FUEL TANKERING IN RELATION TO A DUTCH CO_2 CEILING FOR AVIATION

Input to the working group on the development of a CO_2 ceiling convened by the Ministry of Infrastructure and Water Management

Paul Peeters (Breda University of Applied Sciences, Netherlands)
Gabrielle Uitbeijerse (PBL Netherlands Environmental Assessment Agency)
Bram Peerlings (Royal NLR – Netherlands Aerospace Centre)
Gerben Geilenkirchen (PBL Netherlands Environmental Assessment Agency)

20 September 2021

Colophon

Fuel tankering in relation to a Dutch CO_2 ceiling for aviation. Input to the working group on the development of a CO_2 ceiling convened by the Ministry of Infrastructure and Water Management.

The Hague, 2021
PBL publication number: 4608

Corresponding author
Gerben.Geilenkirchen@pbl.nl

Authors
Paul Peeters (Breda University of Applied Sciences, Netherlands), Gabrielle Uitbeijerse (PBL Netherlands Environmental Assessment Agency - currently working at KiM Netherlands Institute for Transport Policy Analysis), Bram Peerlings (Royal NLR – Netherlands Aerospace Centre), Gerben Geilenkirchen (PBL Netherlands Environmental Assessment Agency).

Supervisor
Danielle Snellen (PBL Netherlands Environmental Assessment Agency)

Acknowledgements
We would like to thank the members of the working group on the development of a CO_2 ceiling for their comments on previous versions of this report.

Visualisations
Beeldredactie PBL

Production coordination
PBL Publishers

Peeters, P., G.C.M. Uitbeijerse, B. Peerlings & G.P. Geilenkirchen (2021), Fuel tankering in relation to a Dutch CO_2 ceiling for aviation, The Hague: PBL Netherlands Environmental Assessment Agency.

Contents

Summary 4

1 Introduction 6

2 Potential current and future tankering 7
2.1 Potential tankering in Europe and at Amsterdam Airport Schiphol 7
2.2 Comparing CO_2 emissions based on bunker-fuel data and modelling 9
2.3 Illustration of technical potential of tankering 12

3 Tankering in relation to a CO_2 emission ceiling 13
3.1 CO_2 emissions reduction task for 2030 13
3.2 Decrease in outbound tankering 14
3.3 Increase in inbound tankering 14
3.4 Other considerations 15

4 Monitoring CO_2 emissions 16
4.1 Potential of advanced modelling 17
4.2 Comparison of monitoring options 18
4.3 Other data sources 18

5 Conclusions 19

References 21

Appendix: Modelling approach 23
Method 23
Results 24

Summary

In order to reduce CO_2 emissions from international aviation, the Dutch Government is considering the introduction of a CO_2 emission ceiling for all flights departing from Dutch airports. Introducing such a ceiling creates challenges with respect to monitoring and enforcement, including how to determine whether the policy is having the desired effects. A basic design choice for this CO_2 emission ceiling is whether to use CO_2 emission data derived from aviation fuel sales data (bunker-fuels) or from a modelling approach. Bunker-fuel sales are reported annually by Statistics Netherlands and provide an accurate indicator for the amount of related CO_2 emissions. As such, using bunker-fuel sales data could be a suitable basis for setting the CO_2 emission ceiling.

Tankering can undermine the effectiveness of a bunker-fuel based CO_2 emission ceiling

A potential problem related to bunker-fuels data, however, could be that not all fuel taken onboard on departing flights is actually required for safe operation of the flight. Tankering is the process where more fuel is taken on board than necessary for safe operation of a flight. There are multiple reasons why tankering might currently be applied. This paper focuses on the economic incentive, created by kerosene price differences between airports. Tankering could undermine the effectiveness of a bunker-fuels-based CO_2 emission ceiling. Airlines might be able to partially avoid the impact of a CO_2 emission ceiling by taking on more fuel on incoming flights to the Netherlands (inbound tankering), as such lowering the need to refuel in the Netherlands. This could not only reduce the impact of a CO_2 emission ceiling but may also result in more CO_2 emissions, as tankering increases the take-off weight of the aircraft, which leads to more fuel being used and, thus, to more CO_2 emissions during the flight.

