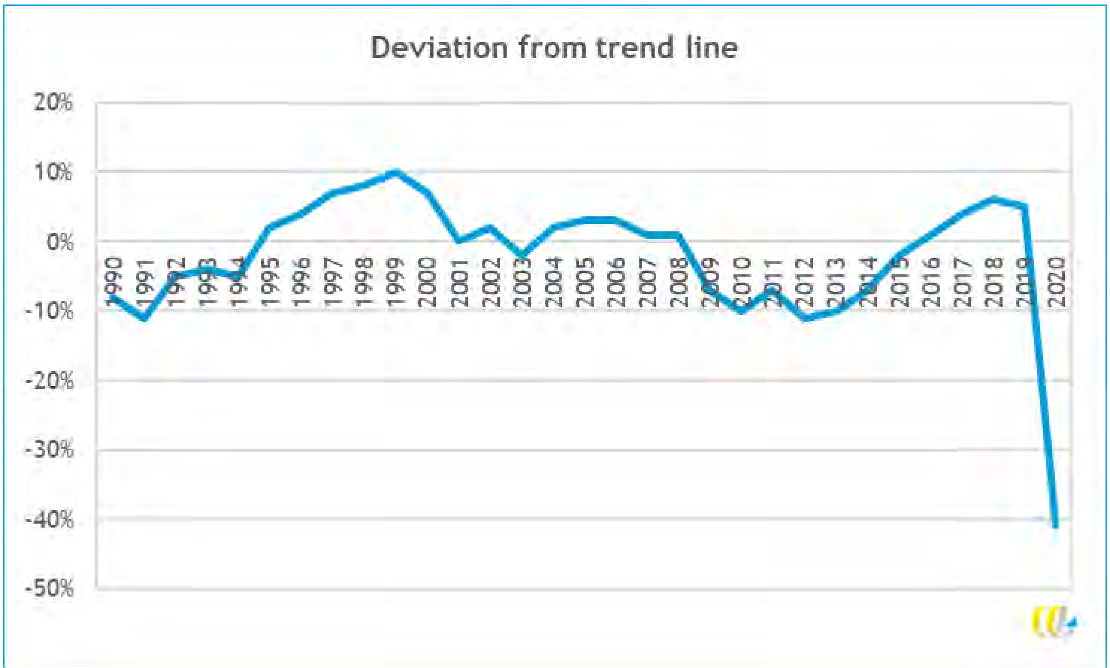


Figure 72 - Deviations of historic kerosene sales compared to the trend line



F.3 Assumptions about future fluctuations

We distinguish two types of fluctuations. First of all, there are periodic fluctuations due to for example economic conditions. These are impossible to predict, but not completely random. A second type of fluctuations is due to external events such as pandemics, volcanos and other types of disasters. These are usually negative deviations from the trend.

Due to the unpredictable nature of the fluctuations, the analysis of the future situations is uncertain; it is uncertain when, how severe and how long the deviations from the trend will occur.

Due to this uncertainty, we chose to present the outcome as a range (lower limit, upper limit and expected value). The 'expected value' corresponds to the AEOLUS output (in which no fluctuations occur). The upper and lower limit are defined as the values with a 10% increase or decrease in demand. This is roughly the range of fluctuations that, excluding the year 2020, can be expected (see Figure 72).

The AEOLUS model calculated the demand for aviation, and reduces the actual amount of flights by means of scarcity costs until the capacity constraints are met (we will from here on call the difference between amount of flights in the baseline and the amount of flights with the CO_2 ceiling the latent demand).[86] In our additional analysis, the assumed fluctuations in demand were used to estimate the amount of flights from the different airports when accounting for these fluctuations. Whenever the CO_2 ceiling, the airport capacity constraints and the noise limit are not reached, the effects of the fluctuations simply is that the number of yearly flights changes. Whenever the ceiling is reached, the level of scarcity was assumed to change, which we assume affects the ticket prices (since airlines can ask more money for the tickets if there demand is high).[87] Results for other parameters, such as the number of passengers, were estimated based on the number of flights.

Apart from the estimated effects of the +10% and -10% fluctuations, we also estimated the cumulative difference in the number of flights for the period during which the CO_2 ceiling is constraining. We did this by calculating the effects of different fluctuations and weighting the probabilities that such a fluctuation could occur based on the historic fluctuations.

F.4 Limited flexibility in the ceiling per airport suboptions

In the ceiling per airport suboptions, the duration of the compliance cycle is of importance. With a long compliance cycle, airlines are able to 'average out' fluctuations in demand, which means that they are able to compensate for years with low demand with high demand. With a short compliance cycle, this becomes increasingly difficult: if the periods of high and low demand are in different cycles, the airlines are not able to compensate (which could effectively mean that there will be years in which the ceiling is not reached, and other years in which the CO_2 prices are relatively high). A downside of a long compliance cycle is that airlines could be tempted to use more of the CO_2 budget than is responsible, which could make it in practice very difficult to meet the targets once the cycle comes to an end. Therefore, a long cycle has a political risk (the targets may not be reached) whereas a short cycle has practical downsides for the airlines (lack of flexibility).

In order to investigate the importance of the compliance cycle, we calculated the effects of fluctuations in demand with a 3-year compliance cycle and a 1-year compliance cycle. The AEOLUS output can be interpreted as an infinite compliance cycle.[88]

[86] There is also latent demand due to airport capacity constraints and noise constraints.

[87] If and upward fluctuation would mean that the constraints are reached, we assume that the number of flights grows until this limit (and that scarcity is introduced due to the further demand). If a downward fluctuation means that the demand falls below the constraints, the number of flights only decreases as much as the difference between the downward fluctuation and the scarcity.

[88] However, the political risk of a long compliance cycle cannot be modelled with AEOLUS.

Adjustments to the AEOLUS output:

- We divided the years when the CO_2 ceiling is restrictive in bins which represent the enforcement terms (either 1-year or 3-year cycle), starting from 2024. We calculated for each bin the percentage of flights what would have to be cancelled. For the three year bin, we assumed that the flexibility would be optimally used (for example by compensating for a year which is under the ceiling by flying more than the ceiling allows in one of the other years). For the one year enforcement cycle no flexibility was assumed.
- For each of the bins we calculated the effects of +10%, +5%, +0%, -5% and -10% fluctuations.
- The effects of the +-10% fluctuations in the cycles which include 2030 and 2050 were used to estimate the range of outcomes.
- The effects of all fluctuations, combined with a probability weighting based on Figure 72, was used to estimate the expected reduction in flights compared to the AEOLUS output due to limited flexibility.

F.5 No stability mechanism in the fuel supplier suboptions

The subvariant fuel supplier - no stability mechanism is characterized by auction incomes that are not channelled back to the aviation sector and a lack of a Market Stability Mechanism (MSR). The first subvariant of the fossil fuel ceiling does have such a price-stabilizing mechanism. The MSR is inspired by the Market Stability Mechanism from the EU ETS. Within the EU ETS, this instrument ensures that the number of emissions allowances in circulation remains between certain boundaries. Whenever the number of allowances becomes too large, fewer allowances will be auctioned in the next monitoring period. The would-be-auctioned rights are then stored in a safe. Whenever the number of allowances in circulation shrinks to undesirable numbers (causing prices to rise), the allowances that are stored in the safe are added to the auction volume in the next monitoring period. Within the fossil fuel ceiling, an MSR would function in a very similar manner: when there are too many fossil fuel rights in circulation, future auction volume are decreased. When fossil fuel rights turn scarce, the saved rights are added to the future auction volumes.

We assume that an MSR will limit the effects of yearly fluctuations such that observed outcomes will be comparable to the smooth AEOLUS output. Implicitly this assumption requires that during the first years of the CO_2-ceiling, there is an abundance of rights, such that the MSR can in fact be filled. After all, an empty MSR cannot stabilize a market where fuel rights are too scarce (in such case there a no saved rights to release in the market). Given this presupposition, the question becomes how large the impacts of yearly fluctuations will be when there is no MSR.

In order to determine the impact of banking, we must first look at the effect of another stabilising mechanism: the possibility for fuel sellers to bank excess right for sales in later years. Banking works in a similar manner as the MSR. When fossil fuel sales are lower than expected, fuel sellers can buy more fossil fuel rights than they need in the given year. If, in a later year, sales are higher than expected, the saved rights can be used. In subvariant 3 of the fossil fuel ceiling, banking is included, and we can hence expect prices and volumes to be remain stable to a certain extent.

The MSR and the banking mechanism differ in the sense that the MSR is fully automated, while the effects of banking depend on the strategic choices of fossil fuel sellers.

Insufficient forward-looking behaviour of fossil fuel sellers, or imprecise predictions can lead to a situation in which too few rights are being banked.

Adjustments to the AEOLUS output:
- For 2030 and 2050 we quantitatively estimate the effects compared to the corresponding subvariant with sufficient flexibility in situations where the aviation demand is 1) equal to the trend 2) 10% above the trend and c) 10% below the trend.
- For 2030 and 2050 we quantitatively estimate the effects of the subvariant without an MSR for three individual scenarios: 1) a scenario in which fuel sales are equal to the trend; 2) a scenario in which fuel sales are 5% higher than the trend; and 3) a scenario in which fuel sales are 5% lower than the trend. Note that we apply 5% fluctuations instead of the previously mentioned 10%. This factor 0.5 is applies to account for the stabilising effects of banking.
- For the cumulative effects, we apply random fuel sales fluctuations whose relative size is equal to 50% of the historically observed fluctuations (this 50% is an expert assumption). The factor 0.5 is again applied to account for the stabilising effects of banking.
- After adding the fluctuations, we determine whether in the new situation the ceiling has become more or less stringent in the given year, based on the reasoning in Figure 72. We adjust total fossil fuel sales and corresponding flight volumes based on these adjustments. Given that the adjustments are of limited size, we propose to calculate all other outcomes by scaling the original results in a linear fashion. For example, if the last step yields that the total number of flights should be decreased by 3%, we also assume that the total number of passengers decreases by 3%.
- Effects on ticket prices are estimated based on the output of the AEOLUS-series in similar situations.

G Detailed results reference scenario

In this section additional data of the central scenario is presented where relevant.

G.1 Impacts on the aviation sector

Fuel consumption by aviation fuel type in the reference baseline and the volumes in the policy options are indicated in Table 105. The aviation fuel consumption in the year 2017 is fossil kerosene (only) with a volume of 3.81 million tonnes.

Table 105 - Absolute fuel consumption in suboptions (million tonnes per year)

Airport	Year	Baseline	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - No stability	Airline - Auctioning State	Airline - Funnelled back
Total	2030	4.15	3.79 (3.68 to 3.79)	3.79 (3.67 to 3.79)	3.76	3.86	3.86	3.86 (3.83 to 3.83)	3.86	3.86
	2040	4.07	3.85 (3.66 to 3.85)	3.85 (3.64 to 3.85)	3.81	3.87	3.87	3.87 (3.56 to 3.57)	3.87	3.87
	2050	3.63	3.59 (3.29 to 3.63)	3.59 (3.31 to 3.62)	3.59	3.66	3.64	3.66 (2.54 to 2.74)	3.66	3.64
Fossil kerosene	2030	3.77	3.45 (3.35 to 3.45)	3.45 (3.34 to 3.45)	3.42	3.51	3.51	3.51 (3.51 to 3.51)	3.51	3.51
	2040	2.77	2.62 (2.49 to 2.62)	2.62 (2.48 to 2.62)	2.59	2.63	2.63	2.63 (2.63 to 2.63)	2.63	2.63
	2050	1.34	1.33 (1.22 to 1.34)	1.33 (1.23 to 1.34)	1.33	1.36	1.35	1.36 (1.3 to 1.41)	1.36	1.35
Total non-synthetic SAF*	2030	0.48	0.31 (0.31 to 0.31)	0.31 (0.3 to 0.31)	0.31	0.32	0.32	0.32 (0.32 to 0.32)	0.32	0.32
	2040	1.30	0.92 (0.88 to 0.92)	0.92 (0.87 to 0.92)	0.91	0.93	0.93	0.93 (0.92 to 0.93)	0.93	0.93
	2050	2.29	1.26 (1.15 to 1.27)	1.26 (1.16 to 1.27)	1.26	1.28	1.27	1.28 (1.23 to 1.33)	1.28	1.27
HEFA	2030	0.16	0.15 (0.14 to 0.15)	0.15 (0.14 to 0.15)	0.15	0.15	0.15	0.15 (0.15 to 0.15)	0.15	0.15
	2040	0.19	0.18 (0.17 to 0.18)	0.18 (0.17 to 0.18)	0.17	0.18	0.18	0.18 (0.18 to 0.18)	0.18	0.18
	2050	0.18	0.18 (0.17 to 0.18)	0.18 (0.17 to 0.18)	0.18	0.18	0.18	0.18 (0.18 to 0.19)	0.18	0.18
Gas. + FT	2030	0.00	0 (0 to 0)	0 (0 to 0)	0.00	0.00	0.00	0 (0 to 0)	0.00	0.00
	2040	0.40	0.38 (0.36 to 0.38)	0.38 (0.36 to 0.38)	0.38	0.38	0.38	0.38 (0.38 to 0.38)	0.38	0.38
	2050	0.61	0.6	0.6	0.60	0.62	0.61	0.62	0.62	0.61

Airport	Year	Baseline	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - No stability	Airline - Auctioning State	Airline - Funnelled back
			(0.55 to 0.61)	(0.56 to 0.61)				(0.59 to 0.61)		
ATJ	2030	0.18	0.17 (0.16 to 0.17)	0.17 (0.16 to 0.17)	0.17	0.17	0.17	0.17 (0.17 to 0.17)	0.17	0.17
	2040	0.39	0.37 (0.35 to 0.37)	0.37 (0.35 to 0.37)	0.36	0.37	0.37	0.37 (0.37 to 0.37)	0.37	0.37
	2050	0.48	0.47 (0.43 to 0.48)	0.47 (0.44 to 0.48)	0.47	0.48	0.48	0.48 (0.46 to 0.48)	0.48	0.48
RFNBO (Synthetic SAF)	2030	0.03	0.03 (0.03 to 0.03)	0.03 (0.03 to 0.03)	0.03	0.03	0.03	0.03 (0.03 to 0.03)	0.03	0.03
	2040	0.33	0.31 (0.29 to 0.31)	0.31 (0.29 to 0.31)	0.30	0.31	0.31	0.31 (0.31 to 0.31)	0.31	0.31
	2050	1.02	1 (0.92 to 1.02)	1 (0.93 to 1.01)	1.01	1.03	1.02	1.03 (0.99 to 1.02)	1.03	1.02

* Total non-synthetic SAF is the sum of HEFA, GAS+FT and ATJ. Due to rounding the figures from the table may not be adding up to the same figure as stated for total non-synthetic SAF.

G.2 Economic impacts

In Table 106 all changes in compliance cost items are indicated.

Table 106 - Compliance cost by cost item (changes in operational cost), in million EUR per year

Cost item	Year	Baseline cost	Airport - Strict (3-year cycle)	Airport - Strict (1-year cycle)	Airport - Soft	Fuel - Auctioning state	Fuel - Funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
Fuel cost	2030	€ 4,478	€ 4,097 (3,980 to 4,097)	€ 4,097 (3,963 to 4,097)	€ 4,057	€ 4,167	€ 4,167	€ 4,167 (4,161 to 4,172)	€ 4,167	€ 4,167
	2040	€ 5,205	€ 4,919 (4,677 to 4,919)	€ 4,919 (4,655 to 4,919)	€ 4,872	€ 4,950	€ 4,950	€ 4,950 (4,942 to 4,955)	€ 4,950	€ 4,950

Cost item	Year	Baseline cost	Airport - Strict (3-year cycle)	Airport - Strict (1-year cycle)	Airport - Soft	Fuel - Auctioning state	Fuel - Funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
	2050	€ 5,627	€ 5,555 (5,090 to 5,616)	€ 5,555 (5,129 to 5,611)	€ 5,559	€ 5,671	€ 5,639	€ 5,671 (5,453 to 5,811)	€ 5,671	€ 5,639
Fleet renewal cost[b]	2030	€ 65	€ -4.8	€ -4.8	€ -5.3	€ 76.3	€ 142.0	€ 76.3	€ 76.3	€ 142.0
	2040	€ 174	€ -7.5	€ -7.5	€ -8.8	€ 185.5	€ 181.2	€ 185.5	€ 185.5	€ 181.2
	2050	€ 244	€ -1.6	€ -1.6	€ -1.3	€ 1.4	€ 0.4	€ 1.4	€ 1.4	€ 0.4
Fuel excise tax (ETD)	2030	€ 251	-17 (-24 to -17)	-17 (-25 to -17)	€ -19	€ -7	€ 5	-7 (-7 to -7)	€ -7	€ 5
	2040	€ 201	-7 (-17 to -7)	-7 (-14 to -7)	€ -9	€ 2	€ 5	2 (2 to 2)	€ 2	€ 5
	2050	€ 70	0 (-6 to 1)	0 (-2 to 0)	€ 0	€ -0	€ -0	0 (-3 to 0)	€ -0	€ -0
ETS and CORSIA cost	2030	€ 323	€-25 (-33 to -25)	€-25 (-34 to -25)	€ -27	€ -16	€ -8	€-16 (-16 to -16)	€ -16	€ -8
	2040	€ 236	€-11 (-22 to -11)	€-11 (-23 to -11)	€ -13	€ -5	€ -3	€-5 (-5 to -5)	€ -5	€ -3
	2050	€ 117	€-1 (-10 to 1)	€-1 (-9 to 1)	€ -0	€ 0	€ 0	€0 (-4 to 5)	€ 0	€ 0
CO_2 ceiling allowance cost	2030	€ 0	€ 0	€ 0	€ 0	€ 0	€ 1,715	€ 1,693	€ 1,715	€ 1,715
	2040	€ 0	€ 0	€ 0	€ 0	€ 0	€ 997	€ 994	€ 997	€ 997
	2050	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Total compliance cost	2030	**€ 5,117**	€ -428 (-416 to -428)	€ -428 (-428 to -427)	€ -473	**€ 1,456**	€ -172	€ 1,456 (1,436 to 1,564)	**€ 1,456**	€ -172
	2040	**€ 5,816**	€ -312 (-297 to -312)	€ -312 (-312 to -311)	€ -364	**€ 924**	€ -73	**€ 924 (870 to 959)**	**€ 924**	€ -73
	2050	**€ 6,058**	€ -75 (-69 to -76)	€ -75 (-76 to -72)	€ -70	**€ 44**	**€ 11**	**€ 44** (-179 to 190)	**€ 44**	**€ 11**

a) The change in fuel cost due to improved energy efficiency of airplanes is included.

b) As outlined earlier, this is fleet renewal cost to obtain fuel cost savings through more energy efficient aircraft. Also in the baseline, airlines renew their fleet as investing in (some) more efficient aircraft will reduce fuel cost.