Low fuel prices are likely to induce outbound tankering from Schiphol Airport

Based on the literature on tankering and on fuel-price differences observed between Amsterdam Airport Schiphol and other European airports, this study concludes that flights departing from Schiphol currently are very likely to apply outbound tankering. Modelled CO_2 emissions, which are insensitive to tankering, are between 3% and 15% lower for flights departing from Dutch airports than CO_2 emissions derived from bunker-fuel sales data for Dutch airports. These differences can be attributed to a number of possible factors, one of which is tankering. The average level of current net outbound tankering is estimated at between 1% and 5%.

CO_2 emission ceiling may induce inbound tankering

The CO_2 emission ceiling for 2030 is proposed to be set at the 2005 emission level. This would require an emission reduction of more than 3 Mt compared to business-as-usual projections for 2030. Approximately 4% to 21% of this reduction, however, could be achieved by terminating currently estimated outbound tankering. By itself, this would result in only minor reductions in actual CO_2 emissions. On top of terminating current outbound tankering, airlines could apply inbound tankering to further undermine the impact of the CO_2 emission ceiling. Based on an analysis of the technical potential for tankering, it was estimated that approximately 25% of the fuel required for flights departing from the Netherlands could be tankered elsewhere. This could undermine the entire impact of the proposed CO_2 emission ceiling.

European Commission proposals may reduce risk of tankering

Merely using bunker-fuels sales data as a basis for a CO_2 emission ceiling could significantly undermine the effectiveness of such a ceiling. The recent ReFuelEU Aviation legislative proposal by

the European Commission would reduce this risk, as the EU proposes that at least 90% of the fuel required for flights departing a Union airport has to be taken onboard at that same airport. The proposal includes a requirement for aircraft operators to report their fuel uplifted and required from 2023 onward. Although no data for the benchmark year 2005 will be available, the Ministry could investigate the potential of this independently verified data as a basis for monitoring CO_2 emissions from flights departing from the Netherlands.

Modelling approach may further reduce risk of tankering

A modelling approach is insensitive to tankering and can include other behavioural responses to a CO_2 emission ceiling as well. More research is needed to investigate whether advanced modelling would improve setting the ceiling and monitoring emissions. Also, a combination of an advanced model with reported bunker-fuel data could be examined as a way to verify whether the observed trends in bunker-fuel data are in line with actual changes in CO_2 emissions of outgoing flights.

1 Introduction

The Dutch Government is considering the introduction of a ceiling on the annual amount of CO_2 emissions from international flights departing from the Netherlands (i.e. an annual CO_2 budget, limit or cap). This CO_2 emission ceiling would be set at the 2005 emission level in 2030 and would be reduced to 50% of the 2005 emission level in 2050 and zero in 2070. The Dutch Ministry of Infrastructure and Water Management has provided a list of requirements for the design of the CO_2 emission ceiling (Ministry of Infrastructure and Water Management, 2020a). Its purpose is to reduce the use of fossil fuels, and as such, the CO_2 emissions from international flights departing from the Netherlands, without accounting for market-based measures such as CORSIA and the EU-ETS.

With the support of an advisory group and external experts, stakeholders are currently working on potential policy designs for the CO_2 emission ceiling. The challenges they face relate, among other things, to monitoring the emission ceiling and how to determine whether it is adhered to each year. Much will depend on the way the CO_2 emissions from outgoing flight are determined. A basic design choice is between using data on bunker-fuel sales at Dutch airports or modelling the fuel used for the flights departing from these airports. Bunker-fuel sales are reported, annually, by Statistics Netherlands (CBS) and provide an accurate indicator of the amount of CO_2 emissions resulting from the use of these fuels[1]. These bunker-fuel sales data are currently used for the annual greenhouse gas emission reporting to the UNFCCC (Ruyssenaars et al., 2021). As such, using fuel sales data could be an attractive basis for setting the CO_2 emission ceiling.