Fiscal impact

Table 107 - Total change in taxes by type of tax in the reference scenario (million EUR per year). Note: the different tax types are including the indirect user tax revenue they bring (see Subsection 4.5.2)

Type of tax	Year	Baseline cost	Airport - Strict (3-year cycle)	Airport - Strict (1-year cycle)	Airport - Soft	Fuel - Auctioning state	Fuel - Funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
Aviation tax	2030	€ 914	€ -40 (-65 to -40)	€ -40 (-69 to -40)	€ -45 (-70 to -45)	€ -21	€ 27	€ -21 (-24 to -18)	€ -21	€ 27
	2040	€ 1,146	€ -11 (-67 to -11)	€ -11 (-72 to -11)	€ -14 (-69 to -14)	€ -11	€ 24	€ -11 (-14 to -8)	€ -11	€ 24
	2050	€ 1,357	€ 12 (-103 to 27)	€ 12 (-93 to 26)	€ 13 (-102 to 27)	€ -3	€ 2	€ -3 (-55 to 8)	€ -3	€ 2
ETS revenue	2030	€ 232	€ -16 (-22 to -16)	€ -16 (-23 to -16)	€ -18 (-24 to -18)	€ -7	€ 4	€ -7 (-7 to -7)	€ -7	€ 4
	2040	€ 169	€ -6 (-14 to -6)	€ -6 (-15 to -6)	€ -7 (-15 to -7)	€ 2	€ 4	€ 2 (2 to 2)	€ 2	€ 4
	2050	€ 85	€ 0 (-7 to 1)	€ 0 (-6 to 1)	€ 0 (-7 to 1)	€ 0	€ 0	€ 0 (-3 to 3)	€ 0	€ 0
Allowance revenue	2030	€ 0	€ 0	€ 0	€ 0	€ 2,027	€ 0	€ 2,027 (2,010 to 2,149)	€ 2,027	€ 0
	2040	€ 0	€ 0	€ 0	€ 0	€ 1,179	€ 0	€ 1,179 (1,123 to 1,214)	€ 1,179	€ 0
	2050	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0 (0 to 0)	€ 0	€ 0
Fuel tax (ETD)	2030	€ 296	€ -20 (-28 to -20)	€ -20 (-29 to -20)	€ -22 (-30 to -22)	€ -9	€ 6	€ -9 (-9 to -9)	€ -9	€ 6
	2040	€ 237	€ -9 (-20 to -9)	€ -9 (-16 to -9)	€ -10 (-21 to -10)	€ 2	€ 6	€ 2 (2 to 2)	€ 2	€ 6
	2050	€ 82	€ 0 (-7 to 1)	€ 0 (-2 to 0)	€ 0 (-7 to 1)	€ 0	€ 0	€ 0 (-3 to 0)	€ 0	€ 0
User tax*	2030	€ 0	€ 8 (0 to 8)	€ 9 (0 to 8)	€ 18 (-8 to -8)	€ -62	€ -62	€ 27 (27 to 27)	€ -62	€ -62
	2040	€ 0	€ 9 (0 to 9)	€ 10 (0 to 9)	€ 1 (-9 to -9)	€ -49	€ -49	€ 10 (10 to 10)	€ -49	€ -49
	2050	€ 0	€ 1 (1 to 0)	€ 0 (1 to 0)	€ -4 (-1 to -1)	€ -1	€ -1	€ -3 (-3 to -3)	€ -1	€ -1
Profit tax airports	2030	€ 92	€ -7 (-9 to -7)	€ -7 (-9 to -7)	€ -7 (-10 to -7)	€ -4	€ -1	€ -4 (-5 to -4)	€ -4	€ -1
	2040	€ 109	€ -5 (-10 to -5)	€ -5 (-11 to -5)	€ -6 (-11 to -6)	€ -1	€ 0	€ -1 (-2 to -1)	€ -1	€ 0
	2050	€ 119	€ -1 (-11 to 0)	€ -1 (-10 to 0)	€ -1 (-11 to 0)	€ 1	€ 1	€ 1 (-4 to 2)	€ 1	€ 1
Profit tax airlines	2030	€ 294	€ -21 (-29 to -21)	€ -21 (-30 to -21)	€ -24 (-32 to -24)	€ -14	€ -3	€ -14 (-15 to -13)	€ -14	€ -3
	2040	€ 339	€ -16 (-32 to -16)	€ -16 (-33 to -16)	€ -19 (-34 to -19)	€ -3	€ 0	€ -3 (-4 to -2)	€ -3	€ 0
	2050	€ 380	€ -3 (-35 to 1)	€ -3 (-32 to 1)	€ -3 (-35 to 1)	€ 3	€ 2	€ 3 (-12 to 6)	€ 3	€ 2
Dividends Schiphol Group	2030	€ 146	€ -10 (-14 to -10)	€ -10 (-15 to -10)	€ -12 (-16 to -12)	€ -7	€ -2	€ -7 (-7 to -6)	€ -7	€ -2
	2040	€ 172	€ -8 (-16 to -8)	€ -8 (-17 to -8)	€ -9 (-17 to -9)	€ -2	€ 0	€ -2 (-3 to -2)	€ -2	€ 0
	2050	€ 189	€ -1 (-17 to 1)	€ -1 (-16 to 0)	€ -1 (-17 to 0)	€ 1	€ 1	€ 1 (-6 to 3)	€ 1	€ 1

Type of tax	Year	Baseline cost	Airport - Strict (3-year cycle)	Airport - Strict (1-year cycle)	Airport - Soft	Fuel - Auctioning state	Fuel - Funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
Total taxes	2030	**€ 1,976**	€ -106 (-168 to -106)	€ -106 (-175 to -106)	€ -128 (-181 to -128)	€ 1,992	€ -32	€ 1,965 (1,944 to 2,091)	€ 1,992	€ -32
	2040	**€ 2,172**	€ -46 (-159 to -46)	€ -46 (-164 to -46)	€ -65 (-169 to -65)	€ 1,175	€ -16	€ 1,165 (1,104 to 1,204)	€ 1,175	€ -16
	2050	**€ 2,213**	**€ 8** (-178 to 31)	**€ 8** (-158 to 28)	**€ 8** (-178 to 31)	**€ 0**	**€ 4**	**€ 2** (-83 to 21)	**€ 0**	**€ 4**

* The user tax revenues are from expenditure inside the Netherlands by people not flying due to increased cost of the CO_2 ceiling.

G.3 Environmental impacts

LTO air pollutants for the Dutch airports specifically.

Table 108 - Change for Schiphol airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-294 (-370 to -294)	-294 (-381 to -294)	-322 (-397 to -322)	-130	-75	-130 (-138 to -122)	-130	-75
	2040	-127 (-251 to -127)	-127 (-262 to -127)	-149 (-271 to -149)	-28	-32	-28 (-35 to -22)	-28	-32
	2050	1 (-193 to 27)	1 (-176 to 25)	3 (-192 to 28)	2	1	2 (-88 to 20)	2	1
NO_x	2030	-440 (-543 to -440)	-440 (-557 to -440)	-481 (-583 to -481)	-222	-195	-222 (-233 to -211)	-222	-195
	2040	-203 (-384 to -203)	-203 (-400 to -203)	-237 (-417 to -237)	-91	-109	-91 (-101 to -81)	-91	-109
	2050	-19 (-318 to 20)	-19 (-293 to 17)	-19 (-318 to 20)	14	6	14 (-124 to 42)	14	6
VOS	2030	-31 (-40 to -31)	-31 (-41 to -31)	-34 (-43 to -34)	-13	-4	-13 (-14 to -12)	-13	-4
	2040	-11 (-23 to -11)	-11 (-24 to -11)	-13 (-25 to -13)	-2	-1	-2 (-2 to -1)	-2	-1
	2050	1 (-14 to 3)	1 (-12 to 3)	1 (-14 to 3)	-0	-0	0 (-7 to 1)	-0	-0
SO_2	2030	-10 (-12 to -10)	-10 (-12 to -10)	-11 (-13 to -11)	-5	-3	-5 (-5 to -4)	-5	-3
	2040	-4 (-7 to -4)	-4 (-7 to -4)	-4 (-8 to -4)	-1	-1	-1 (-1 to -1)	-1	-1
	2050	0 (-4 to 0)	0 (-4 to 0)	0 (-4 to 0)	0	0	0 (-2 to 0)	0	0
PM_{10}	2030	-5 (-6 to -5)	-5 (-7 to -5)	-5 (-7 to -5)	-2	-2	-2 (-2 to -2)	-2	-2

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
	2040	-2 (-4 to -2)	-2 (-4 to -2)	-2 (-4 to -2)	-1	-1	-1 (-1 to -1)	-1	-1
	2050	0 (-2 to 0)	0 (-2 to 0)	0 (-2 to 0)	0	0	0 (-1 to 0)	0	0

Table 109 - Change for Lelystad airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-5.5 (-7 to -5.5)	-5.5 (-7.2 to -5.5)	-6.1 (-7.6 to -6.1)	-1.2	2.3	-1.2 (-1.4 to -1.1)	-1.2	2.3
	2040	-5.4 (-9.8 to -5.4)	-5.4 (-10.2 to -5.4)	-6.2 (-10.6 to -6.2)	-7.2	1.7	-7.2 (-7.4 to -7)	-7.2	1.7
	2050	-1.8 (-11.1 to -0.5)	-1.8 (-10.3 to -0.6)	-1.9 (-11.3 to -0.7)	-0.3	-0.8	-0.3 (-4.7 to 0.6)	-0.3	-0.8
NO_x	2030	-3.6 (-4.6 to -3.6)	-3.6 (-4.7 to -3.6)	-4 (-4.9 to -4)	-0.8	1.5	-0.8 (-0.9 to -0.7)	-0.8	1.5
	2040	-3.7 (-6.7 to -3.7)	-3.7 (-6.9 to -3.7)	-4.2 (-7.2 to -4.2)	-4.9	1.1	-4.9 (-5 to -4.7)	-4.9	1.1
	2050	-1.3 (-8 to -0.4)	-1.3 (-7.4 to -0.5)	-1.4 (-8.1 to -0.5)	-0.2	-0.6	-0.2 (-3.4 to 0.4)	-0.2	-0.6
VOS	2030	-0.8 (-1.5 to -0.8)	-0.8 (-1.6 to -0.8)	-1.1 (-1.4 to -1.1)	-0.2	0.4	-1.1 (-1.1 to -1.1)	-0.2	0.4
	2040	-0.8 (-1.5 to -0.8)	-0.8 (-1.6 to -0.8)	-1 (-1.6 to -1)	-1.1	0.3	-1.1 (-1.1 to -1.1)	-1.1	0.3
	2050	-0.2 (-1.3 to -0.1)	-0.2 (-1.2 to -0.1)	-0.2 (-1.3 to -0.1)	-0.0	-0.1	0 (-0.5 to 0.1)	-0.0	-0.1
SO_2	2030	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	-0.1 (-0.2 to -0.1)	-0.1 (-0.2 to -0.1)	-0.1 (-0.2 to -0.1)	-0.2	0.0	-0.2 (-0.2 to -0.2)	-0.2	0.0
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.2 to 0)	-0.0	-0.0	0 (-0.1 to 0)	-0.0	-0.0
PM_{10}	2030	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2040	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.1 (-0.1 to -0.1)	-0.1	0.0	-0.1 (-0.1 to -0.1)	-0.1	0.0
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-0.0	0 (0 to 0)	-	-0.0

Table 110 - Change for Eindhoven airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-3 (-6.4 to -3)	-3 (-6.9 to -3)	-3.9 (-7.3 to -3.9)	-2.2	5.7	-2.2 (-2.5 to -1.8)	-2.2	5.7
	2040	15 (6.6 to 15)	15 (5.8 to 15)	15.9 (7.4 to 15.9)	-9.8	2.3	-9.8 (-10.2 to -9.5)	-9.8	2.3
	2050	-3.4 (-19 to -1.3)	-3.4 (-17.7 to -1.5)	-1.6 (-17.4 to 0.5)	-0.3	-0.9	-0.3 (-7.6 to 1.2)	-0.3	-0.9
NO_x	2030	-2 (-4.2 to -2)	-2 (-4.5 to -2)	-2.5 (-4.8 to -2.5)	-1.4	3.7	-1.4 (-1.6 to -1.2)	-1.4	3.7
	2040	10.2 (4.5 to 10.2)	10.2 (4 to 10.2)	10.8 (5.1 to 10.8)	-6.7	1.5	-6.7 (-7 to -6.4)	-6.7	1.5
	2050	-2.4 (-13.7 to -0.9)	-2.4 (-12.7 to -1)	-1.2 (-12.5 to 0.3)	-0.2	-0.7	-0.2 (-5.5 to 0.9)	-0.2	-0.7
VOS	2030	2.3 (1 to 2.3)	2.3 (0.9 to 2.3)	-0.7 (-1.3 to -0.7)	-0.4	1.0	-1.5 (-1.6 to -1.5)	-0.4	1.0
	2040	2.3 (1 to 2.3)	2.3 (0.9 to 2.3)	2.4 (1.1 to 2.4)	-1.5	0.3	-1.5 (-1.6 to -1.5)	-1.5	0.3
	2050	-0.4 (-2.2 to -0.2)	-0.4 (-2 to -0.2)	-0.2 (-2 to 0)	-0.0	-0.1	0 (-0.9 to 0.1)	-0.0	-0.1
SO_2	2030	-0.1 (-0.2 to -0.1)	-0.1 (-0.2 to -0.1)	-0.1 (-0.2 to -0.1)	-0.1	0.2	-0.1 (-0.1 to -0.1)	-0.1	0.2
	2040	0.3 (0.1 to 0.3)	0.3 (0.1 to 0.3)	0.3 (0.2 to 0.3)	-0.2	0.1	-0.2 (-0.2 to -0.2)	-0.2	0.1
	2050	0 (-0.3 to 0)	0 (-0.2 to 0)	0 (-0.2 to 0)	-	-0.0	0 (-0.1 to 0)	-	-0.0
PM_{10}	2030	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	0.1 (0.1 to 0.1)	0.1 (0 to 0.1)	0.1 (0.1 to 0.1)	-0.1	0.0	-0.1 (-0.1 to -0.1)	-0.1	0.0
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-0.0	0 (0 to 0)	-	-0.0

Table 111 - Change for Rotterdam airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	12.1 (10.4 to 12.1)	12.1 (10.1 to 12.1)	12.4 (10.7 to 12.4)	-0.8	2.5	-0.8 (-0.9 to -0.6)	-0.8	2.5
	2040	0.3 (-3 to 0.3)	0.3 (-3.4 to 0.3)	0.5 (-2.9 to 0.5)	-0.9	2.3	-0.9 (-1 to -0.7)	-0.9	2.3
	2050	-1.1 (-7.2 to -0.3)	-1.1 (-6.6 to -0.3)	-1.1 (-7.2 to -0.3)	-0.1	-0.5	-0.1 (-3 to 0.5)	-0.1	-0.5
NO_x	2030	7.5 (6.4 to 7.5)	7.5 (6.2 to 7.5)	7.7 (6.6 to 7.7)	-0.5	1.6	-0.5 (-0.5 to -0.4)	-0.5	1.6
	2040	0.2 (-2 to 0.2)	0.2 (-2.2 to 0.2)	0.3 (-1.9 to 0.3)	-0.5	1.5	-0.5 (-0.7 to -0.4)	-0.5	1.5
	2050	-0.7 (-4.9 to -0.2)	-0.7 (-4.5 to -0.2)	-0.8 (-4.9 to -0.2)	-0.1	-0.4	-0.1 (-2 to 0.3)	-0.1	-0.4

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
VOS	2030	0 (-0.4 to 0)	0 (-0.4 to 0)	1.8 (1.6 to 1.8)	-0.1	0.4	-0.1 (-0.1 to -0.1)	-0.1	0.4
	2040	0 (-0.4 to 0)	0 (-0.4 to 0)	0.1 (-0.4 to 0.1)	-0.1	0.3	-0.1 (-0.1 to -0.1)	-0.1	0.3
	2050	-0.1 (-0.7 to 0)	-0.1 (-0.6 to 0)	-0.1 (-0.7 to 0)	-0.0	-0.0	0 (-0.3 to 0)	-0.0	-0.0
SO_2	2030	0.3 (0.3 to 0.3)	0.3 (0.3 to 0.3)	0.3 (0.3 to 0.3)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-	0 (0 to 0)	-	-
PM_{10}	2030	0.2 (0.1 to 0.2)	0.2 (0.1 to 0.2)	0.2 (0.1 to 0.2)	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-	0 (0 to 0)	-	-

Table 112 - Change for Maastricht airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	0.7 (-1.6 to 0.7)	0.7 (-1.9 to 0.7)	0.8 (-1.6 to 0.8)	-1.8	-0.4	-1.8 (-2.1 to -1.6)	-1.8	-0.4
	2040	0 (-4.1 to 0)	0 (-4.4 to 0)	0 (-4.1 to 0)	-1.4	-0.2	-1.4 (-1.6 to -1.2)	-1.4	-0.2
	2050	0 (-6.9 to 0.8)	0 (-6.3 to 0.8)	0 (-6.9 to 0.9)	-0.0	-0.0	0 (-3.2 to 0.6)	-0.0	-0.0
NO_x	2030	0.4 (-3.1 to 0.4)	0.4 (-3.6 to 0.4)	0.4 (-3.1 to 0.4)	-3.1	-0.8	-3.1 (-3.5 to -2.8)	-3.1	-0.8
	2040	0 (-6.8 to 0)	0 (-7.4 to 0)	0 (-6.8 to 0)	-2.4	-0.5	-2.4 (-2.8 to -2.1)	-2.4	-0.5
	2050	0 (-12.6 to 1.6)	0 (-11.5 to 1.5)	0 (-12.6 to 1.6)	-0.0	-0.0	0 (-5.8 to 1.2)	-0.0	-0.0
VOS	2030	0 (-0.4 to 0)	0 (-0.4 to 0)	0.1 (-0.1 to 0.1)	-0.2	-0.0	-0.1 (-0.1 to -0.1)	-0.2	-0.0
	2040	0 (-0.4 to 0)	0 (-0.4 to 0)	0 (-0.4 to 0)	-0.1	-0.0	-0.1 (-0.1 to -0.1)	-0.1	-0.0
	2050	0 (-0.4 to 0.1)	0 (-0.4 to 0.1)	0 (-0.4 to 0.1)	-	-	0 (-0.2 to 0)	-	-
SO_2	2030	0 (0 to 0)	0 (-0.1 to 0)	0 (0 to 0)	-0.1	-0.0	-0.1 (-0.1 to 0)	-0.1	-0.0
	2040	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.0	-0.0	0 (0 to 0)	-0.0	-0.0
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-	0 (-0.1 to 0)	-	-
PM_{10}	2030	0 (0 to 0)	0 (-0.1 to 0)	0 (0 to 0)	-0.0	-0.0	0 (0 to 0)	-0.0	-0.0
	2040	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.0	-0.0	0 (0 to 0)	-0.0	-0.0

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
	2050	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-	-	0 (0 to 0)	-	-

Table 113 - Change for Groningen airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	3.1 (2.7 to 3.1)	3.1 (2.6 to 3.1)	3.2 (2.8 to 3.2)	-0.1	0.8	-0.1 (-0.1 to 0)	-0.1	0.8
	2040	0.1 (-0.8 to 0.1)	0.1 (-0.9 to 0.1)	0.2 (-0.7 to 0.2)	-0.1	0.8	-0.1 (-0.2 to -0.1)	-0.1	0.8
	2050	-0.2 (-1.9 to 0)	-0.2 (-1.8 to 0)	-0.2 (-2 to 0)	0.0	-0.1	0 (-0.8 to 0.2)	0.0	-0.1
NO_x	2030	1.9 (1.6 to 1.9)	1.9 (1.6 to 1.9)	1.9 (1.7 to 1.9)	-0.0	0.5	0 (-0.1 to 0)	-0.0	0.5
	2040	0.1 (-0.5 to 0.1)	0.1 (-0.5 to 0.1)	0.1 (-0.5 to 0.1)	-0.1	0.5	-0.1 (-0.1 to 0)	-0.1	0.5
	2050	-0.1 (-1.3 to 0)	-0.1 (-1.2 to 0)	-0.2 (-1.3 to 0)	-	-0.1	0 (-0.5 to 0.1)	-	-0.1
VOS	2030	0 (-0.1 to 0)	0 (-0.1 to 0)	0.5 (0.5 to 0.5)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	0 (-0.1 to 0)	0 (-0.1 to 0)	0 (-0.1 to 0)	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2050	0 (-0.2 to 0)	0 (-0.2 to 0)	0 (-0.2 to 0)	-	-0.0	0 (-0.1 to 0)	-	-0.0
SO_2	2030	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	-	0.0	0 (0 to 0)	-	0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-	0.0	0 (0 to 0)	-	0.0
	2050	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-	-	0 (0 to 0)	-	-
PM_{10}	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-	0.0	0 (0 to 0)	-	0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-	0.0	0 (0 to 0)	-	0.0
	2050	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-	-	0 (0 to 0)	-	-

H Impacts of policy options in other scenarios

In the main report the impacts for the reference scenario are presented. This scenario assumes that the Fit for 55 package is adopted as proposed, that there are no additional Dutch blending obligations, middle airport capacity and WLO high. In this Annex we summarize the main impacts for the extreme scenario (Scenario 6). In this scenario we assume reduced ambitions of the Fit for 55 package, no additional Dutch blending obligations, high airport capacity and WLO high.

H.1 Impacts on the aviation sector

Impacts on flights

Table 114 - Development of the number of flights at Dutch airports in the baseline (without **CO_2** ceiling)

Airport	Year	No of flights per year (x 1,000)
Total	2017	556
	2030	587
	2040	687
	2050	760
Amsterdam	2017	497
	2030	517
	2040	587
	2050	630
Lelystad	2017	0
	2030	15
	2040	25
	2050	35
Eindhoven	2017	35
	2030	32
	2040	41
	2050	55
Rotterdam	2017	16
	2030	14
	2040	23
	2050	26
Maastricht	2017	4
	2030	5
	2040	6
	2050	7
Groningen	2017	3
	2030	3
	2040	6
	2050	7

Figure 73 - Total number of flights at Dutch airports

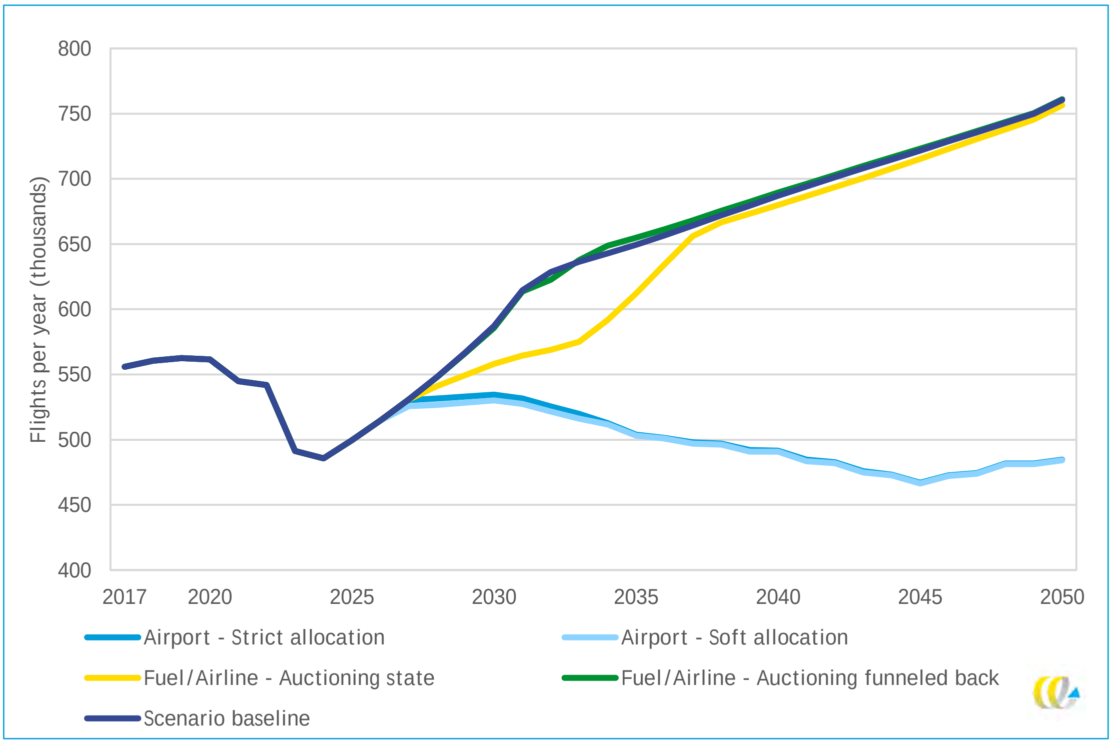


Table 115 - Development of the number of flights at Dutch airports compared to the baseline (thousands per year)

Airport	Year	Airport - Strict allocation (3-year cycle)[a]	Airport - Strict allocation (1-year cycle)[a]	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability mechanism[a]	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-52.5 (-54.7 to -52.5)	-52.5 (-59.2 to -52.5)	-56.9 (-59.1 to -56.9)	-29.0	-1.3	-29 (-30.6 to -27.4)	-29.0	-1.3
	2040	-195.5 (-195.5 to -195.5)	-195.5 (-195.5 to -195.5)	-196.2 (-196.2 to -196.2)	-7.0	2.4	-7 (-8.5 to -5.6)	-7.0	2.4
	2050	-275.9 (-275.9 to -275.9)	-275.9 (-275.9 to -275.9)	-276.2 (-276.2 to -259.7)	-4.1	0.6	-4.1 (-5.2 to -3)	-4.1	0.6
Amsterdam	2030	-54.9 (-56.9 to -54.9)	-54.9 (-60.7 to -54.9)	-59.7 (-61.6 to -59.7)	-27.4	-4.9	-27.4 (-27.4 to -27.4)	-27.4	-4.9
	2040	-180.1 (-180.1 to -180.1)	-180.1 (-180.1 to -180.1)	-185.5 (-185.5 to -185.5)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2050	-230.1 (-230.1 to -230.1)	-230.1 (-230.1 to -230.1)	-235.7 (-235.7 to -235.7)	0.0	0.0	0 (0 to 0)	0.0	0.0
Lelystad	2030	-1.7 (-1.8 to -1.7)	-1.7 (-1.9 to -1.7)	-1.8 (-1.9 to -1.8)	-0.4	0.7	-0.4 (-0.8 to -0.1)	-0.4	0.7
	2040	-7.9 (-7.9 to -7.9)	-7.9 (-7.9 to -7.9)	-8.1 (-8.1 to -8.1)	-3.3	-0.1	-3.3 (-3.6 to -3)	-3.3	-0.1
	2050	-14.3 (-14.3 to -14.3)	-14.3 (-14.3 to -14.3)	-14.5 (-14.5 to -14.5)	-0.8	0.2	-0.8 (-1.1 to -0.5)	-0.8	0.2
Eindhoven	2030	-0.9 (-1 to -0.9)	-0.9 (-1.2 to	-0.5 (-0.6 to -0.5)	-0.7	1.7	-0.7 (-1.5 to 0)	-0.7	1.7

Airport	Year	Airport - Strict allocation (3-year cycle)[a]	Airport - Strict allocation (1-year cycle)[a]	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability mechanism[a]	Airline - Auctioning state	Airline - Funnelled back
			-0.9)						
	2040	-3.7 (-3.7 to -3.7)	-3.7 (-3.7 to -3.7)	-0.7 (-0.7 to -0.7)	-2.5	1.2	-2.5 (-3 to -1.9)	-2.5	1.2
	2050	-19.4 (-19.4 to -19.4)	-19.4 (-19.4 to -19.4)	-16.6 (-16.6 to 0)	-2.9	-0.1	-2.9 (-3.3 to -2.4)	-2.9	-0.1
Rotterdam	2030	3.9 (3.8 to 3.9)	3.9 (3.6 to 3.9)	3.9 (3.9 to 3.9)	-0.3	0.9	-0.3 (-0.6 to 0)	-0.3	0.9
	2040	-2.5 (-2.5 to -2.5)	-2.5 (-2.5 to -2.5)	-1.9 (-1.9 to -1.9)	-0.9	1.0	-0.9 (-1.2 to -0.6)	-0.9	1.0
	2050	-7.9 (-7.9 to -7.9)	-7.9 (-7.9 to -7.9)	-7.6 (-7.6 to -7.6)	-0.3	0.3	-0.3 (-0.5 to -0.1)	-0.3	0.3
Maastricht	2030	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	-0.2	0.0	-0.2 (-0.3 to 0)	-0.2	0.0
	2040	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	-0.2	0.0	-0.2 (-0.3 to -0.1)	-0.2	0.0
	2050	-0.9 (-0.9 to -0.9)	-0.9 (-0.9 to -0.9)	0.3 (0.3 to 0.3)	0.0	0.0	0 (-0.1 to 0)	0.0	0.0
Groningen	2030	0.9 (0.9 to 0.9)	0.9 (0.9 to 0.9)	1 (0.9 to 1)	0.0	0.3	0 (-0.1 to 0.1)	0.0	0.3
	2040	-1.4 (-1.4 to -1.4)	-1.4 (-1.4 to -1.4)	-0.2 (-0.2 to -0.2)	-0.2	0.3	-0.2 (-0.3 to -0.1)	-0.2	0.3
	2050	-3.3 (-3.3 to -3.3)	-3.3 (-3.3 to -3.3)	-2 (-2 to -2)	-0.1	0.1	-0.1 (-0.1 to 0)	-0.1	0.1

Figure 74 - Development of the number of EEA flights at Dutch airports

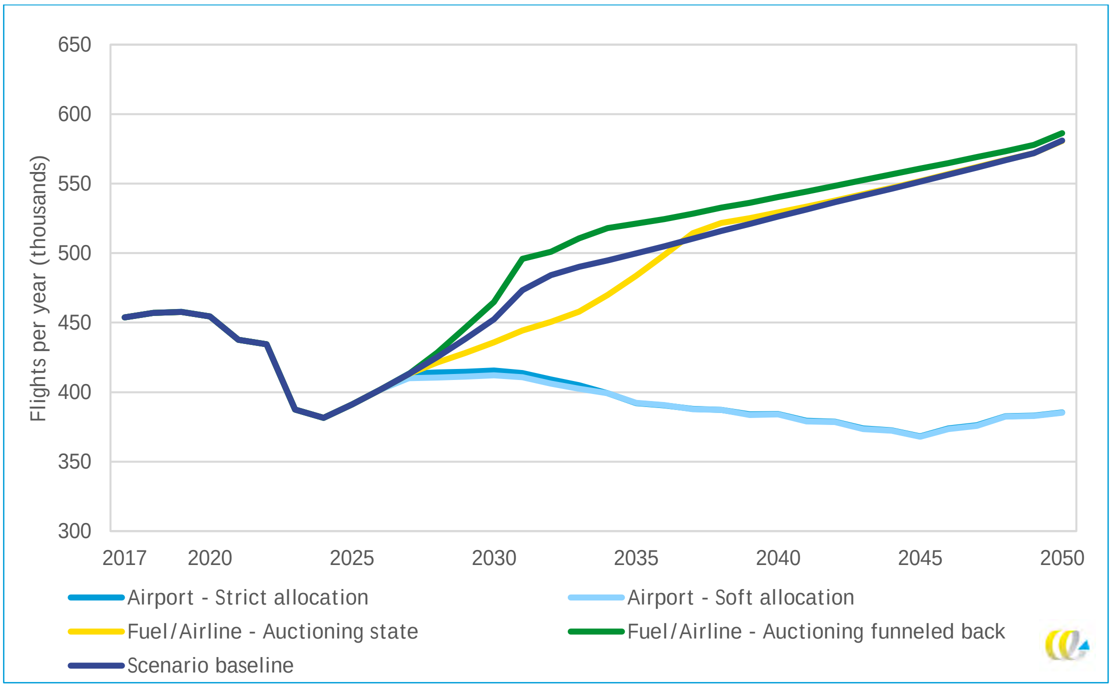


Figure 75 - Development of the number of intercontinental flights at Dutch airports

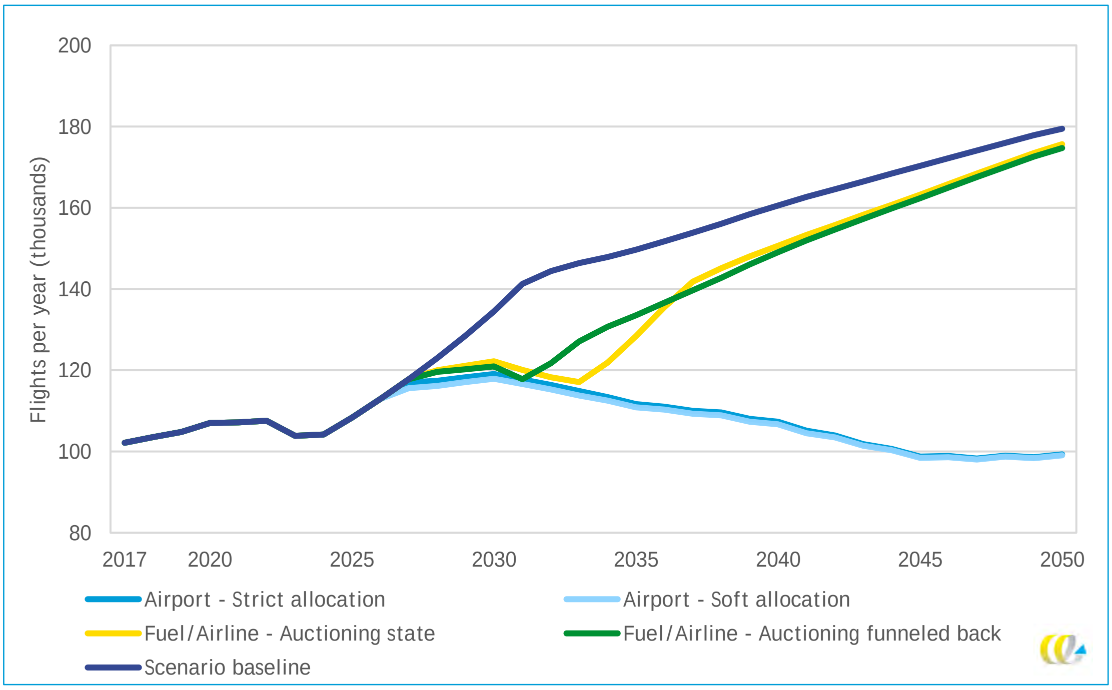


Figure 76 - Development of the number of passenger flights at Dutch airports

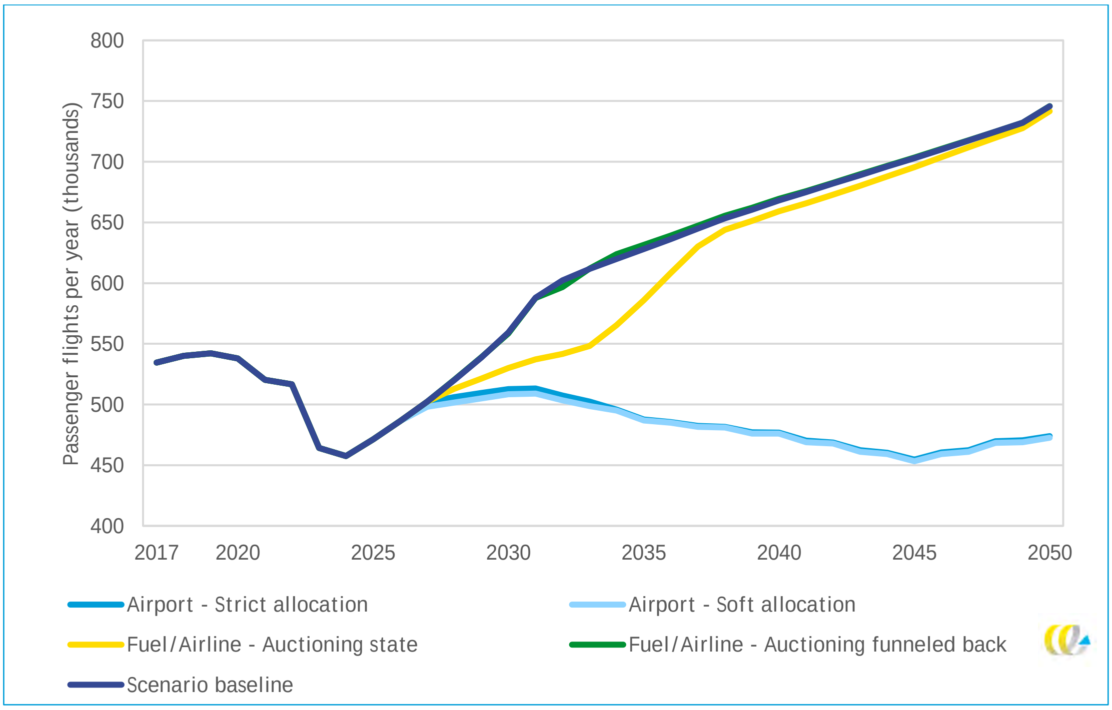


Figure 77 - Development of the number of full freighter flights at Dutch airports

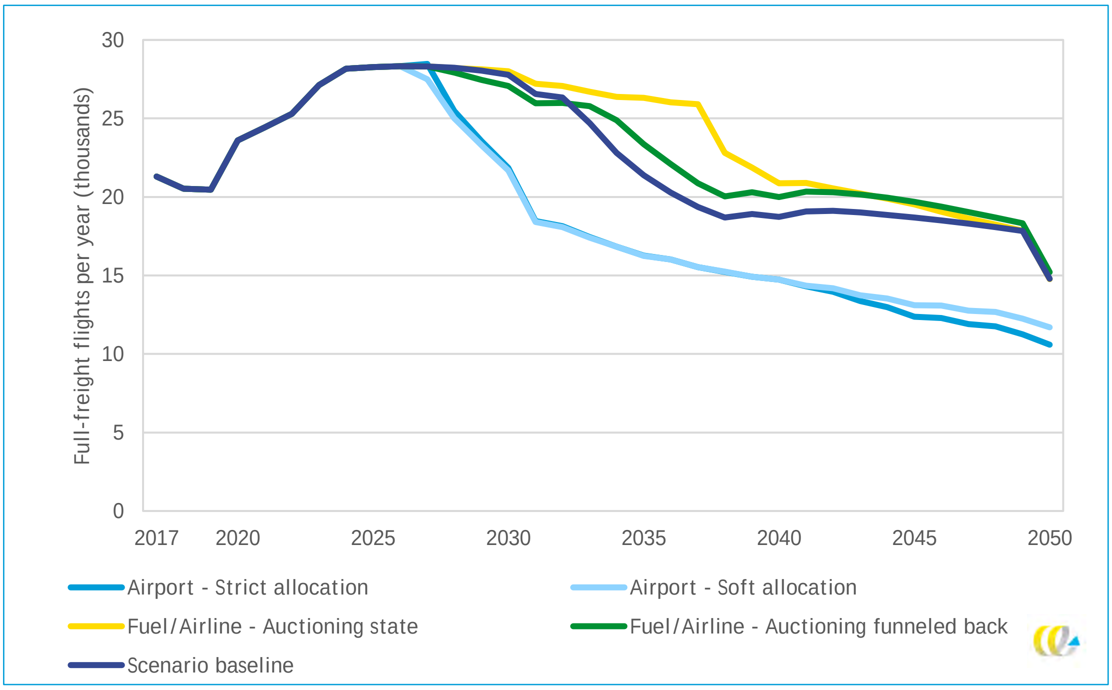


Table 116 - Impacts on the number of flights for the different policy options in 2030 as a proxy for connectivity

Year	Flight segment	Airport - strict allocation	Airport - soft allocation	Fuel supplier/Airline - auctioning state	Fuel supplier/Airline - auctioning funnelled back
2030	Total flights	-8.9%	-9.7%	-4.9%	-0.2%
	EEA	-8.2%	-8.9%	-3.7%	+2.7%
	Intercontinental	-11.5%	-12.3%	-9.1%	-10.1%
2040	Total flights	-28.5%	-28.6%	-1.0%	+0.4%
	EEA	-27.0%	-27.0%	+0.6%	+2.7%
	Intercontinental	-33.2%	-33.6%	-6.2%	-7.2%

Impacts on passenger demand

Table 117 - Development of the passenger demand at Dutch airports in the baseline (without CO_2 ceiling)

Airport	Year	Passenger demand (x 1,000)
Total	2017	76,197
	2030	103,873
	2040	135,149
	2050	156,917
Amsterdam	2017	68,393
	2030	91,741
	2040	116,436
	2050	131,380
Lelystad	2017	0
	2030	3,171
	2040	5,567
	2050	8,030
Eindhoven	2017	5,701
	2030	6.583
	2040	9,117
	2050	12,612
Rotterdam	2017	1,733
	2030	1,947
	2040	3,276
	2050	3,961
Maastricht	2017	168
	2030	192
	2040	301
	2050	346
Groningen	2017	202
	2030	239
	2040	452
	2050	588

Figure 78 - Total number of passengers at Dutch airports

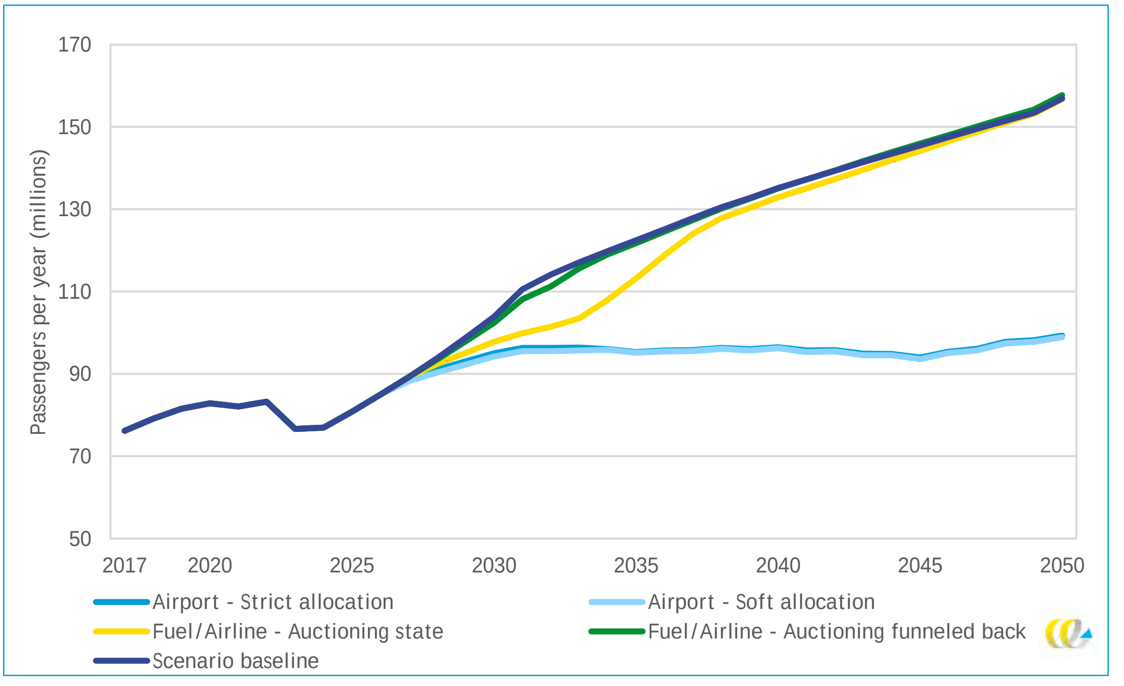


Table 118 - Impacts on passenger demands (millions per year)

Airport	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-8.9 (-9.3 to -8.9)	-8.9 (-10.1 to -8.9)	-9.7 (-10 to -9.7)	-6.1	-1.4	-6.1 (-6.4 to -5.8)	-6.1	-1.4
	2040	-38.6 (-38.6 to -38.6)	-38.6 (-38.6 to -38.6)	-38.9 (-38.9 to -38.9)	-2.3	-0.1	-2.3 (-2.5 to -2)	-2.3	-0.1
	2050	-57.6 (-57.6 to -57.6)	-57.6 (-57.6 to -57.6)	-58 (-58 to -54)	-0.1	0.8	-0.1 (-0.4 to 0.1)	-0.1	0.8
Amsterdam	2030	-9 (-9.3 to -9)	-9 (-10 to -9)	-9.8 (-10.2 to -9.8)	-5.8	-2.1	-5.8 (-5.8 to -5.8)	-5.8	-2.1
	2040	-35.6	-35.6	-36.6 (-36.6 to -36.6)	-1.0	-0.7	-1	-1.0	-0.7
	2050	-48.4	-48.4	-49.6 (-49.6 to -49.6)	0.5	0.5	0.5	0.5	0.5
Lelystad	2030	-0.4	-0.4	-0.4 (-0.4 to -0.4)	-0.1	0.1	-0.1 (-0.2 to 0)	-0.1	0.1
	2040	-1.8	-1.8	-1.8 (-1.8 to -1.8)	-0.7	0.0	-0.7 (-0.8 to -0.6)	-0.7	0.0
	2050	-3.3	-3.3	-3.3 (-3.3 to -3.3)	-0.1	0.1	-0.1 (-0.2 to -0.1)	-0.1	0.1
Eindhoven	2030	-0.2 (-0.2 to -0.2)	-0.2 (-0.3 to -0.2)	-0.1 (-0.1 to -0.1)	-0.1	0.4	-0.1 (-0.3 to 0)	-0.1	0.4
	2040	-0.9	-0.9	-0.2 (-0.2 to -0.2)	-0.5	0.4	-0.5 (-0.6 to -0.3)	-0.5	0.4
	2050	-4.5	-4.5	-3.8 (-3.8 to 1)	-0.6	0.1	-0.6 (-0.7 to -0.4)	-0.6	0.1
Rotterdam	2030	0.5	0.5	0.5 (0.5 to 0.5)	0.0	0.1	0 (-0.1 to 0)	0.0	0.1
	2040	-0.4	-0.4	-0.3 (-0.3 to -0.3)	-0.1	0.2	-0.1 (-0.1 to -0.1)	-0.1	0.2
	2050	-1.2	-1.2	-1.2 (-1.2 to -1.2)	0.0	0.1	0 (0 to 0)	0.0	0.1
Maastricht	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2050	0 (0 to 0)	0 (0 to 0)	0.1 (0.1 to 0.1)	0.0	0.0	0 (0 to 0)	0.0	0.0
Groningen	2030	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2040	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	0 (0 to 0)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2050	-0.3 (-0.3 to -0.3)	-0.3 (-0.3 to -0.3)	-0.2 (-0.2 to -0.2)	0.0	0.0	0 (0 to 0)	0.0	0.0