A potential problem related to using bunker-fuel data could be that not all of the fuel taken onboard for a departing flight would actually be needed for the safe operation of the flight. Due to fuel price differences between airports, airlines may choose to take on more fuel at airports with low fuel prices, in order to reduce the amount they would need to refuel at airports with higher fuel prices. This is what is called tankering. Other reasons for tankering include airlines avoiding having to take in low quality fuel at a destination airport, an unreliable fuel supply or even unavailability of fuel at certain destinations, and currency-related problems (Eurocontrol, 2019; Tabernier et al., 2021). Contingency and reserve fuel, taken on board for safety reasons and for dealing with possible adverse weather conditions, are not regarded as tankering in this report, in line with the definition issued by IATA (IATA, 2021, p. 56).[2]

Tankering could undermine the effectiveness of a CO_2 emission ceiling. Airlines might be able to avoid some or all of the impact of a CO_2 emission ceiling by taking on more fuel on flights to the Netherlands, thus lowering the need to refuel at a Dutch airport. This could not only reduce the impact of a CO_2 emission ceiling, but might result in higher CO_2 emission levels. Tankering increases the take-off weight and, therefore, results in higher fuel use and more CO_2 emissions.

---

[1] According to the Dutch list of emission factors, the combustion of 1 kg of fuel results in 3.11 kg of CO2 emissions (Zijlema, 2020). Internationally, other emission factors are used, such as 3.15 (used by IPCC, Eurocontrol, EU ETS) and 3.16 (ICAO (2020), CORSIA). This report uses a value of 3.11 kg CO2/kg fuel.

[2] IATA describes fuel tankering as: ‘The fuel transported for economic reasons or for operator convenience (e.g. due to price/availability at destination).’

This report discusses possible risks with respect to the effectiveness of a CO_2 emission ceiling in relation to tankering. It first assesses what share of the current bunker-fuel uptake (and associated CO_2 emissions) in the Netherlands could be related to tankering; it looks at the extent to which bunker-fuel data represents the actual amount of fuel burnt during the outgoing flights (Section 2). Section 3 explores the conceivable impact of a CO_2 emission ceiling on tankering, Section 4 compares the two methods and Section 5 presents the conclusions.

2 Potential current and future tankering

In the autumn of 2020, the Dutch Ministry of Infrastructure and Water Management organised expert discussion sessions on the CO_2 emission ceiling in relation to tankering. The participating experts assumed that tankering is currently applied to take advantage of price differences between airports and to save turn-around time. The minutes of the sessions, furthermore, state that tankering is currently only economically interesting on short flights. However, in a situation where fuel sales at Dutch airports are constrained by a limit on the total amount of fossil fuel that can be bunkered due to the implementation of a CO_2 emission ceiling, tankering could be a behavioural response to reduce the impact of this ceiling.

2.1 Potential tankering in Europe and at Amsterdam Airport Schiphol

Airlines may apply tankering on inbound and/or outbound flights, which may consist of what is known as ‘full tankering’ (i.e. taking on board enough fuel for the entire return flight, as well) or ‘partial tankering’ (i.e. only part of the fuel required for the return flight is taken on board). Based on interviews with airline pilots, business dispatchers and handling agents, Eurocontrol (2019) confirmed that tankering is a practice commonly used by airlines. Based on these interviews, Eurocontrol estimates that both full and partial tankering each are applied 15% of the time. The Eurocontrol study also reports that, in 90% of cases, tankering is applied for fuel price reasons, with the remaining 10% due to social disruption, technical failure at the refuelling facilities, fuel shortage, risk of delays, or contaminated fuel at destination airports.