Figure 79 - Development of the number of OD and transfer passengers at Dutch airports

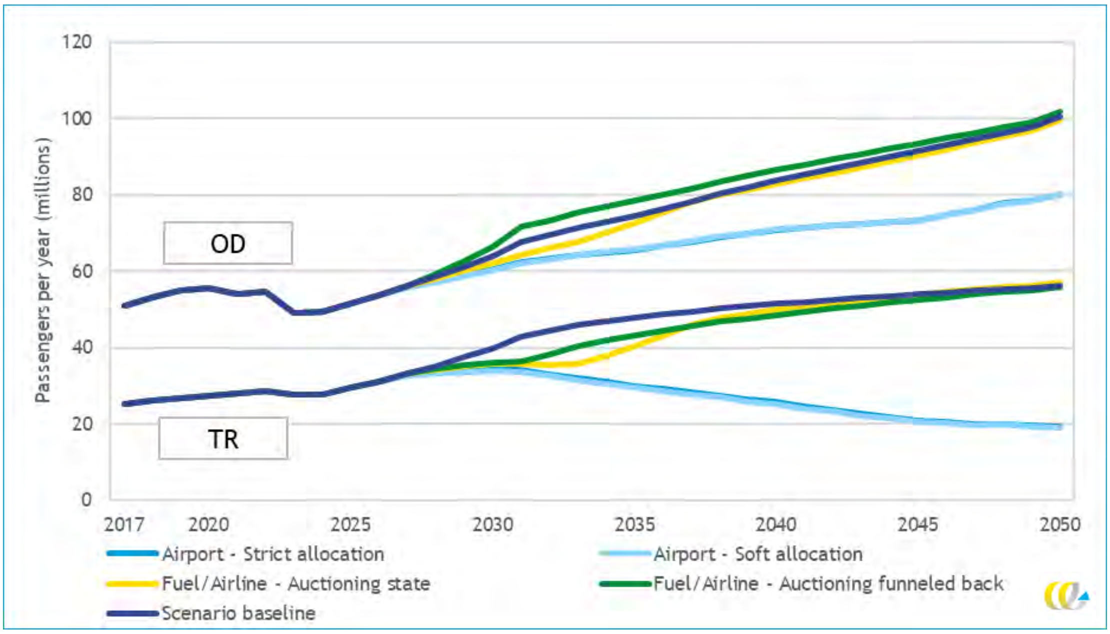


Figure 80 - Development of the number of EEA OD passengers at Dutch airports

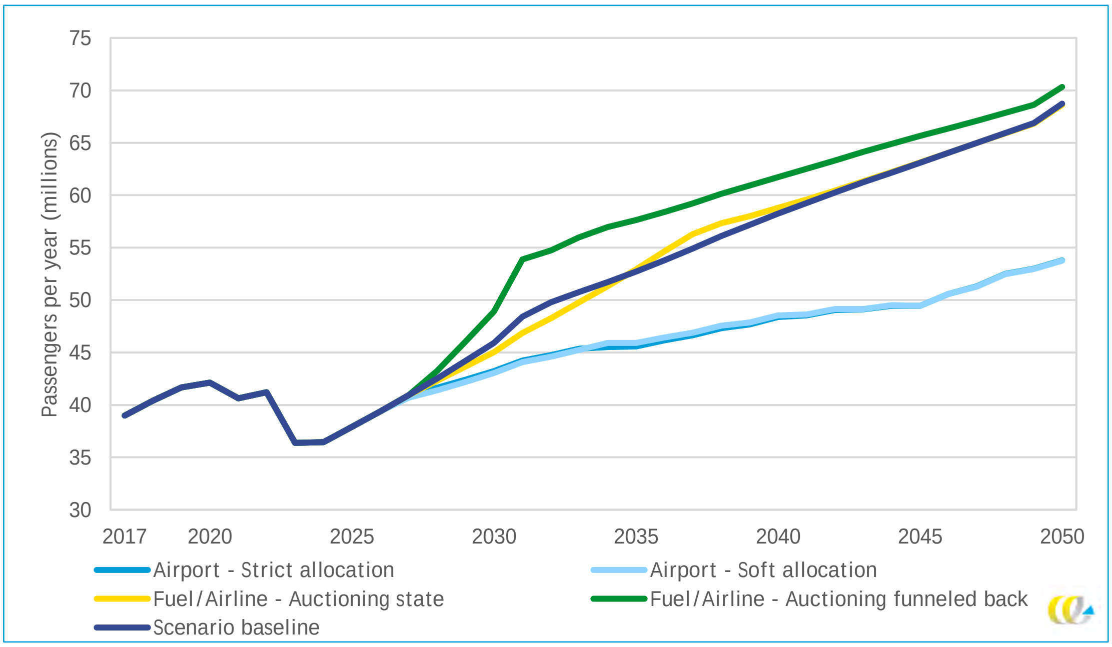


Figure 81 - Development of the number of intercontinental OD passengers at Dutch airports

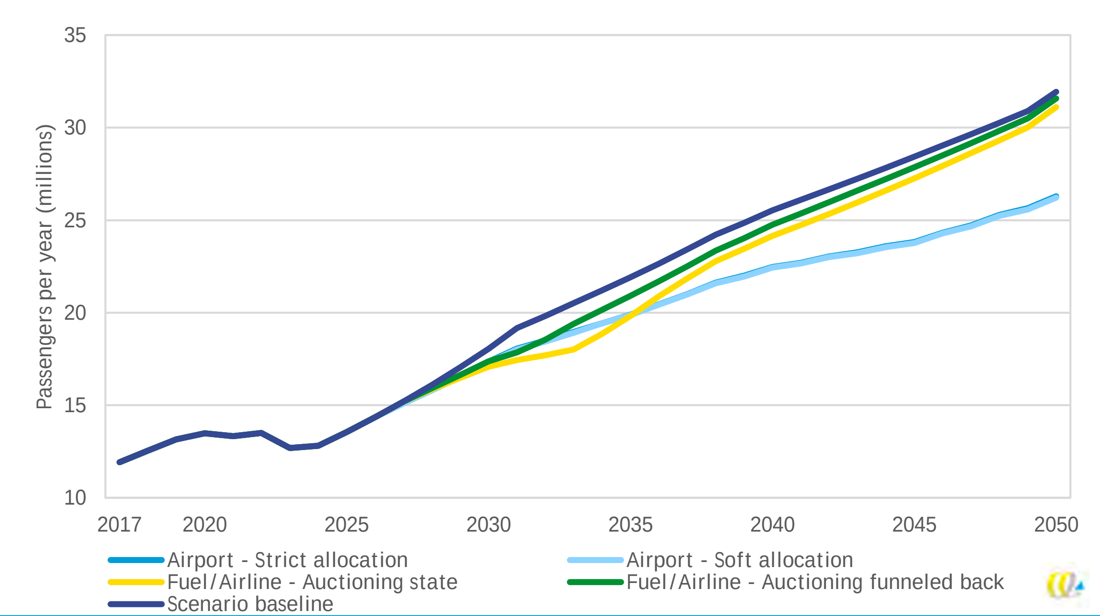


Figure 82 - Development of the number of business and other passengers at Dutch airports

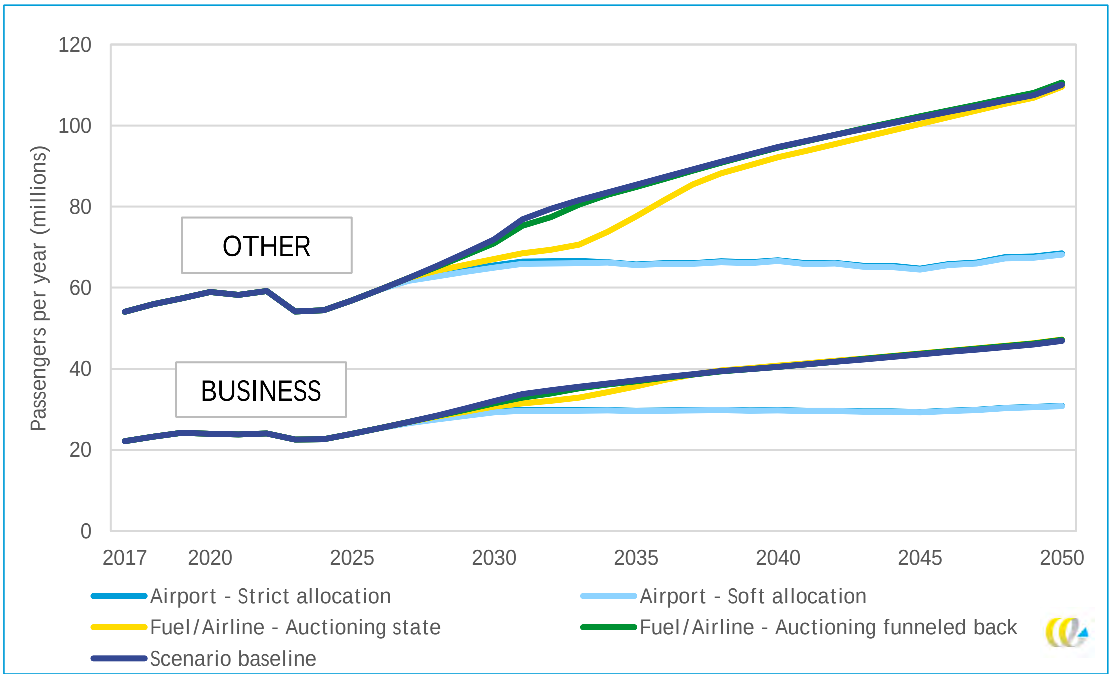


Table 119 - Impacts on passenger demand with origin in NL or the rest of the Catchment area - evasion (millions per year)

CO_2 ceiling variant	Year	Netherlands	Non-Dutch Catchment area[89]	Total
Airport - Strict allocation (3-year cycle)	2030	-2.6 (-2.9 to -2.6)	2.0	-0.7 (-0.9 to -0.7)
	2040	-0.8 (-0.8 to -0.8)	0.5	-0.4 (-0.4 to -0.4)
	2050	0.8 (0.8 to 4.4)	-0.7	0.1 (0.1 to 3.7)
Airport - Strict allocation (1-year cycle)	2030	-2.6 (-3.4 to -2.6)	2.0	-0.7 (-1.4 to -0.7)
	2040	-0.8 (-0.8 to -0.8)	0.5	-0.4 (-0.4 to -0.4)
	2050	0.8 (0.8 to 4.4)	-0.7	0.1 (0.1 to 3.7)
Airport - Soft allocation	2030	-2.9 (-3.2 to -2.9)	2.2	-0.7 (-1 to -0.7)
	2040	-1 (-1 to -1)	0.6	-0.4 (-0.4 to -0.4)
	2050	0.9 (0.9 to 4.5)	-0.8	0.1 (0.1 to 3.8)
Fuel - Auctioning state	2030	-1.4	0.3	-1.1
	2040	-0.7	0.0	-0.7
	2050	-0.2	0.3	0.1
Fuel - Auctioning funnelled back	2030	1.8	0.1	1.9
	2040	1.6	0.0	1.6
	2050	0.1	-0.1	0.1
Fuel - No stability	2030	-1.4 (-1.6 to -1.2)	0.3	-1.1 (-1.3 to -0.9)
	2040	-0.7 (-0.9 to -0.6)	0.0	-0.7 (-0.9 to -0.6)
	2050	-0.2 (-0.3 to 0)	0.3	0.1 (-0.1 to 0.2)
Airline - Auctioning State	2030	-1.4	0.3	-1.1
	2040	-0.7	0.0	-0.7
	2050	-0.2	0.3	0.1
Airline - Funnelled back	2030	1.8	0.1	1.9
	2040	1.6	0.0	1.6
	2050	0.1	-0.1	0.1

Impacts on cargo demand

Table 120 - Development of the cargo volume at Dutch airports without **CO_2** ceiling

Airport	Year	Kilo tonnes per year
Total	2017	1,839
	2030	2,786
	2040	2,841
	2050	2,914
Amsterdam	2017	1,787
	2030	2,708
	2040	2,748
	2050	2,801
Maastricht	2017	52
	2030	78
	2040	94
	2050	113

[89] The Catchment area includes besides the Dutch airports also the airports of Brussels, Charleroi, Keulen-Bonn, Düsseldorf, Frankfurt, Weeze, Luxemburg and Charles de Gaulle.

Figure 83 - Total volume of cargo at Dutch airports

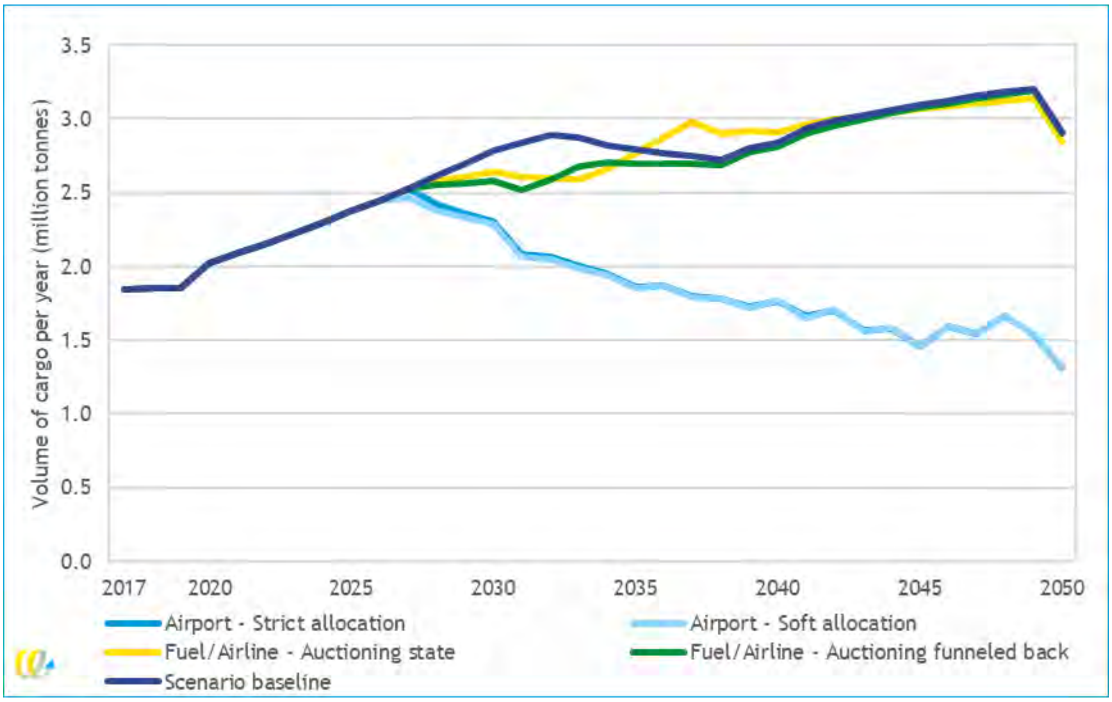
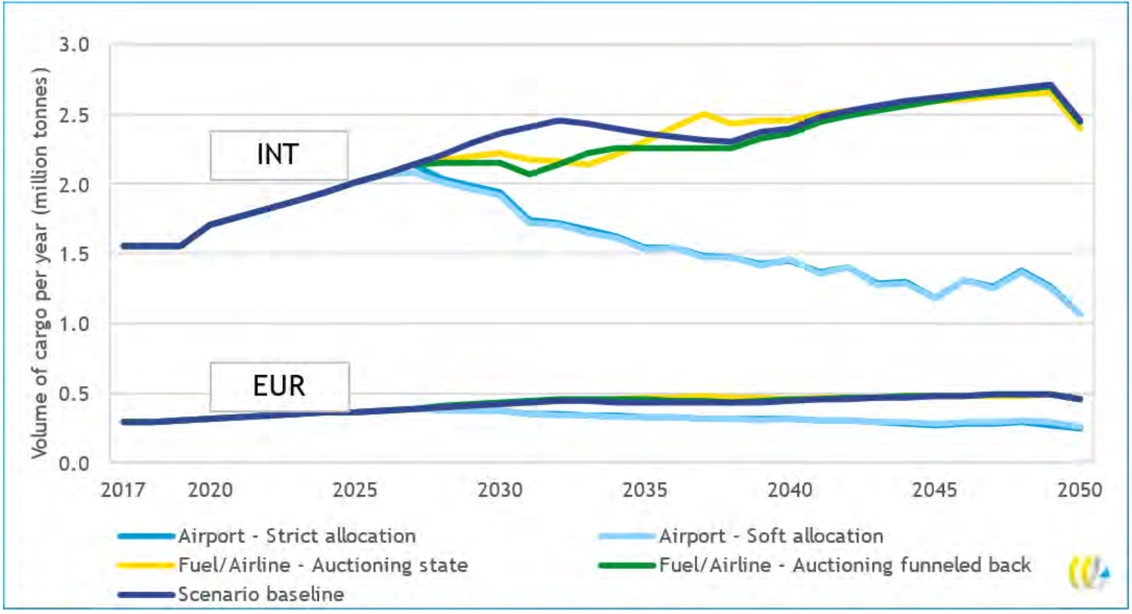


Table 121 - Impacts on the cargo volume at Dutch airports (kilo tonnes per year)

Airport	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
Total	2030	-476 (-486 to -476)	-476 (-505 to -476)	-499 (-509 to -499)	-142	-205	-142 (-150 to -135)	-142	-205
	2040	-1,074 (-1,074 to -1,074)	-1,074 (-1,074 to -1,074)	-1,072 (-1,072 to -1,072)	68	-31	68 (61 to 74)	68	-31
	2050	-1,602 (-1,602 to -1,602)	-1,602 (-1,602 to -1,602)	-1,598 (-1,598 to -1,545)	-62	-15	-62 (-66 to -58)	-62	-15
Amsterdam	2030	-476 (-485 to -476)	-476 (-504 to -476)	-499 (-509 to -499)	-139	-203	-139 (-139 to -139)	-139	-203
	2040	-1,074 (-1,074 to -1,074)	-1,074 (-1,074 to -1,074)	-1,072 (-1,072 to -1,072)	71	-30	71 (71 to 71)	71	-30
	2050	-1,578 (-1,578 to -1,578)	-1,578 (-1,578 to -1,578)	-1,598 (-1,598 to -1,550)	-61	-15	-61 (-61 to -61)	-61	-15
Maastricht	2030	0 (0 to 0)	0 (-1 to 0)	0 (0 to 0)	-3	-2	-3 (-5 to -1)	-3	-2
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-3	-1	-3 (-4 to -1)	-3	-1
	2050	-23 (-23 to -23)	-23 (-23 to -23)	0 (0 to 5)	-1	0	-1 (-2 to 0)	-1	0

Figure 84 - Development of EU and intercontinental cargo at Dutch airports



Impacts on fuel consumption

Table 122 - Fuel consumption in baseline scenario (million tonnes per year)

Year	Total	Kerosene	HEFA	Gas + FT	ATJ	RFNBO
2017	3.81	3.81	0.00	0.00	0.00	0.00
2030	4.23	3.85	0.17	0.00	0.19	0.03
2040	4.68	3.93	0.11	0.23	0.22	0.19
2050	4.61	3.16	0.12	0.39	0.30	0.65

Figure 85 - Development of the demand in kerosene and SAF at Dutch airports

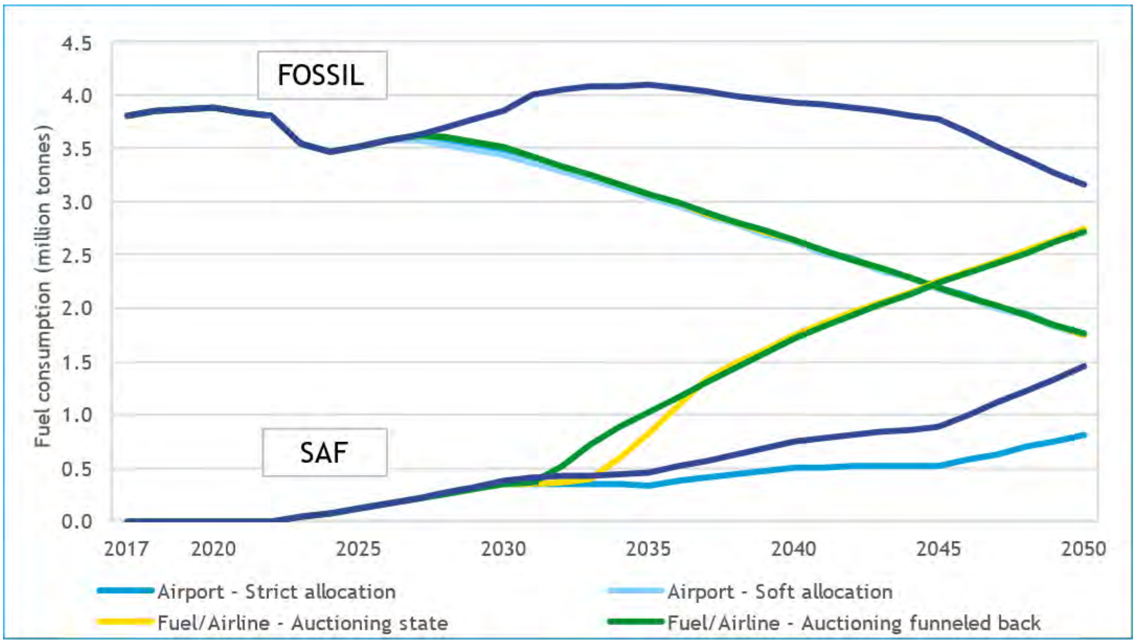


Table 123 - Absolute fuel consumption in suboptions (million tonnes per year)

Fuel type	Year	Airport - Strict allocation (3y cycle)	Airport - Strict allocation (1y cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability mechanism	Airline - Auctioning State	Airline - Funnelled back
Total	2030	3.8 (3.8 to 3.8)	3.8 (3.8 to 3.8)	3.8 (3.8 to 3.8)	3.9	3.9	3.9 (3.8 to 3.8)	3.9	3.9
	2040	3.1 (3.1 to 3.1)	3.1 (3.1 to 3.1)	3.1 (3.1 to 3.1)	4.4	4.3	4.4 (4.2 to 4.2)	4.4	4.3
	2050	2.6 (2.6 to 2.7)	2.6 (2.6 to 2.7)	2.6 (2.6 to 2.7)	4.5	4.5	4.5 (3.9 to 3.9)	4.5	4.5
Kerosene	2030	3.5 (3.4 to 3.5)	3.5 (3.4 to 3.5)	3.4 (3.4 to 3.4)	3.5	3.5	3.5 (3.5 to 3.5)	3.5	3.5
	2040	2.6 (2.6 to 2.6)	2.6 (2.6 to 2.6)	2.6 (2.6 to 2.6)	2.6	2.6	2.6 (2.6 to 2.6)	2.6	2.6
	2050	1.8 (1.8 to 1.8)	1.8 (1.8 to 1.8)	1.8 (1.8 to 1.8)	1.8	1.8	1.8 (1.8 to 1.8)	1.8	1.8
Total non-synthetic SAF	2030	0.3 (0.3 to 0.3)	0.3 (0.3 to 0.3)	0.3 (0.3 to 0.3)	0.3	0.3	0.3 (0.3 to 0.3)	0.3	0.3
	2040	0.4 (0.4 to 0.4)	0.4 (0.4 to 0.4)	0.4 (0.4 to 0.4)	1.6	1.5	1.6 (1.6 to 1.6)	1.6	1.5
	2050	0.4 (0.4 to 0.5)	0.4 (0.4 to 0.5)	0.4 (0.4 to 0.5)	2.1	2.1	2.1 (2.1 to 2.1)	2.1	2.1
HEFA	2030	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.2	0.2	0.2 (0.1 to 0.2)	0.2	0.2
	2040	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.3	0.3	0.3 (0.3 to 0.3)	0.3	0.3
	2050	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.3	0.3	0.3 (0.3 to 0.3)	0.3	0.3
Gas. + FT	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2040	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.6	0.6	0.6 (0.6 to 0.6)	0.6	0.6
	2050	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	1.0	1.0	1 (1 to 1)	1.0	1.0
ATJ	2030	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2	0.2	0.2 (0.2 to 0.2)	0.2	0.2
	2040	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.1 (0.1 to 0.1)	0.6	0.6	0.6 (0.6 to 0.6)	0.6	0.6
	2050	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.8	0.8	0.8 (0.8 to 0.8)	0.8	0.8
RFNBO (Synthetic SAF)	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0.0	0.0	0 (0 to 0)	0.0	0.0
	2040	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.2	0.2	0.2 (0.2 to 0.2)	0.2	0.2
	2050	0.4 (0.4 to 0.4)	0.4 (0.4 to 0.4)	0.4 (0.4 to 0.4)	0.6	0.6	0.6 (0.6 to 0.6)	0.6	0.6

International relations

The outcome of impacts are similar in Scenario 6 as in the central scenario. See Section 3.8 in the main report.

H.2 Economic impacts

Compliance costs

Table 124 - Overview of total compliance cost in extreme scenario (Fit for 55 reduced. increased airport cap. no Dutch SAF blending)

Year	Baseline	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel supplier - Auctioning state	Fuel supplier - Auctioning funnelled back	Fuel supplier - No stability	Airline - Auctioning State	Airline - Funnelled back
2030	€ 5,224	€ -518 (-516 to -518)	€ -518 (-518 to -517)	€ -561 (-559 to -561)	€ 1,353	€ -202	€ 1,353 (1,343 to 1,364)	€ 1,353	€ -202
2040	€ 7,617	€ -2120 (-2120 to -2120)	€ -2120 (-2120 to -2115)	€ -2142 (-2,142 to -2,142)	€ 802	€ -214	€ 802 (794 to 809)	€ 802	€ -214
2050	€ 9,682	€ -3211 (-3211 to -3339)	€ -3211 (-3339 to -3206)	€ -3,221 (-3,221 to -3,331)	€ 219	€ 61	€ 219 (219 to 219)	€ 219	€ 61

Administrative costs

Same as in the central scenario. See main report.

Auction revenue and revenue use

Table 125 - CO_2 ceiling auctioning revenues. in million EUR per year

Year	Baseline	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability mechanism	Airline - Auctioning state	Airline - Funnelled back
2030	€ -	€ -	€ -	€ -	€ -	€ -
2040	€ -	€ 1,680	€ 1,660	€ 1,680 (1,710 to 1,830)	€ 1,680	€ 1,660
2050	€ -	€ 990	€ 980	€ 990 (1,020 to 1,020)	€ 990	€ 980

Impacts on ticket prices and freight rates

Figure 86 - Ticket prices in the baseline scenario for different destinations

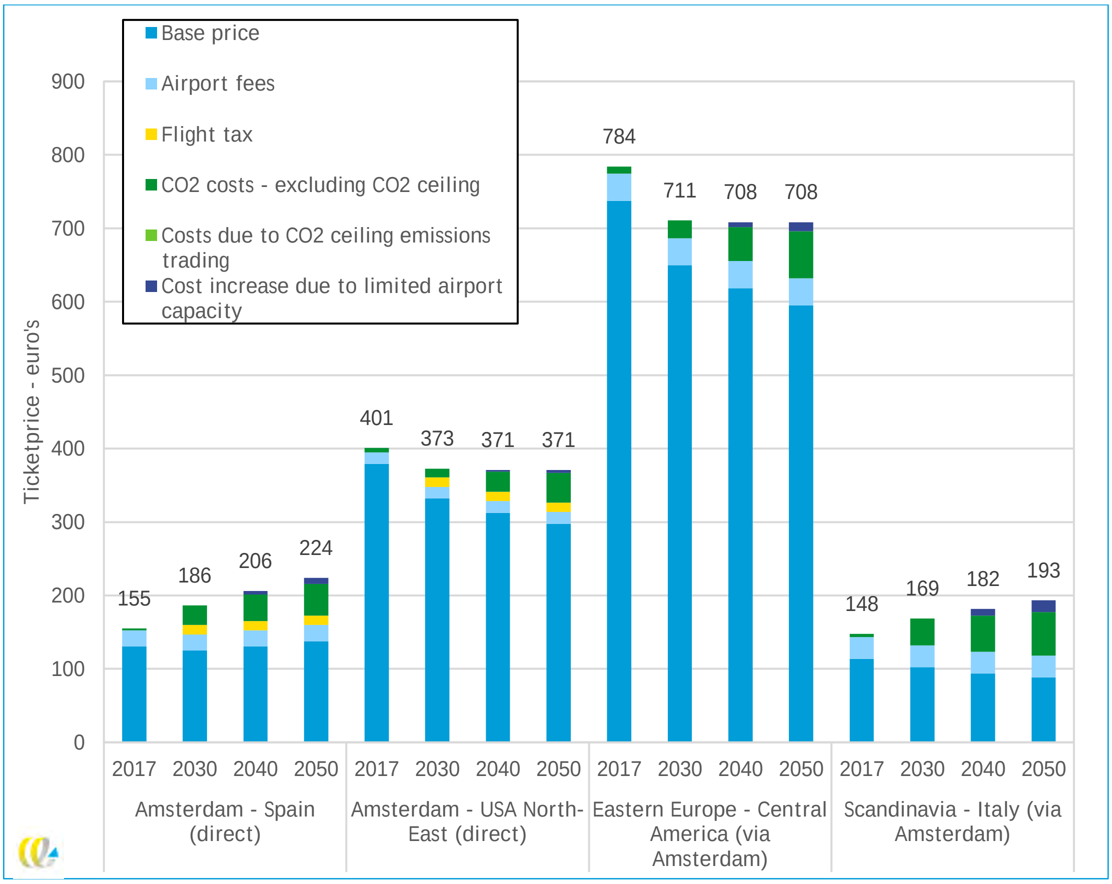


Figure 87 - Ticket prices for direct flights from Amsterdam to Spain in the different suboptions in 2030

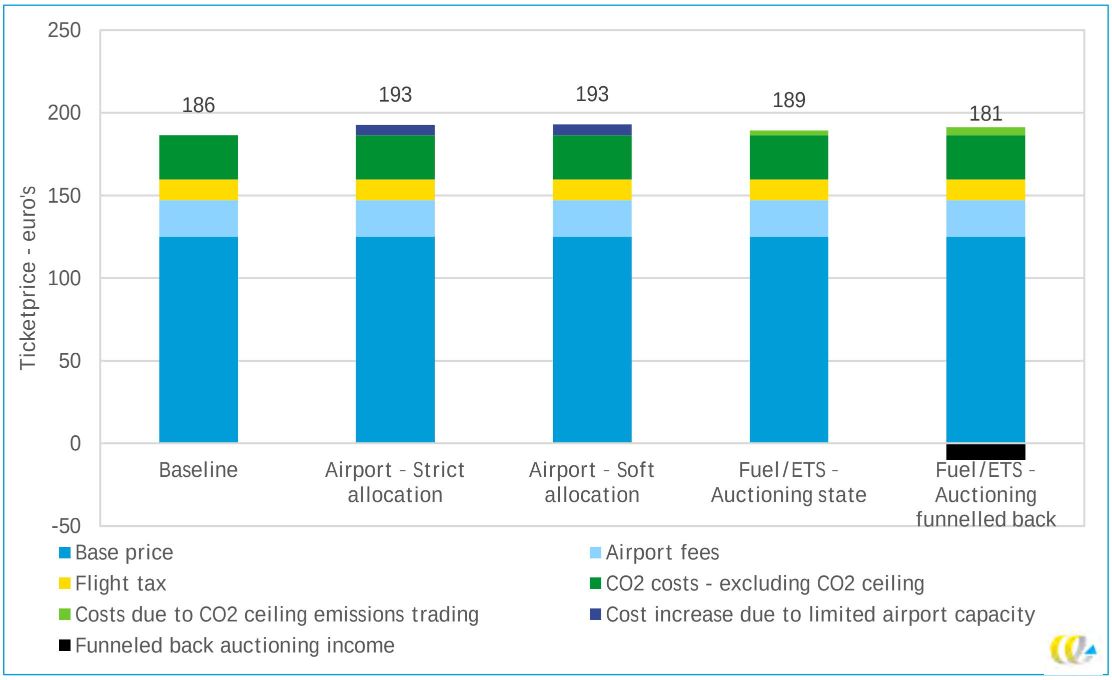


Figure 88 - Ticket prices for direct flights from Amsterdam to the USA North-East in the different suboptions in 2030

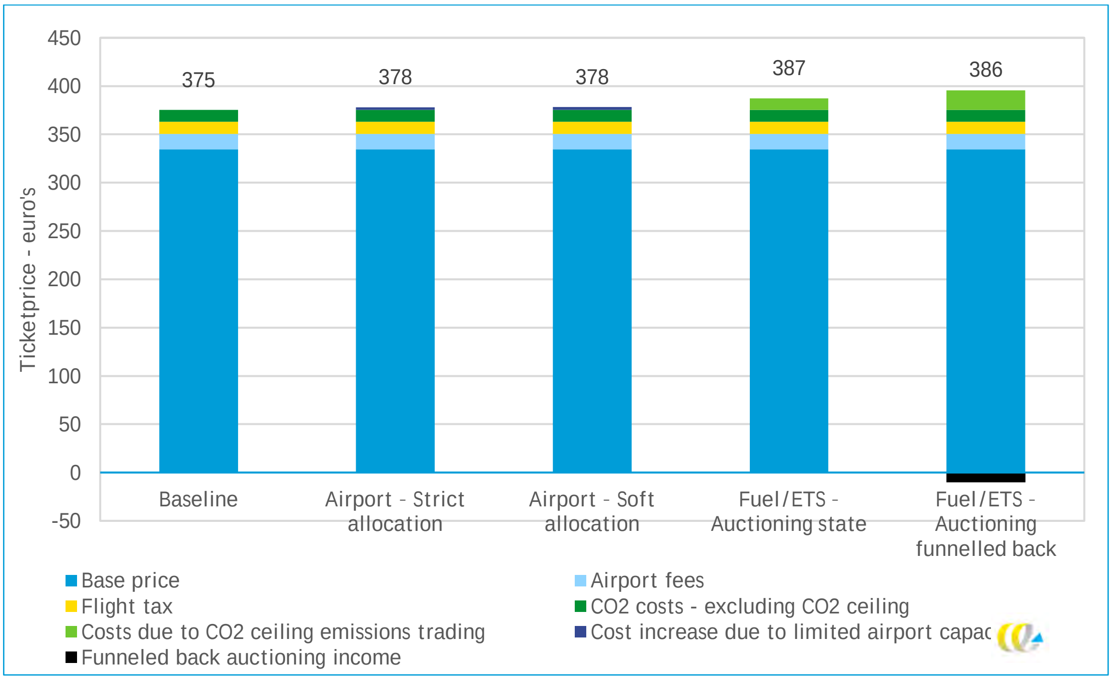


Figure 89 - Ticket prices for transfer flights from Central America to Eastern Europe via Amsterdam in the different suboptions in 2030

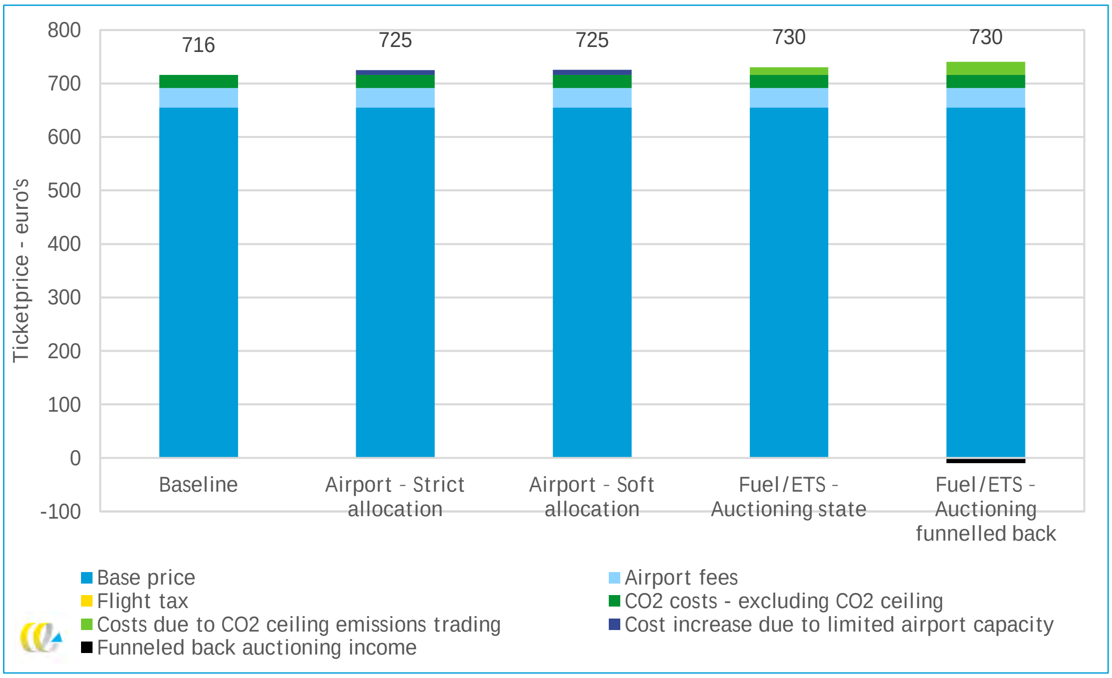
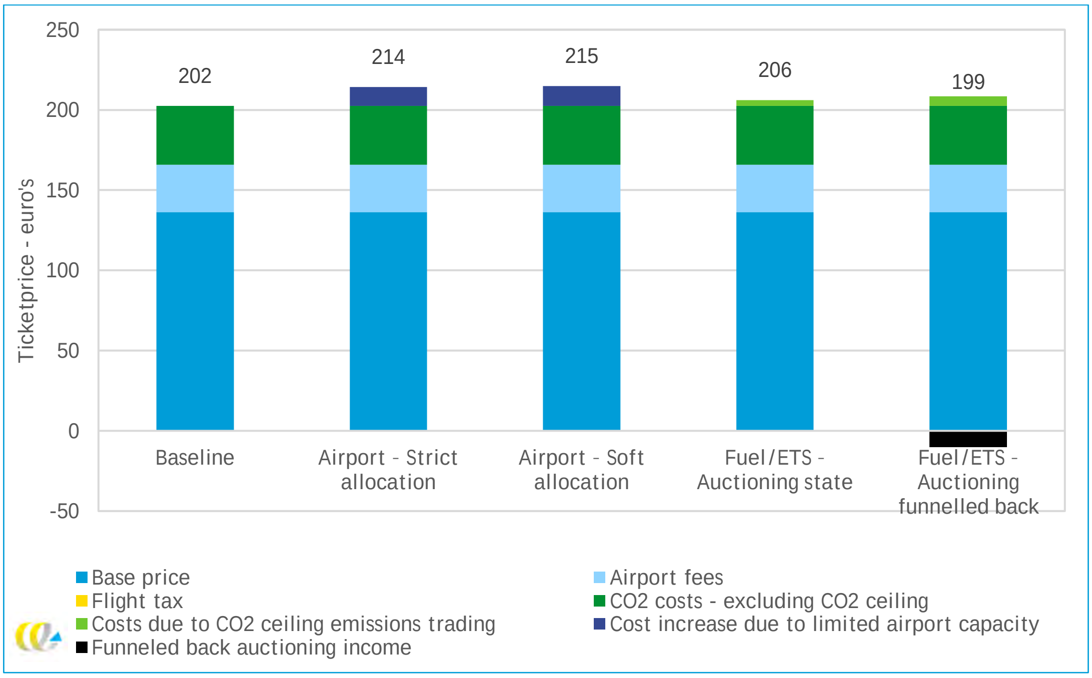


Figure 90 - Ticket prices for transfer flights from Scandinavia to Italy via Amsterdam in the different suboptions in 2030



Fiscal impacts

Table 126 - Total mutations in fiscal effects (compared to baseline) in million EUR per year

Year	Airport strict (3-year cycle)	Airport strict (1-year cycle)	Airport soft - (3-year cycle)	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Funnelled back
2030	€ -133 (-141 to -133)	€ -133 (-158 to -133)	€ -157 (-165 to -157)	€ 1,940	€ -51	€ 1,907 (1,897 to 1,917)	€ 1,940	€ -51
2040	€ -468 (-468 to -468)	€ -468 (-472 to -468)	€ -568 (-568 to -568)	€ 991	€ -209	€ 966 (959 to 972)	€ 991	€ -209
2050	€ -628 (-628 to -540)	€ -628 (-630 to -547)	€ -777 (-777 to -708)	€ -68	€ -204	€ -76 (-80 to -72)	€ -68	€ -204

Costs of enforcement

Same effects as in the reference scenario. See the main report.

Upstream and downstream effects

Table 127 - Total mutations in consumer expenditures (compared to baseline) in million EUR per year

Year	Airport strict (3-year cycle)	Airport strict (1-year cycle)	Airport soft	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning state	Airline - Grandfathering
2030	€ 67 (67 to 67)	€ 67 (67 to 67)	€ 76 (76 to 76)	€ 182	€ -476	€ 182 (181 to 182)	€ 182	€ -476
2040	€ 550 (550 to 550)	€ 550 (550 to 550)	€ 558 (558 to 558)	€ 137	€ -450	€ 137 (137 to 137)	€ 137	€ -450
2050	€ 807 (807 to 839)	€ 807 (807 to 839)	€ 829 (829 to 857)	€ 43	€ -190	€ 43 (43 to 43)	€ 43	€ -190

Due to the applied assumptions, it appears an increase of up to 800 million EUR in consumer expenditures may be expected. This is however in case all saved spending from flights are spent in the Netherlands, which is highly unlikely. This practicality should be taken in consideration when evaluating these outcomes.