Aviation is a highly competitive sector, and tankering can be expected to be applied as a cost reduction measure, as fuel accounts for approximately a quarter of the operating costs of airlines (Tabernier et al., 2021). The average worldwide price of jet fuel is largely influenced by the demand and supply of crude oil, and related processing and refining costs, but prices at specific airports may deviate, significantly, due to local circumstances. Generally, airlines negotiate fuel prices at each of the airports they serve for an agreed period of time. Mostly, they negotiate a fixed fuel price for a certain period of time (hedging) to protect themselves against major price fluctuations (Tabernier et al., 2021).

Figure 1

Example of differences between jet fuel prices at European airports , June 2018

Source: Eurocontrol (2019); adaptation by PBL

Figure 1 shows fuel price differences between various airports in Europe, in June 2018. These data were derived by Eurocontrol from the reporting by several airlines on their negotiated fuel prices at each airport. It shows that fuel prices vary significantly between European airports. For instance, fuel suppliers at Amsterdam Airport Schiphol (Netherlands) offered the lowest prices and Bastia (Corsica) offered prices that were 55% higher (Eurocontrol, 2019). Possible reasons for the relatively low prices at Amsterdam Airport Schiphol could be the airport's location close to refineries and import facilities at the Port of Rotterdam, and a competitive environment created by multiple fuel suppliers.

Eurocontrol has studied the economic benefits and environmental impacts of fuel tankering in Europe[3] (Eurocontrol, 2019). Taking into account aircraft characteristics (data on performance, relevant weights, tank capacity) and legal fuel minima, simulations were performed to determine the percentage of flights for which full or partial tankering could be applied[4]. The study estimates that, in 16.5% of all intra-European flights, full tankering is applied and in an additional 4.5% of flights partial tankering is applied. Partial tankering may be applied in lieu of full tankering due to an aircraft's technical limitations (fuel capacity and maximum take-off and landing weight) or a particular cost optimum. Tankering is estimated to have saved airlines around EUR 265 million in fuel cost, while increasing fuel burn by 286,000 tonnes, causing an additional 0.9 Mt in CO_2 emissions. Compared to CO_2 emissions from all flights departing from European airports[5] in 2016, tankering could represent an emission share of 0.5%.

Due to the fact that short- and medium-haul aircraft used on intra-European routes typically do not utilise their full tank capacity and because fuel prices at Amsterdam Airport Schiphol are among the lowest in de European Union, it is hypothesised that intra-European flights departing from Schiphol are applying tankering. For long-haul flights, tankering is less likely because excess fuel capacity is typically lower, price differences between hubs might generally be smaller, and the penalty from increased fuel consumption due to tankering is larger due to the longer flight. The actual use of tankering on long-haul flights depends, however, on specific price differences between airports for each airline, which are not publicly available. Based on the Eurocontrol study, it is assumed that current and historical bunker-fuel data are likely to overestimate the actual amount of fuel consumed (and, therefore, also the amount of CO_2 emitted) on intra-European flights departing from Schiphol. For the purpose of setting and monitoring a CO_2 emission ceiling, it is relevant to estimate how much tankering is included in the current bunker-fuel data in the Netherlands.

2.2 Comparing CO_2 emissions based on bunker-fuel data and modelling

This section describes our estimation of which share of the current bunker-fuel uptake (and associated CO_2 emissions) in the Netherlands could be related to tankering. It compares CO_2 emissions based on bunker-fuel data with those based on modelling. Current and historical CO_2 emissions in the Netherlands were calculated using two models and compared to the emissions related to bunker-fuel data.

Figure 2 compares the trends in CO_2 emissions as obtained from our 'combined model' (as described in the Appendix) with modelling by Eurocontrol (2021a) and CO_2 emissions derived from bunker-fuel sales in the Netherlands (Ruyssenaars et al., 2021) for the 2005–2019 period. The figure shows that both modelling approaches are in good agreement. The figure also shows that the trend

---

[3] More precisely, flights within ECAC airspace, European Civil Aviation Conference (Eurocontrol, 2019). Calculations are based on modelling with BADA and the EASA aircraft database and model.

[4] The study only considered full tankering to be an option for flight legs under 1500 NM (approximately 2800 km) and partial tankering for flight legs under 2500 NM (about 4700 km).