H.3 Environmental impacts

Impacts on CO_2 emissions

Table 128 - Baseline TTW and WTT CO_2 emissions for flights departing from Dutch airports

Year	TTW CO_2 emissions	WTT CO_2 emissions
2017	12.0	2.5
2030	12.1	2.8
2040	12.4	3.5
2050	9.9	3.8

Figure 91 - Development of the TTW CO_2 emissions of flights departing from Dutch airports

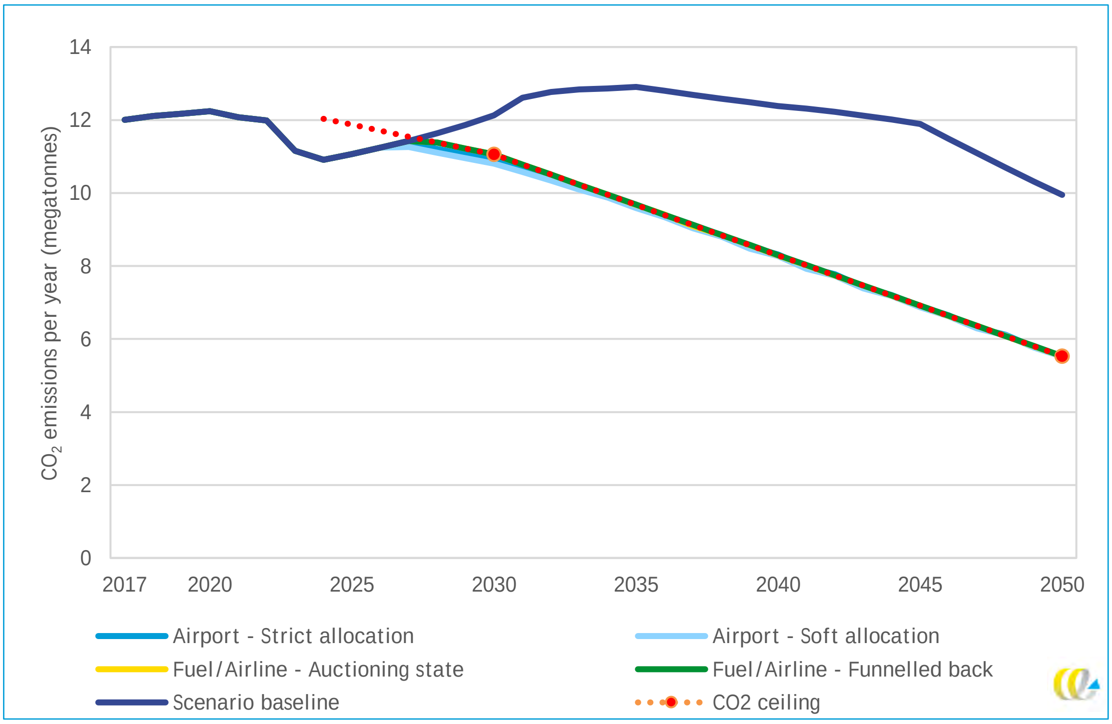


Table 129 - Change in aviation TTW and WTT CO_2 emissions for the different CO_2 ceiling options compared to baseline (million tonnes)

CO_2 ceiling variant	Year	Aviation TTW CO_2 emissions			Aviation WTT CO_2 emissions		
		Flights with origin at a Dutch airport	Flights from non-Dutch airports in the Catchment area	Net effect	Flights with origin at a Dutch airport	Flights from non-Dutch airports in the Catchment area	Net effect
Airport - Strict allocation (3-year cycle)	2030	-0.23 (-0.25 to -0.23)	0.15	-0.08 (-0.11 to -0.08)	-0.05 (-0.06 to -0.05)	0.03	-0.02 (-0.02 to -0.02)
	2040	-0.07 (-0.07 to -0.07)	0.02	-0.05 (-0.05 to -0.05)	-0.02 (-0.02 to -0.02)	0.00	-0.01 (-0.01 to -0.01)
	2050	0 (0 to 0.11)	-0.01	-0.01 (-0.01 to 0.1)	0 (0 to 0.03)	0.00	0 (0 to 0.03)
Airport - Strict allocation (1-year cycle)	2030	-0.23 (-0.3 to -0.23)	0.15	-0.08 (-0.15 to -0.08)	-0.05 (-0.07 to -0.05)	0.0	-0.02 (-0.03 to -0.02)
	2040	-0.07 (-0.07 to -0.07)	0.02	-0.05 (-0.05 to -0.05)	-0.02 (-0.02 to -0.02)	0.0	-0.01 (-0.01 to -0.01)
	2050	0 (0 to 0.11)	-0.01	-0.01 (-0.01 to 0.1)	0 (0 to 0.03)	0.0	0 (0 to 0.03)
Airport - Soft allocation	2030	-0.25 (-0.28 to -0.25)	0.15	-0.09 (-0.11 to -0.09)	-0.06 (-0.06 to -0.06)	0.0	-0.02 (-0.03 to -0.02)
	2040	-0.08 (-0.08 to -0.08)	0.02	-0.06 (-0.06 to -0.06)	-0.02 (-0.02 to -0.02)	0.0	-0.02 (-0.02 to -0.02)
	2050	0 (0 to 0.11)	-0.01	-0.01 (-0.01 to 0.1)	0 (0 to 0.03)	0.0	0 (0 to 0.03)
Fuel - Auctioning state	2030	-0.25	0.05	-0.20	-0.06	0.01	-0.05
	2040	-0.15	0.03	-0.13	0.31	-0.35	-0.03
	2050	0.01	0.00	0.01	0.59	-0.59	0.00
Fuel - Auctioning funnelled back	2030	-0.10	0.03	-0.06	-0.02	0.01	-0.01
	2040	-0.06	0.01	-0.05	0.34	-0.35	-0.01
	2050	0.01	0.00	0.01	0.58	-0.58	0.00
Fuel - No stability	2030	-0.25 (-0.27 to -0.24)	0.05	-0.2 (-0.22 to -0.19)	-0.06 (-0.06 to -0.05)	0.01	-0.05 (-0.05 to -0.04)
	2040	-0.15 (-0.16 to -0.15)	0.03	-0.13 (-0.14 to -0.12)	0.31 (0.31 to 0.32)	-0.35	-0.03 (-0.03 to -0.03)
	2050	0.01 (0 to 0.01)	0.00	0.01 (0.01 to 0.02)	0.59 (0.59 to 0.6)	-0.59	0 (0 to 0.01)
Airline - Auctioning State	2030	-0.25	0.05	-0.20	-0.06	0.01	-0.05
	2040	-0.15	0.03	-0.13	0.31	-0.35	-0.03
	2050	0.01	0.00	0.01	0.59	-0.59	0.00
Airline - Funnelled back	2030	-0.10	0.03	-0.06	-0.02	0.01	-0.01
	2040	-0.06	0.01	-0.05	0.34	-0.35	-0.01
	2050	0.01	0.00	0.01	0.58	-0.58	0.00

Impacts on land transport CO_2 emissions

Table 130 - Changes in WTW CO_2 emissions by land transport (million tonnes per year)

CO_2 ceiling variant	Year	Car	Train	Total
Airport - Strict allocation (3-year cycle)	2030	0.010	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Airport - Strict allocation (1-year cycle)	2030	0.010	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Airport - Soft allocation	2030	0.011	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Fuel - Auctioning state	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000
Fuel - Auctioning funnelled back	2030	0.015	0.000	0.015
	2040	0.005	0.000	0.005
	2050	0.000	0.000	0.000
Fuel - No stability	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000
Airline - Auctioning State	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000
Airline - Funnelled back	2030	0.015	0.000	0.015
	2040	0.005	0.000	0.005
	2050	0.000	0.000	0.000

Impacts on global CO_2 emissions

Table 131 - Change in total CO_2 emissions of aviation, land transport and other EU sectors combined; the different CO_2 ceiling options compared to baseline (million tonnes)

CO_2 ceiling variant	Year	Effects on global aviation CO_2 emissions		Effects on land transport CO_2 emissions	Effect on CO_2-emissions in other EU ETS sectors	Total combined effect on global CO_2 emissions
		The Netherlands OD aviation WTW emissions	Evasion of OD aviation WTW emissions	Land transport WTW emissions	Additional emissions due to the EU ETS waterbed effect	Total WTW emissions
Airport - Strict allocation (3-year cycle)	2030	-0.28 (-0.31 to -0.28)	0.18	0.01	0.02	-0.07 (-0.1 to -0.07)
	2040	-0.09 (-0.09 to -0.09)	0.02	0.00	0.01	-0.06 (-0.06 to -0.06)
	2050	0 (0 to 0.15)	-0.01	0.00	0	-0.01 (-0.01 to 0.13)
Airport - Strict allocation (1-year cycle)	2030	-0.28 (-0.37 to -0.28)	0.18	0.01	0.02	-0.07 (-0.16 to -0.07)
	2040	-0.09 (-0.09 to -0.09)	0.02	0.00	0.01	-0.06 (-0.06 to -0.06)
	2050	0 (0 to 0.15)	-0.01	0.00	0	-0.01 (-0.01 to 0.13)
Airport - Soft allocation (3 year cycle)	2030	-0.31 (-0.34 to -0.31)	0.20	0.01	0.02	-0.08 (-0.11 to -0.08)
	2040	-0.1 (-0.1 to -0.1)	0.02	0.00	0.01	-0.07 (-0.07 to -0.07)
	2050	0 (0 to 0.15)	-0.01	0.00	0	-0.01 (-0.01 to 0.13)

CO_2 ceiling variant	Year	Effects on global aviation CO_2 emissions		Effects on land transport CO_2 emissions	Effect on CO_2-emissions in other EU ETS sectors	Total combined effect on global CO_2 emissions
		The Netherlands OD aviation WTW emissions	Evasion of OD aviation WTW emissions	Land transport WTW emissions	Additional emissions due to the EU ETS waterbed effect	Total WTW emissions
Fuel - Auctioning state	2030	-0.31	0.06	0.01	0.02	-0.22
	2040	0.16	-0.32	0.01	-0.01	-0.16
	2050	0.60	-0.59	0.00	0	0.02
Fuel - Auctioning funnelled back	2030	-0.12	0.04	0.01	-0.05	-0.11
	2040	0.28	-0.34	0.01	-0.06	-0.11
	2050	0.59	-0.58	0.00	0	0.01
Fuel - No stability	2030	-0.31 (-0.33 to -0.29)	0.06	0.01	0.02	-0.22 (-0.24 to -0.2)
	2040	0.16 (0.15 to 0.17)	-0.32	0.01	-0.01	-0.16 (-0.17 to -0.15)
	2050	0.6 (0.6 to 0.61)	-0.59	0.00	0	0.02 (0.01 to 0.02)
Airline - Auctioning State	2030	-0.31	0.06	0.01	0.02	-0.22
	2040	0.16	-0.32	0.01	-0.01	-0.16
	2050	0.60	-0.59	0.00	0	0.02
Airline - Funnelled back	2030	-0.12	0.04	0.01	-0.05	-0.11
	2040	0.28	-0.34	0.01	-0.06	-0.11
	2050	0.59	-0.58	0.00	0	0.01

Non-CO_2 climate impacts of land transport evasion

Table 132 - Changes in WTW CO_2 emissions by land transport (million tonnes per year)

CO_2 ceiling variant	Year	Car	Train	Total
Airport - Strict allocation (3-year cycle)	2030	0.010	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Airport - Strict allocation (1-year cycle)	2030	0.010	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Airport - Soft allocation	2030	0.011	0.000	0.011
	2040	0.000	0.000	0.000
	2050	-0.001	0.000	-0.001
Fuel - Auctioning state	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000
Fuel - Auctioning funnelled back	2030	0.015	0.000	0.015
	2040	0.005	0.000	0.005
	2050	0.000	0.000	0.000
Fuel - No stability	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000
Airline - Auctioning State	2030	0.010	0.000	0.010
	2040	0.006	0.000	0.006
	2050	0.000	0.000	0.000

CO_2 ceiling variant	Year	Car	Train	Total
Airline - Funnelled back	2030	0.015	0.000	0.015
	2040	0.005	0.000	0.005
	2050	0.000	0.000	0.000

Impacts on air pollutant LTO emissions

Table 133 - Development of air pollutant LTO emissions at Dutch airports without CO_2 ceiling (tonnes)

Airport	Year	CO	NO_x	VOS	SO_2	PM_{10}
Total	2017	3,075	4,000	382	111	112
	2030	3,368	4,410	405	107	62
	2040	3,582	4,877	405	111	55
	2050	3,601	5,018	369	98	49
Amsterdam	2017	2,818	3.690	349	101	101
	2030	3,027	4,116	351	98	57
	2040	3,135	4,502	337	99	50
	2050	3,077	4,574	297	86	44
Lelystad	2017	-	-	-	-	-
	2030	64	42	12	2	1
	2040	100	66	17	3	1
	2050	128	87	20	3	1
Eindhoven	2017	126	148	17	5	6
	2030	133	88	24	4	1
	2040	164	108	28	4	2
	2050	202	137	31	4	2
Rotterdam	2017	53	54	6	2	2
	2030	51	33	7	1	1
	2040	77	48	11	2	1
	2050	83	53	10	2	1
Maastricht	2017	67	96	9	2	2
	2030	81	123	9	2	2
	2040	86	139	9	2	2
	2050	87	150	8	2	1
Groningen	2017	11	12	1	0	1
	2030	12	8	2	0	0
	2040	21	13	3	1	0
	2050	24	15	3	0	0

Table 134 - Change for all Dutch airports of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-346 (-359 to -346)	-346 (-384 to -346)	-371	-178	-85	-178 (-187 to -169)	-178	-85
	2040	-1,050 (-1,050 to -1,050)	-1,050 (-1,050 to -1,050)	-1,056	-165	-147	-165 (-173 to -158)	-165	-147
	2050	-1,375 (-1,375 to -1,375)	-1,375 (-1,375 to -1,375)	-1,365	-168	-154	-168 (-173 to -163)	-168	-154
NO_x	2030	-519 (-535 to -519)	-519 (-567 to -519)	-556	-296	-244	-296 (-307 to -284)	-296	-244
	2040	-1,561 (-1,561 to -1,561)	-1,561 (-1,561 to -1,561)	-1.579	-137	-168	-137 (-147 to -127)	-137	-168
	2050	-2,101 (-2,101 to -2,101)	-2,101 (-2,101 to -2,101)	-2.087	-53	-63	-53 (-60 to -46)	-53	-63
VOS	2030	-37 (-39 to -37)	-37 (-42 to -37)	-40	-18	-4	-18 (-19 to -17)	-18	-4
	2040	-106 (-106 to -106)	-106 (-106 to -106)	-106	-62	-57	-62 (-63 to -62)	-62	-57
	2050	-128 (-128 to -128)	-128 (-128 to -128)	-127	-77	-74	-77 (-77 to -76)	-77	-74
SO_2	2030	-11 (-12 to -11)	-11 (-13 to -11)	-12	-6	-4	-6 (-7 to -6)	-6	-4
	2040	-34 (-34 to -34)	-34 (-34 to -34)	-34	-23	-22	-23 (-23 to -22)	-23	-22

	2050	-39 (-39 to -39)	-39 (-39 to -39)	-39	-27	-27	-27 (-27 to -27)	-27	-27
PM_{10}	2030	-6 (-6 to -6)	-6 (-7 to -6)	-6	-3	-2	-3 (-3 to -3)	-3	-2
	2040	-17 (-17 to -17)	-17 (-17 to -17)	-17	-9	-9	-9 (-9 to -9)	-9	-9
	2050	-20 (-20 to -20)	-20 (-20 to -20)	-20	-10	-10	-10 (-10 to -10)	-10	-10

Table 135 - Change for Schiphol airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-354 (-365 to -354)	-354 (-387 to -354)	-380	-170	-99	-170 (-178 to -162)	-170	-99
	2040	-990 (-990 to -990)	-990 (-990 to -990)	-1,014	-123	-142	-123 (-130 to -117)	-123	-142
	2050	-1199 (-1199 to -1199)	-1199 (-1199 to -1199)	-1,221	-133	-136	-133 (-137 to -128)	-133	-136
NO_x	2030	-523 (-538 to -523)	-523 (-568 to -523)	-561	-288	-252	-288 (-299 to -277)	-288	-252
	2040	-1522 (-1522 to -1522)	-1522 (-1522 to -1522)	-1.552	-116	-173	-116 (-125 to -107)	-116	-173
	2050	-1964 (-1964 to -1964)	-1964 (-1964 to -1964)	-1,990	-42	-64	-42 (-49 to -36)	-42	-64
VOS	2030	-38 (-39 to -38)	-38 (-42 to -38)	-41	-17	-6	-17 (-18 to -16)	-17	-6
	2040	-96 (-96 to -96)	-96 (-96 to -96)	-99	-49	-48	-49 (-49 to -48)	-49	-48
	2050	-103 (-103 to -103)	-103 (-103 to -103)	-105	-60	-59	-60 (-61 to -60)	-60	-59

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
SO_2	2030	-12 (-12 to -12)	-12 (-13 to -12)	-12	-6	-4	-6 (-6 to -6)	-6	-4
	2040	-32 (-32 to -32)	-32 (-32 to -32)	-33	-20	-20	-20 (-20 to -20)	-20	-20
	2050	-35 (-35 to -35)	-35 (-35 to -35)	-35	-23	-23	-23 (-24 to -23)	-23	-23
PM_{10}	2030	-6 (-6 to -6)	-6 (-7 to -6)	-6	-3	-2	-3 (-3 to -3)	-3	-2
	2040	-16 (-16 to -16)	-16 (-16 to -16)	-16	-8	-8	-8 (-8 to -8)	-8	-8
	2050	-18 (-18 to -18)	-18 (-18 to -18)	-19	-9	-9	-9 (-9 to -9)	-9	-9

Table 136 - Change for Lelystad airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-7.1 (-7.4 to -7.1)	-7.1 (-7.8 to -7.1)	-7.7	-1.7	2.9	-1.7 (-1.9 to -1.6)	-1.7	2.9
	2040	-31.7 (-31.7 to -31.7)	-31.7 (-31.7 to -31.7)	-32.3	-15.9	-3.4	-15.9 (-16 to -15.7)	-15.9	-3.4
	2050	-52.6 (-52.6 to -52.6)	-52.6 (-52.6 to -52.6)	-53.2	-7.9	-4.1	-7.9 (-8.1 to -7.7)	-7.9	-4.1
NO_x	2030	-4.7 (-4.8 to -4.7)	-4.7 (-5.1 to -4.7)	-5.0	-1.1	1.9	-1.1 (-1.2 to -1)	-1.1	1.9
	2040	-20.9 (-20.9 to -20.9)	-20.9 (-20.9 to -20.9)	-21.3	-8.7	-0.3	-8.7 (-8.9 to -8.6)	-8.7	-0.3
	2050	-35.6 (-35.6 to -35.6)	-35.6 (-35.6 to -35.6)	-36.1	-2.1	0.6	-2.1 (-2.2 to -1.9)	-2.1	0.6
VOS	2030	-5.5 (-5.5 to -5.5)	-5.5 (-5.5 to -5.5)	-1.4	-0.3	0.5	-4.4 (-4.5 to -4.4)	-0.3	0.5

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
	2040	-5.5 (-5.5 to -5.5)	-5.5 (-5.5 to -5.5)	-5.6	-4.4	-2.5	-4.4 (-4.5 to -4.4)	-4.4	-2.5
	2050	-8.1 (-8.1 to -8.1)	-8.1 (-8.1 to -8.1)	-8.2	-4.4	-3.9	-4.4 (-4.4 to -4.4)	-4.4	-3.9
SO_2	2030	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.2	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	-0.8 (-0.8 to -0.8)	-0.8 (-0.8 to -0.8)	-0.8	-0.8	-0.5	-0.8 (-0.8 to -0.7)	-0.8	-0.5
	2050	-1.2 (-1.2 to -1.2)	-1.2 (-1.2 to -1.2)	-1.2	-0.8	-0.8	-0.8 (-0.8 to -0.8)	-0.8	-0.8
PM_{10}	2030	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.1	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2040	-0.3 (-0.3 to -0.3)	-0.3 (-0.3 to -0.3)	-0.3	-0.3	-0.1	-0.3 (-0.3 to -0.2)	-0.3	-0.1
	2050	-0.5 (-0.5 to -0.5)	-0.5 (-0.5 to -0.5)	-0.5	-0.3	-0.2	-0.3 (-0.3 to -0.2)	-0.3	-0.2

Table 137 - Change for Eindhoven airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	-3.6 (-4.1 to -3.6)	-3.6 (-5.2 to -3.6)	-2.1	-3.1	7.2	-3.1 (-3.4 to -2.7)	-3.1	7.2
	2040	-15 (-15 to -15)	-15 (-15 to -15)	-2.6	-14.6	-0.2	-14.6 (-14.9 to -14.2)	-14.6	-0.2
	2050	-71.2 (-71.2 to -71.2)	-71.2 (-71.2 to -71.2)	-60.8	-17.9	-8.2	-17.9 (-18.2 to -17.6)	-17.9	-8.2
NO_x	2030	-2.3 (-2.7 to -2.3)	-2.3 (-3.4 to -2.3)	-1.3	-2.0	4.7	-2 (-2.2 to -1.8)	-2.0	4.7
	2040	-9.9 (-9.9 to -9.9)	-9.9 (-9.9 to -9.9)	-1.7	-6.5	3.2	-6.5 (-6.7 to -6.3)	-6.5	3.2
	2050	-48.3 (-48.3 to -48.3)	-48.3 (-48.3 to -48.3)	-41.3	-7.1	-0.3	-7.1 (-7.3 to -6.9)	-7.1	-0.3

VOS	2030	-2.6 (-2.6 to -2.6)	-2.6 (-2.6 to -2.6)	-0.4	-0.5	1.3	-5.5 (-5.6 to -5.5)	-0.5	1.3
	2040	-2.6 (-2.6 to -2.6)	-2.6 (-2.6 to -2.6)	-0.5	-5.5	-3.3	-5.5 (-5.6 to -5.5)	-5.5	-3.3
	2050	-11 (-11 to -11)	-11 (-11 to -11)	-9.4	-7.6	-6.4	-7.6 (-7.7 to -7.6)	-7.6	-6.4
SO_2	2030	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.1	-0.1	0.2	-0.1 (-0.1 to -0.1)	-0.1	0.2
	2040	-0.4 (-0.4 to -0.4)	-0.4 (-0.4 to -0.4)	-0.1	-1.0	-0.7	-1 (-1 to -1)	-1.0	-0.7
	2050	-1.6 (-1.6 to -1.6)	-1.6 (-1.6 to -1.6)	-1.3	-1.4	-1.2	-1.4 (-1.4 to -1.4)	-1.4	-1.2
PM_{10}	2030	0 (0 to 0)	0 (0 to 0)	-0.0	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.0	-0.3	-0.2	-0.3 (-0.3 to -0.3)	-0.3	-0.2
	2050	-0.6 (-0.6 to -0.6)	-0.6 (-0.6 to -0.6)	-0.5	-0.4	-0.4	-0.4 (-0.4 to -0.4)	-0.4	-0.4

Table 138 - Change for Rotterdam airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	13.8 (13.6 to 13.8)	13.8 (13 to 13.8)	14.1	-1.1	3.2	-1.1 (-1.2 to -0.9)	-1.1	3.2
	2040	-8.7 (-8.7 to -8.7)	-8.7 (-8.7 to -8.7)	-6.6	-5.3	0.9	-5.3 (-5.5 to -5.1)	-5.3	0.9
	2050	-24.9 (-24.9 to -24.9)	-24.9 (-24.9 to -24.9)	-24.0	-4.1	-2.2	-4.1 (-4.2 to -4)	-4.1	-2.2
NO_x	2030	8.6 (8.4 to 8.6)	8.6 (8 to 8.6)	8.7	-0.7	2.0	-0.7 (-0.8 to -0.6)	-0.7	2.0

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
	2040	-5.4 (-5.4 to -5.4)	-5.4 (-5.4 to -5.4)	-4.1	-1.9	2.1	-1.9 (-2 to -1.8)	-1.9	2.1
	2050	-16 (-16 to -16)	-16 (-16 to -16)	-15.5	-0.6	0.6	-0.6 (-0.7 to -0.5)	-0.6	0.6
VOS	2030	-1.2 (-1.2 to -1.2)	-1.2 (-1.2 to -1.2)	2.0	-0.2	0.5	-1.9 (-1.9 to -1.9)	-0.2	0.5
	2040	-1.2 (-1.2 to -1.2)	-1.2 (-1.2 to -1.2)	-0.9	-1.9	-1.1	-1.9 (-1.9 to -1.9)	-1.9	-1.1
	2050	-3.1 (-3.1 to -3.1)	-3.1 (-3.1 to -3.1)	-3.0	-2.2	-2.0	-2.2 (-2.2 to -2.2)	-2.2	-2.0
SO_2	2030	0.4 (0.4 to 0.4)	0.4 (0.3 to 0.4)	0.4	-0.0	0.1	0 (0 to 0)	-0.0	0.1
	2040	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.2	-0.4	-0.3	-0.4 (-0.4 to -0.4)	-0.4	-0.3
	2050	-0.5 (-0.5 to -0.5)	-0.5 (-0.5 to -0.5)	-0.5	-0.5	-0.5	-0.5 (-0.5 to -0.5)	-0.5	-0.5
PM_{10}	2030	0.2 (0.2 to 0.2)	0.2 (0.2 to 0.2)	0.2	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2040	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.1	-0.2	-0.1	-0.2 (-0.2 to -0.2)	-0.2	-0.1
	2050	-0.3 (-0.3 to -0.3)	-0.3 (-0.3 to -0.3)	-0.3	-0.2	-0.2	-0.2 (-0.2 to -0.2)	-0.2	-0.2

Table 139 - Change for Maastricht airport of air pollutant LTO emissions compared to baseline (tonne)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	0.8 (0.5 to 0.8)	0.8 (-0.2 to 0.8)	0.9 (0.5 to 0.9)	-2.4	-0.7	-2.4 (-2.6 to -2.2)	-2.4	-0.7
	2040	0.7 (0.7 to 0.7)	0.7 (0.7 to 0.7)	0.6 (0.6 to 0.6)	-4.8	-2.9	-4.8 (-5 to -4.6)	-4.8	-2.9
	2050	-16.2 (-16.2 to -13.3)	-16.2 (-16.2 to -13.3)	0.9 (0.9 to 4.4)	-3.9	-3.4	-3.9 (-4 to -3.8)	-3.9	-3.4
NO_x	2030	0.5 (0 to 0.5)	0.5 (-1.1 to 0.5)	0.5 (0 to 0.5)	-4.0	-1.3	-4 (-4.3 to -3.7)	-4.0	-1.3
	2040	0.4 (0.4 to 0.4)	0.4 (0.4 to 0.4)	0.3 (0.3 to 0.3)	-3.8	-0.7	-3.8 (-4.1 to -3.5)	-3.8	-0.7
	2050	-29.8 (-29.8 to -25)	-29.8 (-29.8 to -25)	0.5 (0.5 to 6.6)	-0.9	-0.2	-0.9 (-1.1 to -0.7)	-0.9	-0.2
VOS	2030	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.2 (0.1 to 0.2)	-0.2	-0.1	-1.4 (-1.4 to -1.4)	-0.2	-0.1
	2040	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	-1.4	-1.2	-1.4 (-1.4 to -1.4)	-1.4	-1.2
	2050	-1.3 (-1.3 to -1)	-1.3 (-1.3 to -1)	0.1 (0.1 to 0.4)	-1.6	-1.5	-1.6 (-1.6 to -1.6)	-1.6	-1.5
SO_2	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-0.1	-0.0	-0.1 (-0.1 to -0.1)	-0.1	-0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-0.5	-0.5	-0.5 (-0.5 to -0.5)	-0.5	-0.5
	2050	-0.4 (-0.4 to -0.3)	-0.4 (-0.4 to -0.3)	0 (0 to 0.1)	-0.6	-0.6	-0.6 (-0.6 to -0.6)	-0.6	-0.6
PM_{10}	2030	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-0.0	-0.0	0 (-0.1 to 0)	-0.0	-0.0
	2040	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	-0.3	-0.2	-0.3 (-0.3 to -0.3)	-0.3	-0.2

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
	2050	-0.3 (-0.3 to -0.2)	-0.3 (-0.3 to -0.2)	0 (0 to 0.1)	-0.3	-0.3	-0.3 (-0.3 to -0.3)	-0.3	-0.3

Table 140 - Change for Groningen airport of air pollutant LTO emissions compared to baseline (tonnes)

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
CO	2030	3.6 (3.5 to 3.6)	3.6 (3.4 to 3.6)	3.7	-0.1	1.1	-0.1 (-0.1 to -0.1)	-0.1	1.1
	2040	-5.1 (-5.1 to -5.1)	-5.1 (-5.1 to -5.1)	-0.7	-1.3	0.6	-1.3 (-1.4 to -1.3)	-1.3	0.6
	2050	-11 (-11 to -11)	-11 (-11 to -11)	-6.8	-1.1	-0.5	-1.1 (-1.1 to -1.1)	-1.1	-0.5
NO_x	2030	2.2 (2.1 to 2.2)	2.2 (2.1 to 2.2)	2.2	-0.1	0.7	-0.1 (-0.1 to 0)	-0.1	0.7
	2040	-3.1 (-3.1 to -3.1)	-3.1 (-3.1 to -3.1)	-0.4	-0.4	0.8	-0.4 (-0.5 to -0.4)	-0.4	0.8
	2050	-7 (-7 to -7)	-7 (-7 to -7)	-4.3	-0.1	0.3	-0.1 (-0.1 to -0.1)	-0.1	0.3
VOS	2030	-0.8 (-0.8 to -0.8)	-0.8 (-0.8 to -0.8)	0.6	-0.0	0.2	-0.6 (-0.6 to -0.6)	-0.0	0.2
	2040	-0.8 (-0.8 to -0.8)	-0.8 (-0.8 to -0.8)	-0.1	-0.6	-0.3	-0.6 (-0.6 to -0.6)	-0.6	-0.3
	2050	-1.5 (-1.5 to -1.5)	-1.5 (-1.5 to -1.5)	-1.0	-0.7	-0.6	-0.7 (-0.7 to -0.7)	-0.7	-0.6

Air pollutant	Year	Airport - Strict allocation (3-year cycle)	Airport - Strict allocation (1-year cycle)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - no stability	Airline - Auctioning state	Airline - Funnelled back
SO_2	2030	0.1 (0.1 to 0.1)	0.1 (0.1 to 0.1)	0.1	-0.0	0.0	0 (0 to 0)	-0.0	0.0
	2040	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.0	-0.1	-0.1	-0.1 (-0.1 to -0.1)	-0.1	-0.1
	2050	-0.2 (-0.2 to -0.2)	-0.2 (-0.2 to -0.2)	-0.1	-0.1	-0.1	-0.1 (-0.1 to -0.1)	-0.1	-0.1
PM_{10}	2030	0 (0 to 0)	0 (0 to 0)	0.0	-	0.0	0 (0 to 0)	-	0.0
	2040	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.0	-0.0	-0.0	0 (0 to 0)	-0.0	-0.0
	2050	-0.1 (-0.1 to -0.1)	-0.1 (-0.1 to -0.1)	-0.1	-0.1	-0.1	-0.1 (-0.1 to 0)	-0.1	-0.1

Impacts on airport noise

Table 141 - Schiphol airport - Absolute results of number of houses (thousands) within 58 dB L_{den}-contours related to extreme baseline scenario

Year	Central baseline	Airport - strict allocation	Airport - soft allocation	Fuel supplier/ airline - auctioning state	Fuel supplier/ airline auctioning funnelled back
2017	11.2	11.2	11.2	11.2	11.2
2030	9.0	8.1	8.1	8.7	8.9
2040	7.4	5.0	5.0	7.3	7.4
2050	2.6	0.1	0.1	3.1	3.1

Table 142 - Rotterdam The Hague Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to extreme baseline scenario

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier / airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	14,970	14,970	14,970
		2030	4,661	6,102	4,863
		2050	6,557	3,723	6,642
	≥ 56 dB(A) L_{den}	2017	664	664	664
		2030	35	40	36
		2050	37	27	37
Severely annoyed	≥ 48 dB(A) L_{den}	2017	9,395	9,395	9,395
		2030	3,040	3,986	3,171
		2050	4,117	2,484	4,176
	≥ 56 dB(A) L_{den}	2017	1,188	1,188	1,188
		2030	259	306	268
		2050	291	228	293

Table 143 - Maastricht Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to extreme baseline scenario

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	13,943	13,943	13,943
		2030	14,089	14,215	14,051
		2050	10,873	10,941	10,851
	≥ 56 dB(A) L_{den}	2017	1,879	1,879	1,879
		2030	1,716	1,723	1,703
		2050	957	981	951
Severely annoyed	≥ 48 dB(A) L_{den}	2017	8,150	8,150	8,150
		2030	8,155	8,219	8,122

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
		2050	6,176	6,219	6,161
	≥ 56 dB(A) L_{den}	2017	1,873	1,873	1,873
		2030	1,734	1,743	1,718
		2050	992	1,013	986

Table 144 - Eindhoven Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to extreme baseline scenario

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier / airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	2,859	2,859	2,859
		2030	270	261	280
		2050	400	258	389
	≥ 56 dB(A) L_{den}	2017	141	141	141
		2030	11	11	14
		2050	32	13	30
Severely annoyed	≥ 48 dB(A) L_{den}	2017	1,880	1,880	1,880
		2030	293	286	302
		2050	448	283	437
	≥ 56 dB(A) L_{den}	2017	286	286	286
		2030	25	33	38
		2050	67	28	65

Table 145 - Groningen Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to extreme baseline scenario

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	111	111	111
		2030	36	44	38
		2050	7	31	82
	≥ 56 dB(A) L_{den}	2017	5	5	5
		2030	2	2	2
		2050	2	1	2
Severely annoyed	≥ 48 dB(A) L_{den}	2017	83	83	83
		2030	26	35	28
		2050	46	21	49
	≥ 56 dB(A) L_{den}	2017	7	7	7
		2030	2	2	2
		2050	2	1	2

Table 146 - Lelystad Airport - Absolute results of number of houses and severely annoyed people within L_{den}-contours related to extreme baseline scenario

Aspect	Contour level	Year	Extreme baseline scenario	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 48 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	74	31	77
		2050	53	34	53
	≥ 56 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	3	2	3
		2050	8	3	8
Severely annoyed	≥ 48 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	106	71	112
		2050	104	77	104
	≥ 56 dB(A) L_{den}	2017	N/A	N/A	N/A
		2030	36	27	38
		2050	65	33	65

H.4 Social impacts and safety

External safety

Table 147 - Rotterdam The Hague Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 10^{-5}	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	≥ 10^{-6}	2017	4	4	4
		2030	3	3	3
		2050	4	4	4

Table 148 - Maastricht Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario.

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	≥ 10^{-5}	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	≥ 10^{-6}	2017	96	96	96
		2030	75	75	75
		2050	85	85	85

Table 149 - Eindhoven Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario.

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	5	1	1
		2030	0	0	0
		2050	0	0	0

Table 150 - Groningen Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario.

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	$\geq 10^{-5}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	0	0	0
		2030	0	0	0
		2050	0	0	0

Table 151 - Lelystad Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	$\geq 10^{-5}$	2017	N/A	N/A	N/A
		2030	0	0	0
		2050	0	0	0
	$\geq 10^{-6}$	2017	N/A	N/A	N/A
		2030	0	0	0
		2050	1	1	1

Table 152 - Schiphol Airport - Absolute results of number of houses within IR-contours related to extreme baseline scenario

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
Houses	$\geq 10^{-5}$	2017	2	2	2
		2030	2	2	2
		2050	3	3	0

Aspect	Contour level	Jaar	Scenario baseline	Airport - soft allocation (largest noise reduction)	Fuel supplier/airline - auctioning funnelled back (lowest noise reduction)
	≥ 10^{-6}	2017	645	645	645
		2030	741	604	481
		2050	1,126	1,097	265

Jobs in the aviation sector

The changes in employment of the Dutch aviation sector under the CO_2 ceiling in the extreme scenario is presented in Table 153. Due to the fact the CO_2 ceiling is an absolute norm, we estimate for this scenario the impact of reduction of air transport activities has a relative higher impact on the aviation sector. This is due to the projected higher growth of air transport activities in the baseline of this scenario.

Table 153 - Overview of the number of jobs in Dutch aviation in extreme scenario (Fit for 55 reduced. increased airport cap. no Dutch SAF blending)

Year	Baseline	Airport - Strict allocation (3-year)	Airport - Strict allocation (1-year)	Airport - Soft allocation	Fuel - Auctioning state	Fuel - Auctioning funnelled back	Fuel - No stability	Airline - Auctioning State	Airline - Funnelled back
2017	65,030	0	0	0	0	0	0	0	0
2030	68,670	-6,140 (-6,400 to -6,140)	-6,140 (-6,920 to -6,140)	-6,660 (-6,920 to -6,660)	-3,390	-160	-3,390 (-3,580 to -3,210)	-3,390	-160
2040	80,370	-22,870 (-22,870 to -22,870)	-22,870 (-22,870 to -22,870)	-22,950 (-22,950 to -22,950)	-820	290	-820 (-990 to -650)	-820	290
2050	88,970	-32,280 (-32,280 to -30,010)	-32,280 (-32,280 to -30,010)	-32,310 (-32,310 to -30,380)	-480	70	-480 (-610 to -350)	-480	70

I Second opinion To70 and SEO on airport and airline response

NOTE

To	Dutch Ministry of Infrastructure and Water management
	Directie Luchtvaart en Maritieme Zaken (DGLM)
date	19 september 2022
subject	Second opinion – airport and airline response to CO2 ceiling per airport
our reference	22.171.19

1 Our interpretation of the request

The Dutch Ministry of Infrastructure and Water management (hereafter: "IenW") is currently working on the impact assessment study of the proposed Dutch aviation CO_2 ceiling policy. This impact assessment study is performed by CE Delft commissioned by IenW. IenW would like to have a second opinion on the expected reactions by the airports and airlines when a CO_2 ceiling per airport will be introduced. The introduction of such a ceiling is one of the options in the impact assessment study performed by CE Delft.

IenW is particularly interested in knowing to what extent the airlines would unilaterally or collectively undertake CO_2 reducing measures when the airports CO_2 ceiling becomes (or threatens to become) limiting and how a CO_2 ceiling per airport is comparable to other environmental (specifically noise) restrictions at airports. To70 and SEO will therefore answer the following sub questions:

1. To what extent is the regulation of CO_2 emissions different or similar from regulating aircraft noise or other emissions via the airports?
2. To what extent can you expect **collective** action from airlines when the CO_2 ceiling becomes (or threatens to become) limiting? And as part of that: to what extent can the government break through the prisoner's dilemma?
3. To what extent can you expect **individual** action from airlines when the CO_2 ceiling becomes (or threatens to become) limiting? And as part of that: what can you expect from the biggest airlines/alliances (such as SkyTeam) at Schiphol?

IenW has asked To70 and SEO Amsterdam Economics (hereafter: "SEO") to perform this second opinion. This second opinion focusses on the reasoning applied in the impact analysis. To do so, we use economic theory and expert knowledge, furthermore we examine the similarities and differences between the CO_2 ceiling policy with other policies (e.g. noise). We report our qualitative findings in this concise report/note.

2 Approach

The second opinion should answer the three sub questions as mentioned in previous section. The second opinion focuses primarily on Schiphol, since the airline mix at the airport is the most complex and the airport accounts for the almost 97 per cent of the CO_2 emissions of all national airports.

To perform this second opinion, To70/SEO received the draft report (version dated 1 March 2022) on the impact assessment by CE Delft. Throughout this second opinion two meetings between CE Delft, IenW, To70/SEO were organized. Furthermore, CE Delft and To70/SEO organized one bilateral meeting. The definition and the working of the CO_2 ceiling airport scenario are fully derived from the CE Delft impact assessment study report To70/SEO received. Additional insights, related to the slot mechanism and governmental policy actions when the airports CO_2 ceiling becomes (or threatens to become) limiting, were shared with To70/SEO during the discussions with CE Delft and IenW. It is clearly stated in the second opinion when these additional insights are taken into account in addition to the definition of the scenario as used by CE Delft.

The findings are presented in Section 4 and Section 5. The findings of the first sub question are presented in Section 4 and the answer to the second and third sub question are reported in Section 5. Section 6 concludes.

3 Disclaimer

This second opinion only considers a limited part of the impact assessment as drafted by CE Delft. As a result, our second opinion does not provide an integral assessment of this draft and or the policies assessed. The second opinion focusses on the question whether airlines would unilaterally or collectively undertake CO_2 reducing measures when the airports CO_2 ceiling becomes (or threatens to become) limiting. In particular, we have not been asked to examine the two other policy options included in the impact assessment, to examine the numerical simulations and calculations performed by CE Delft/Significance or examine the quantitative results and conclusions.

4 Comparison of CO2 ceiling with current environmental regulations

Dutch airports have a range of operating restrictions. Currently, the most restrictive are a maximum amount of movements per year, night closures and environmental restrictions. There are also other operating restrictions, such as third-party risk and local air quality, but these are (at the moment) less restrictive. All Dutch airports have to operate within a designated noise zone (either via limit values within enforcement points or a noise envelope/zone) and Schiphol has an additional cap on the total movements per annum[1].

Airports translate these restrictions into the capacity declaration, after which the slot coordinator issues the amount of slots fitting within the capacity declaration to airlines. Airports therefore have a strong control on the process at the beginning of every slot cycle (2 times per annum), when drafting the capacity declaration. However, in the rest of the slot cycle that follows, the control of the airport is limited since this is governed by the independent slot coordinator and EU regulations. When slots are issued, they are not aircraft or destination specific (assuming Schiphol to be the origin). Airlines have the right to change the aircraft or destination serviced with the slot.

Since airlines can change how they operate a slot, the slot allocation process causes information asymmetry between the airport and the airline on how a slot is operated. Airports cannot accurately steer or control aircraft movements to fit within the CO_2 ceiling within a single slot cycle. This in itself is not optimal, but should be manageable when a multiple slot cycle period is used for enforcement and with the knowledge that Schiphol has several (financial) incentives in place to stimulate the use of quieter and less polluting planes and the use of Sustainable Aviation Fuels (SAF) for airlines. However, the important conclusion derived from this is that (all things considered) the airport currently does not have the instruments to regulate the incentives of the airlines and that it is unknown how the introduction of the CO_2 ceiling will change the incentives of the airlines.

Comparison to noise regulation

Schiphol and the other regional airports have been restricted by noise limits for the past decades. Schiphol is restricted by limit values for noise in an array of enforcement points positioned around the airport. Schiphol has been managing the distribution of noise across these enforcement points to stay under the limit values for over 20 years. To do so, Schiphol uses noise models to calculate the expected noise levels in these enforcement points roughly 6-12 months prior to the actual operation. By doing so, Schiphol can identify potential violations of these limit values in enforcement points and take mitigating measures (mainly on runway usage) to avoid a violation of these limit values.

As further elaborated below, the long existing policy of noise limits is not suited to be used as an example how the CO_2 ceiling might work. Both the CO_2 ceiling and the noise limits benefit from

[1] The consequences of the decision by the Dutch government to reduce the maximum of flights to 440.000 instead of 500.000 for Schiphol has not been taken into account for this second opinion.

fleet renewal, but in terms of other measures to remain within set limits/ceilings they differ in a number of ways.

The (potential violation of) noise limits and the way potential violations are mitigated should not be compared to a scenario where a CO_2 ceiling/limit value becomes limiting. A CO_2 ceiling per airport is an overall limit driven by four variables: number of movements, type of aircraft, type of fuel, destination airport and route optimization (although this variable has far less impact then the other variables). For noise, a potential violation of a limit value in an enforcement point can be mitigated through measures by two additional variables, being runway/route use and route optimization (which airports can influence in coordination with the ANSP). Type of fuel is however a variable that doesn't work to reduce noise in enforcement points, but is a variable to reduce CO_2. The incentive for the type of fuel does however lays at the airline, not at the airport. This results in the fact that an airport only has one (concrete) action that can be taken when a CO2 ceiling becomes limiting, being a change in the number of movements. The other three variables are the domain of the airlines, which makes this a different situation compared to mitigating violations in noise enforcement points.