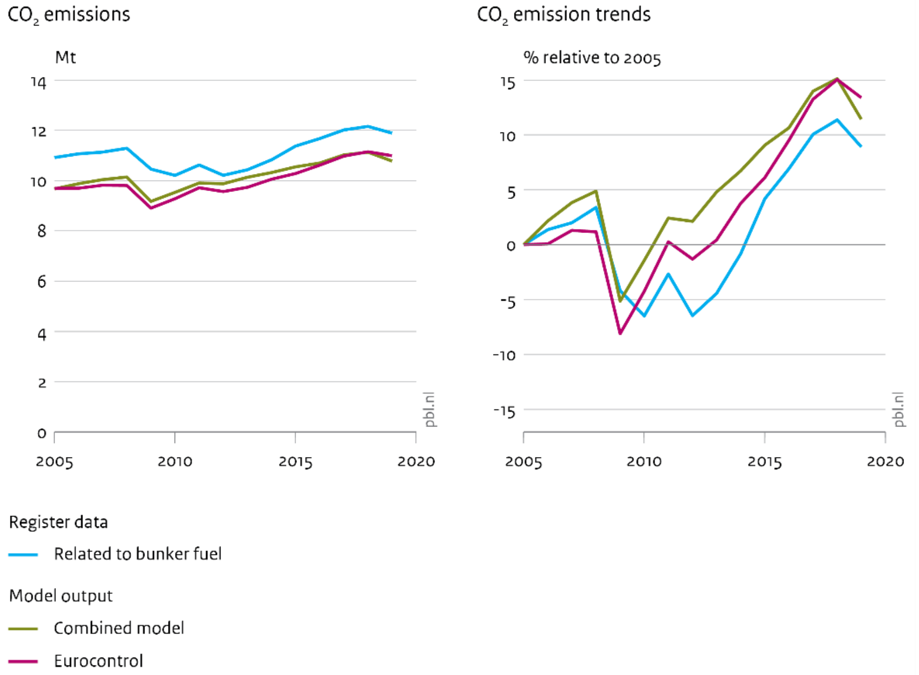
[5] EU-28 + EFTA departures, together, add up to a total of 171 Mt in CO2 emissions (EASA et al., 2019).

in bunker-based CO_2 emissions in the 2005–2009 period is quite similar with that in the model calculations. Emission levels vary between bunker-fuel data and both models, with the models showing approximately 12% lower emission levels. The trends from the bunker-fuel data and models start to deviate substantially over the 2010–2015 period, with bunker-fuels decreasing stronger than predicted in both modelling approaches. This difference might be explained by the economic crisis during that period and the relatively high oil prices. As is shown in Box 1 of Section 3.4, tankering is less attractive from an economic perspective when fuel prices are high. In the 2016–2019 period, the differences between CO_2 emissions from bunker fuels and those calculated in both models are consistent, at between 8% and 10%. In 2019, all three sources report CO_2 emission levels that are 10% higher than the 2005 level. CO_2 emission levels from the combined model are between 3% and 14% lower than those related to the bunker-fuel data over the entire 2005–2019 period. The average deviation over this period is 9%. The Eurocontrol model shows 7-15% lower CO_2 emissions than bunker-fuel data for the same period, with the same average of 9% deviation.

The 2019 European Aviation Environmental Report (EASA, EEA & Eurocontrol, 2019), presents a similar comparison between CO_2 determined from modelling, using Eurocontrol's IMPACT, and as reported to the UNFCCC, derived from bunker fuels (Figure 3). Over the period where both datasets are available (2005 – 2016), the difference between model-based and bunker-fuel-based emissions varies between 7% and 12%, with the model predicting lower CO_2 emissions than those derived from bunker-fuel data, for all years. As the scope of this comparison spans all flights departing from Europe, tankering on European flights cannot be used to explain this difference.

Figure 2

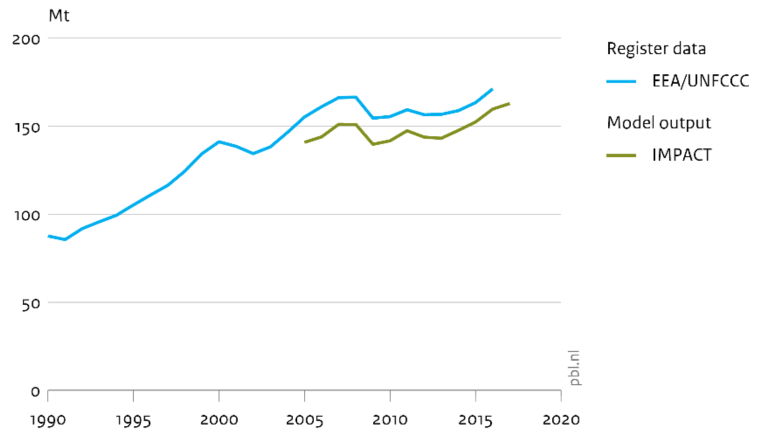
CO_2 emissions from aviation, based on register data and models



Bron: CBS Statline (2021); FEM; CO_2-tool; Eurocontrol (2021); adaptation by BUAS/PBL

Figure 3

Full flight CO_2 emissions from all flights departing the EU-28 and EFTA countries



Source: EASA; adaptation by PBL

Based on these comparisons, and irrespective of individual model results, all models show CO_2 emission levels that are lower than those estimated from fuel-use data. Depending on the model, different factors could be used to explain these differences. A number of factors, as well as their impacts as estimated by the authors, are listed in Table 1.

Quantifying the impact of all factors contributing to the differences between bunker-fuel data and modelled CO_2 emissions is difficult, making it equally difficult to quantify the exact current amount of outbound tankering at Dutch airports, based on the data currently available to the authors. Based on the literature reviewed in Section 2.1, the price differences between airports and the comparison between bunker-fuel data and different modelling approaches, we estimated the current amount of outbound tankering to be between 1% and 5%.

Table 1

Possible explanations for differences between CO_2 emissions derived from models and those from bunker-fuel use

	Combined model versus bunker-fuels	**Eurocontrol model versus bunker-fuels**	**IMPACT model versus bunker-fuels**
Scope	The Netherlands (departures)	The Netherlands (departures)	EU28+EFTA (departures)
Tankering included in bunker-fuel data	Somewhat likely	Somewhat likely	Only intercontinental departures
Modelling limitations and inaccuracies related to:			
Flight distance	Somewhat likely	Somewhat likely	No
Vertical track	Somewhat likely	Somewhat likely	No
Wind effects	Very likely	Very likely	Very likely
Load factor	Very likely; limited impact	Very likely; limited impact	Very likely; limited impact
Aircraft configuration	Very likely; limited impact	Very likely; limited impact	Very likely; limited impact

2.3 Illustration of technical potential of tankering

Irrespective of the economic argument, the fuel capacity and certified weight limits of aircraft also limit the technical potential for tankering. Tankering is technically possible for all flight distances and all types of aircraft, as long as an aircraft has not reached its maximum certified take-off and landing weight. The results from a rough calculation using Lissys Piano-X (Lissys Limited, 2021), a free version of the aircraft performance and design model Piano (Table 2), illustrates this technical potential for tankering. Unfortunately, the free version of Piano-X does not include the Airbus A320 or Boeing 737-800 series (extensively used on intra-European flights). Table 2 shows this potential for four cases of single flights: three flights with the Boeing 787-8 (a wide-body long-haul aircraft) and one with a Fokker 70 (a narrow-body short-haul aircraft). The result for Boeing 787-8 flights strongly depend on the assumed flight distance and payload. The payload of 24.45 tonnes refers to a typical passenger load plus 11 tonnes of belly freight. The 23.45 tonnes represent the typical passenger-only payload. With a lower payload, more fuel can be taken on board within the limits of the certified maximum landing weight.