Over the past years we have seen (on rare occasions) that an airport was close to violating its noise limits. This potential violation has been mitigated by operational interventions, not by a reduction in the number of movements. By changing runway use and by route optimization airports have been able to remain within their noise limits. These interventions are being used to stay below the limit values in enforcement point by the airport in close coordination with the ANSP, which is in charge of runway and route usage. Airlines don't play a role in setting the runway/route usage, which makes this an easier measure to coordinate for the airport. The coordination is also simplified since the ANSP does not have any commercial incentives to use a specific runway or route. Asking airlines to make changes to their flight schedules to remain within the noise limits is for example much more difficult to coordinate for the airport, since there are multiple airlines with different commercial incentives.

Airports have been able to grow in terms of number of movements and passenger volume within their noise limits due to continuous fleet renewal. Continuous fleet renewal is an essential process for airlines to reduce operating cost (newer aircraft generally uses less fuel) and improve customer experience. The side effect that newer aircraft are (in most cases) quieter and emit less CO_2 than older aircraft and therefore contribute to staying within the limit values of the enforcement points is coincidental and not a main objective. Airlines have shown to renew their narrowbody fleet within 15-20 years and their widebody fleet within 20-30 years. At Schiphol the large number of airlines results in an almost continuous process of fleet renewal, causing a year on year decrease. At the other regional airports, fleet renewal occurs much more in steps due to the limited number of airlines. Airports do stimulate fleet renewal through discounts on airport charges for more quiet and efficient aircrafts. Fleet renewal is therefore a strong, but slow measure which airlines and airports are unable to use in order to steer on any environmental limit in the short term.

NOTE

In conclusion, an airport will mainly have one variable to stay under the CO_2 ceiling or correct a CO_2 ceiling violation of the previous slot cycle, being the number of movements. At the same time airports have an asymmetrical information position compared to airlines on the correlation between the number of movements and the total CO_2 emissions. This is a clear example of a principal-agent problem in which the institution (in this case the airport) to administer a resource has not been given the correct instrument and not the right information. This uncertainty complicates observing true emissions levels and leads to costly emission supervision and the need for (financial) incentives to use more SAF and reduce the changes of aircraft types and destinations serviced by a slot. It is different to other environmental regulation since airports have other variables (runway use, route use etc.) to manage to meet the limit values within their own power.

5 Airline strategies

The second and third research questions of this second opinion concern the incentives of airlines once the airport-level CO_2 ceiling becomes limiting. To reflect upon the question whether and under which conditions airlines may have collective or individual incentives to avoid hitting the airport-level CO_2 ceiling, one needs to introduce the incentive scheme of the airlines and the way airlines interact. Game theory is the common methodology in economics to study these schemes and interactions.[2]

Complexity and resemblance with previous theoretical models

Describing the game and potential strategies are essential in game theory. The game resulting from the airport-level CO_2 ceiling is characterized by airlines maximizing profits over period t and period $t + 1$. Period $t + 1$ includes multiple years. In period t airlines can choose to take measures – essentially causing profits to be lower in period t – to increase the probability of not hitting the CO_2 ceiling in period t. By doing so, the airline increases their (potential) profitability in period $t + 1$ because they potentially are entitled to more slots in period $t + 1$. However, all other airlines may also benefit from the additional available slots in period $t + 1$.

This seemingly simple trade-off between lowering economic activities (profits) in period t and potentially higher profits in period $t + 1$ already leads to a complex set of (continuous) strategies to be played under uncertainty. Each airline can play different (continuous) strategies, ranging from taking no measures at all, only aiming for a partial decrease in CO_2 emissions or fully aiming to avoid the CO_2 ceiling. A game theoretical framework is needed to assess which set of strategies would likely form the equilibrium / final outcome depending on the competition parameters.

In its impact assessment CE Delft summarizes and simplifies the game theoretical framework by pointing out that a so-called prisoners dilemma prevents airlines to avoid hitting the airport-level CO_2 ceiling. As we show below, this might be one of the outcomes, but does not necessarily has to be the only or resulting equilibrium. We recommend a full numerical analysis of the potential strategies within the same modelling framework as the original impact assessment of CE Delft in order to formulate quantitative conclusions on the likelihood of the type of equilibrium (yes/no airlines avoiding hitting the ceiling) to arise. As part of this second opinion, in Appendix A we give a brief overview of the game and which strategies should be included in this numerical assessment. The game is too complex to provide closed-form solutions or allow for ad-hoc calculations to assess the incentives of airlines. The uncertainties surrounding costs and profits in the period $t + 1$ are the main driver. The relevant profit and costs function of the airlines are unknown, an assessment of the value (over time) of additional slots at Schiphol is not straightforward given the uncertain demand and policy conditions, the probability of getting allocated additional slots (how many, etc.) is not known, etc.

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[2] See, for example, Brechet & Picard (2010) The price of silence: markets for noise licenses and airport. *International Economic Review*, 51(4); Verhoef (2010) Congestion pricing, slot sales and slot trading in aviation. *Transportation Research Part B*, 44(3) and Anand & Giraud-Carrier (2020) Pollution regulation of competitive markets. *Managements Science*, 66(9).

To illustrate this uncertainty, we take the example of a slot value. The value of a slot at Schiphol is unknown, there is no market for trading these slots. The most likely comparison is London Heathrow. This airport is capacity constrained and – at least pre-COVID – has an active secondary market of slot trading. Behrens, Van Spijker & Zuidberg (2018) show a large variation in the price of slot, mainly based on the time during the day of the slot.[3] These specific slots were traded ranging from €6 million to €86 million. However, a direct comparison of these numbers with the value of a slot at Schiphol is difficult. At Schiphol in the CO_2 ceiling scenario it is about an additional slot – based on slot growth – hence, it most likely will be about slots with less favourable conditions (time of day). This decreases the value of a slot quickly. Assuming an ad-hoc value for the slots in order to calculate the potential future profits of additional slots will make a comparison with and overarching conclusions regarding the impact assessment as executed by CE Delft invalid.

Additionally, one should take into account the impact of additional slots on the average fares of airlines. Fukui (2019) shows analysing a few airports in the US that slot constraints result in scarcity rent and removal of the slot constraint cause the average fare (over all output) to decrease by about 2.5 per cent. This finding by Fukui (2019) is an example showing that output maximizing – hence maximizing number of slots – not necessarily equals profit maximization.

The set-up of the game resembles game theoretical modelling exercises available in the literature, see e.g. Verhoef (2010), but also deviates from the existing literature in important aspects. First of all, the literature looks quite often at static games, whereas the current question requires dynamic optimization over multiple periods. Second, most if not all studies looking into CO_2 ceilings assume a certain (often tradable) permit system. This differs from the current question because these permits are airline based whereas the proposed CO_2 ceiling at Schiphol is airport based and the resulting airport slots (coupled to the CO_2 ceiling) are not tradeable. Third, there is a large literature on constraints, mainly capacity constraints, and game theory initiated by the seminal paper by Kreps and Scheinkman (1983).[4] The capacity constraint in all these studies, however, is producer (airline) specific, and not, as for the current question, airport/market specific (aggregate over all producers/airlines). In other words, in the current question airlines have less control (more uncertainty) than assumed in the models studied in the more traditional game theoretical literature. These deviations prevent a direct comparison of results from the literature and the current question to be available.

Drivers of individual or common action by airlines

In its impact assessment CE Delft assumes that a prisoners dilemma between the airlines prevents an airline to act unilaterally to reduce CO_2 levels in the current period. Instead, the airlines end up in the equilibrium where none of the airlines would take measures to avoid hitting the ceiling, and, subsequently, ending up in a less favorable equilibrium (sum of profits over airlines/welfare lower).

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3 Behrens, Van Spijker & Zuidberg (2018) Secundaire slothandel op Schiphol, SEO-rapport 2018-29.

4 Kreps & Scheinkman (1983) Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes, The Bell Journal of Economics, 14(2).

This coordination problem may decrease if one of the airlines has such a high market share that it would be profitable for this airline to take the measures in the current period irrespective of what the other (smaller) airlines would do, as also indicated by CE Delft.

To illustrate this, let's look at the extreme case of a monopoly airline. The result of the CO_2 ceiling would be simpler: the airline would – depending on the level of uncertainty – fully internalize the costs regarding the CO_2 ceiling and adjust its operation to stay within the limits under most circumstances (i.e. regulation that makes this choice a profit maximizing strategy). However, at most Dutch airports multiple airlines operate in strong competition with each other. Having a larger market share would *ceteris paribus* imply that the incentive to internalize external costs (e.g. slot scarcity) is higher. The market presence of SkyTeam implies that the coordination problem is smaller than in the case of a symmetric oligopolistic market. The market presence of SkyTeam would also justify the use of a leader-follower (Stackelberg[5]) game to identify the profit maximizing strategy. Whether the current market share in passengers or number of traffic movements is sufficient to solve the coordination problem is ultimately an empirical question. There are two important additional remarks. First, concentration in market share is not necessarily a good proxy for the level of competition. Hence, a high market share of SkyTeam does not imply a low level of competition at Schiphol. Second, solving the coordination problem does not directly imply that the airline has the incentive to avoid hitting the CO_2 ceiling. It does imply, instead, that the airline with the higher market share (being the leader) can more easily steer toward their preferred market outcome. Again, this could be either avoiding hitting the CO_2 ceiling or not.

Current operational practices at airports show that airports and airlines do in some occasions cooperate and coordinate efforts to adjust the operation to restrictions. A specific reoccurring example of this are foul weather days at Schiphol. When weather predictions indicate that runway usage at Schiphol will be limited and therefore capacity will be (much) lower, airlines operating at the airport cancel flights to make the operation fit within the (restricting) capacity. This is however an example of a temporary restriction.

Based on the definition, setup and assumptions of the scenario in the CE-study we do not consider (voluntarily) collective action to avoid hitting the CO_2 ceiling by airlines to be plausible. The CO_2 ceiling outcome cannot be predicted accurately by airlines which limits the potential of horizontal agreements, furthermore each airline strives for individual profit maximization and may therefore have the incentive to cheat regarding the agreements alike in a cartel.[6] Horizontal cooperation, without further action by the government, amongst competing airlines on this matter seems unlikely because airlines do not have a mechanism to monitor and, eventually, take corrective

[5] In the Stackelberg leadership model (a strategic game in economics) the Stackelberg leader firm moves first and then the follower firms move sequentially, see also the subsection on numerical analysis later in this second opinion.

[6] See for an overview of the economics on horizontal agreements for example Motta (2015) Competition policy: theory and practice, chapter 4: Collusion and horizontal agreements, Cambridge University Press.

measures when an airline does not comply with the horizontal agreements made.[7] Hence, the stability of such cooperation can be highly questioned. Furthermore, for airlines to make decisions, they need to know about future outcomes when no collective or individual action is achieved. This, for example, requires regulation to be consistent and anticipatable. If there are doubts whether the regulator, slot coordinator or airport would indeed lower the (growth of) number of slots in period $t + 1$, the probability common action is close to zero.

With these requirements not being met, the coordination problem to solve via the horizontal agreement is more profound because airlines are not able to fully predict the behavior of their competitors. Such a coordination problem makes a standard prisoners dilemma game not suitable to reflect the situation of the CO_2 ceiling because the stand game cannot deal with uncertainty in outcomes.

During the meetings with CE Delft and IenW we were asked to review what would change in our conclusion regarding the plausibility of collective action in case the government would be included as one of the active stakeholders being able to enforce the collective action via additional policies.[8] If this would be the case, the additional policy by the government would solve the coordination problem and the additional policy would cause airlines to take (collectively) the measures to avoid hitting the CO_2 ceiling.[9]

Numerical analysis and backward induction to identify airlines' strategies
We conclude that given the complexity and uncertainty surrounding the airline strategies and the deviations from previous academic modelling exercises, it is not possible to indicate with a reasonable likelihood the strategies individual airlines will follow based on the information provided in the CE Delft study (draft report version dated 1 March 2022). We are able to conclude, however, that collective action by airlines – in absence of further governmental action – is not plausible. As part of this second opinion, we identify the way how within the framework of the CE Delft-study one may arrive at insights needed to assess the individual airline strategies.

To consistently numerically analyze the research question, we strongly recommend to use the framework of the original impact assessment. In this way, the numerical assumptions are in line

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7 This is mainly due to the complexity regarding own profits, uncertainty and lack of transparency regarding the impact of collective and individual measures to avoid hitting the CO_2 ceiling.

8 Please note that in the CE-study the CO_2 ceiling will always be enforced, hence, the additional policies mentioned here only refer to the enforcement of avoiding hitting the CO_2 ceiling in period t (and subsequently less growth in the number of slots in period $t + 1$).

9 This is of course only true when airlines consider the alternative of not following the additional policy less favorable for current and future profits. It is possible that airlines would attain higher profits by 1) accepting the additional policy (e.g. a tax) in period t and further and 2) accepting a lower growth in slots in *period* $t + 1$, however, this seems a rather theoretical option. Furthermore, this would be easy to avoid by changing the additional policy in such a way that the incentive scheme of the airlines matches the one of the government.

with the original impact assessment. A common method to numerically solve complex games is to apply backward induction. Basically, backward induction requires to numerically calculate or estimate the profits of each strategy an airline potentially can play, given the strategy of the other airlines. In the most simplified example of two airlines having each two strategies – taking measures in period *t* or not – one gets the following 2 by 2 pay-off matrix:

	Airline 2 takes measures	Airline 2 does not take measures
Airline 1 takes measures	(profit airline 1 ; profit airline 2)	(profit airline 1 ; profit airline 2)
Airline 1 does not take measures	(profit airline 1 ; profit airline 2)	(profit airline 1 ; profit airline 2)

In this example, the profit of airline 1 may differ based on its own strategy, but also on the strategy of the other airline(s). After calculating the individual profits, one needs a few additional assumptions to arrive at the insights on the final outcome – which strategies are most likely to be chosen by the airlines. So, instead of first looking at the decision on the strategy, the game is solved by first looking at all potential outcomes (backward induction). The most common assumption is that airlines act independently and simultaneously taking into account the optimal quantity chosen by their competitors (Cournot-Nash game). An alternative assumption is that one airline acts first – as a leader – taking into account that the followers will adapt their strategy to the optimal strategy of the leader (Stackelberg game). Finally, another relevant option is that airlines collude and act simultaneously collectively.

In our view, the output of the numerical modeling of the CE Delft-study could potentially be used – most likely via extending the output as reported so far – to estimate the profit levels of airlines (e.g. SkyTeam as a leader and other airlines as followers) in each of the strategy scenarios as depicted in the pay-off matrix above. Via backward induction one uses the output of the simulations to reveal which would be the best strategy of the airline. This would be an iterative process. The likelihood of the conditions than determines whether it is more likely the airline would unilateral decide to reduce CO_2 levels in period *t* to allow for growth of capacity (slots) in period *t + 1* (taking into account lower market share) or not. In our opinion, the numbers presented in Chapter 3 (Table 2, ticket price figures, number of passenger tables, etc.) of the CE-Delft report could be used for such an analysis. It is essential to provide airline specific results on average fares and quantities for these particular scenarios to yield insights on the (proxy) of profitability while doing nothing or taking unilateral action to avoid hitting the CO_2 ceiling.

6 Conclusion

This section provides an overview of the findings and answers to the three sub questions.

To what extent is the regulation of CO2 emissions different or similar from regulating aircraft noise or other emissions via the airports?

In conclusion, an airport will mainly have one variable to stay under the CO_2 ceiling or correct a CO_2 ceiling violation of the previous slot cycle, being the number of movements. This makes it different from other environmental regulations such as noise. Airports have an asymmetrical information position compared to airlines on the correlation between the number of movements and the total CO_2 emissions. This uncertainty complicates observation of true emissions and leads to costly emission supervision due to lack of information or mitigation measures such as (financial) incentives to use more SAF and reduce the changes of aircraft types and destinations serviced by a slot.

To what extent can you expect collective action from the airlines when the CO_2 ceiling becomes (or threatens to become) limiting? And as part of that: to what extent can the government break through the prisoner's dilemma?

Based on the definition, setup and assumptions of the scenario in the CE Delft-study To70/SEO do consider (voluntarily) collective action to avoid hitting the CO_2 ceiling by airlines to be not plausible. The CO_2 ceiling outcome cannot be predicted accurately by airlines which limits the potential of horizontal agreements, furthermore each airline strives for individual profit maximization and may therefore have the incentive to cheat regarding the agreements alike in a cartel.

If the government would be included as one of the active stakeholders being able to enforce the collective action via additional policies, the additional policy by the government would solve the coordination problem and the additional policy would cause airlines to take (collectively) the measures to avoid hitting the CO_2 ceiling.

To what extent can you expect individual action from the airlines when the CO_2 ceiling becomes (or threatens to become) limiting? And as part of that: what can you expect from the biggest airlines/alliances (such as AF KLM and partners) at Schiphol?

While the likelihood of individual action increases by the market presence of an airline (alliance) at the airport, we conclude that given the complexity and uncertainty surrounding the airline strategies and the deviations from previous academic modelling exercises, it is not possible to indicate with a reasonable likelihood the strategies individual airlines will follow based on the information provided in the CE Delft-study so far. Instead we recommend to use the numerical framework applied in the CE Delft-study to estimate/calculate profit levels of the airline (alliances) with the largest market presence (in output) at Schiphol for different strategies (intensity of taking measures avoiding hitting the CO_2 ceiling) and subsequently using standard assumption in game theory and backward induction to derive the likelihood of the different potential market outcomes/equilibria. In this way, the numerical assumptions used to answer the question on which strategies are profit maximizing for the individual airlines are in line with the original impact assessment. This at least requires to extend the current numerical analysis by CE Delft to report airline (alliance) specific results as well.

NOTE

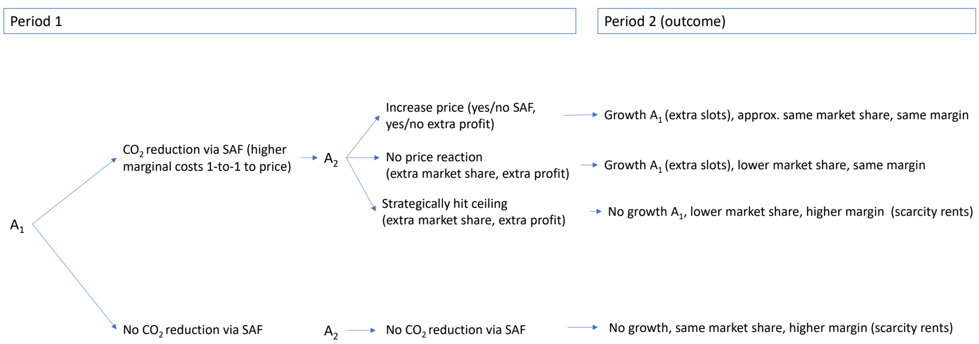
A 1 A model example - A simple but already complex airline strategy game

The following model shall be understood as an example completely based on underlying assumptions that might or might not reflect the current market situation. As such it is an illustration and therefore not suitable for policy conclusion in its current form.

The figure below depicts the simplified schematic airline strategy game. We are interested under which conditions airline 1 has the unilateral incentive to avoid hitting the CO_2 ceiling. In the profit maximizing behaviour, the airline has to take into account the reaction of the other airlines, the time dimension, the impact on costs of own actions. Based on these considerations the airline has a preferred strategy, being a pure (probability 1 or 0) or mixed strategy (probability between 1 or 0). The nature of (the behaviour of) airline 1 is important. We here assume that airline 1 has a significant market share at the airports, and might even act as a Stackelberg leader at the airport.

Reaction other airlines

After realizing that airline 1 reduces CO_2 emissions to avoid hitting the ceiling, the other airlines have roughly three different type of strategies. First, they observe (or anticipate) the higher prices by airline 1 and react to these higher prices by increasing their prices as well (same output, higher margins). In this way, the other airlines take advantage of the price increase in the market. There is also a possibility the other airlines will not react to the increase in prices and therefore would increase their market share (more output, same margins). The third option is that they strategically aim to sabotage the strategy by airline 1 and take the additional profit in period 1 (even more output, same margins). Out of these three potential options, a mix of the first and second one is most likely: the other airlines react partially by increasing their price and gain in this way a (slightly) higher margin with higher market share. Under the assumption that each of the other airlines are (relatively) small, the probability that one of these other airlines unilaterally can raise the CO_2 levels in such a way that the ceiling will be hit is small. Additionally, by playing this third strategy, the other airlines also risk losing their own growth opportunities and retaliation from airline 1 in other markets.



Strategy of airline 1

Airline 1 has two strategies. Airline 1 may or may not reduce the CO_2 levels. In reality, the strategy can also include reducing part of the CO_2 levels while still hitting the ceiling. However, this strategy would create additional uncertainty of the growth in available slots over time, and would depend on the actual slot growth policy in this policy alternative. Airline 1 aims to maximize profits over two time periods. To do so, the strategy in period 1 has to be chosen in such a way – taking into account the anticipated behaviour of the other airlines – that profits over time are maximized. Choosing for the reducing CO_2 strategy is costly in period 1, but might gain more profits in period 2, and the other way around. We assume that reducing CO_2 would take place via more SAF, thereby increasing the own marginal (operational) costs of airline 1 and, for simplicity, that airline 1 will charge the full cost increase to the consumers. This implies that airline 1 will remain the same profit margin, but its market share will be lower (the other airlines react most likely with a price-market share mix strategy as discussed above). In period 2, however, airline 1 will obtain additional slots, still with lower market share but remains the same margin.

Airline 1 can also choose not to reduce CO_2 (lower half of the figure) for no additional costs in period 1, but this would result in no growth in period 2. As demand than outgrows supply, all airlines will enjoy scarcity rents (without additional policy).

In brief, airline 1 has the choice to forego some profits in period 1, with the risk of lowering its market share in both period 1 and 2, but with higher total capacity, versus same profits in period 1 but with lower capacity in period 2 (yielding scarcity rents).