Based on these results and estimates, the technical potential of tankering was estimated for all outbound flights included in the combined model used in this study. The calculated and derived results for flights leaving the Netherlands can be assumed to also apply to all inbound flights — for which the point of tankering is not in the Netherlands but elsewhere. For the estimation of this technical potential, we took the maximum aircraft range into account and conservatively assumed that:

- For their return flight, departing narrow-body aircraft are taking fuel onboard to cover a maximum distance of 500 km. If the return leg is longer than that, the additionally required fuel will be taken onboard elsewhere.
- For wide-body aircraft, the fuel taken onboard for the return flight is to cover a maximum distance of 1500 km.

Under the assumptions described above, the technical potential for tankering of both outbound and inbound flights is estimated at about 25%. This adds around 1% to total fuel consumption and fuel cost.

Table 2
Technical potential for tankering using Lissys Piano-X in four different cases

Aircraft type	**Boeing 787-8**	**Boeing 787-8**	**Boeing 787-8**	**Fokker 70**
Flight length (base leg)	6000 km	3000 km	3000 km	635 km
Payload (tonnes)	34.45	34.45	23.45	7.17
Tankering capacity (km)	1500 km	1700 km	5300 km	>635 km
Tankering capacity (% of return distance)	25%	56%	>100%	>100%
Additional cost due to tankering compared to base and return leg				
Fuel costs	+2.2%	+2.2%	+7.5%	+2%
Direct operating costs	< +1%	< +1%	+1.9%	< +1%

3 Tankering in relation to a CO_2 emission ceiling

Although, to date, the specific design of a CO_2 emission ceiling has not been agreed on, its intended targets are clear. Airlines could apply various strategies to comply with a potential emission ceiling, including improving operational efficiency or applying sustainable aviation fuels to reduce net CO_2 emissions. Airlines could also apply different tankering strategies. The design of the emission ceiling and the emission data used are likely to affect the way airlines respond.

Section 3.1 defines the CO_2 emission reduction task for 2030. The subsequent section provides estimations of possible behavioural responses for a situation in which the CO_2 emission ceiling is based on bunker-fuel data. It first looks at a reduction in current outbound tankering (following the estimates presented in Section 2.2) followed by an investigation of potential future inbound tankering (using the estimates on the technical potential for tankering from Section 2.3).

3.1 CO_2 emissions reduction task for 2030

Following the targets set by the Dutch Ministry of Infrastructure and Water Management's agreement on sustainable aviation (‘*Akkoord Duurzame Luchtvaart*’, Ministry of Infrastructure and Water Management, 2020b), the CO_2 emission ceiling for 2030 would be set at the 2005 CO_2 emission level. Computed with the use of bunker-fuel data (CBS, 2021), this would mean an emission ceiling of 11 Mt. The most recent Dutch Climate and Energy Projections (PBL et al., 2020) projects 14 Mt CO_2 emissions related to aviation bunker-fuel for 2030, based on the ‘proposed policy’ scenario [11–15 Mt][6]. These projections suggest a gap of 3.4 Mt CO_2 between the projected growth and the intended CO_2 emission ceiling by 2030, and thus indicate a required 24% CO_2 reduction, compared to current projections.

It should be noted, though, that the projections are rather uncertain, as shown by the relatively large bandwidth. This uncertainty stems from, amongst other things, the uncertainty of the speed of recovery from the COVID19-pandemic and potentially long-lasting effects from the pandemic, which might include lower business travel than pre-pandemic levels (Bouwer et al., 2021). In theory, when using the lower estimate for 2030 CO_2 emissions from the energy projections (11 Mt), no additional CO_2 reduction would be required by 2030. As the CO_2 emission ceiling is expected to further decline after 2030, however, additional reduction would still be required from then on.
It should also be noted that new policies that could achieve additional CO_2 emission reductions, such as an alternative fuel mandate, are currently being elaborated at national and EU (European

---

[6] The ‘proposed policy’ scenario in 2030 includes an aviation tax for passengers, inclusion of aviation in the EU-ETS, 2% biofuel blending in aviation fuel in the Netherlands and an average fleetwide 0,8% annual fuel efficiency improvement. Growth capacity at Schiphol is restricted: half of the future decrease in aircraft noise may be used for extra flight movements above the cap of 500,000 flight movements per year (50/50 rule). After taking a decrease due to corona measures into account, a 26% growth in flight movements to and from Dutch airports over the period 2019-2030 is projected.

Commission, 2021a) level, but had not yet been proposed when the 2020 energy projections were made and, as such, were not included in these projections.

3.2 Decrease in outbound tankering

If the CO_2 emission ceiling would be based on bunker-fuel-derived CO_2 emission levels, decreasing current outbound tankering would decrease bunker-fuel sales in the Netherlands, which in turn could help compliance with the CO_2 emission ceiling, but this would not achieve any significant decreases in actual CO_2 emissions from outbound flights. The level of current tankering for outbound flights is estimated at between 1% and 5% of all fuel sales, as described in Section 2.2.

Table 3 shows the resulting reduction in the effectiveness of the emission ceiling when it is assumed that the CO_2 emission ceiling results in all outbound tankering being abandoned. This reduction varies between 4% and 21%. In other words, one fifth of the required CO_2 reduction from the intended CO_2 emission ceiling by 2030 could potentially be realised without major reductions in the actual CO_2 emissions from outgoing flights. Even though the reduction in outbound tankering would also make a true contribution to reducing global CO_2 levels, such reductions would be much smaller than those observed in bunker-derived CO_2 emissions levels in the Netherlands. If the CO_2 emission ceiling would be based on a model that is insensitive to tankering, changes in tankering strategy could not be used to substantially influence the observed progress towards meeting the ceiling.

Table 3
Effects of reduction in outbound tankering on bunker-fuel-derived CO_2 emission levels in 2030

Projected CO_2 emissions in 2030 (Mt)	14.3
CO_2 emissions ceiling 2030 (Mt)	10.9
CO_2 reduction task (Mt)	3.4
CO_2 reduction task (%)	24%
Current outbound tankering (estimate)	1% - 5%
CO_2 reduction from avoiding outbound tankering (Mt)	0.1 – 0.7
% of reduction task	4% - 21%

3.3 Increase in inbound tankering

In addition to reducing outbound tankering, a CO_2 emission ceiling could also incentivise inbound tankering. When additional costs of inbound tankering are lower than other options to reduce CO_2 emissions from fossil fuel bunkering in the Netherlands, this response could become economically attractive. However, inbound tankering does not reduce actual CO_2 emissions from flights arriving in and departing from the Netherlands. It may actually result in a small increase in CO_2 emissions due to the additional weight carried onboard incoming flights.

Based on the technical potential for tankering, illustrated in Section 2.3, about 25% of the fuel required on flights departing from the Netherlands could be tankered at other airports. Based on bunker-fuel-derived CO_2 emissions, this would be an amount of 3.6 Mt — more than the entirety of the projected reduction task for 2030, thereby severely undermining the effectiveness of a CO_2

emission ceiling for 2030. Again, a modelling approach might not be susceptible to this potential problem.

3.4 Other considerations

Apart from possibly changing tankering strategies, airline operators might show other behavioural responses to a CO_2 emission ceiling. For example, they might optimise fleet schedules, deploying the most fuel-efficient aircraft on routes on which emissions are capped and use less fuel-efficient aircraft elsewhere — ultimately not reducing, but shifting emissions to another country or region. This behavioural response cannot be negated by using modelling data instead of bunker-fuel-based data, as in both cases the resulting CO_2 emissions are related to specific aircraft used on routes to and from the Netherlands.

The attractiveness of various options truly realising global CO_2 emission reductions is strongly affected by fuel prices and related costs, as well as by the alignment between national or regional policies. If fuel-related costs increase, investments to reduce fuel consumption become more attractive. Investments may consist of fleet renewal, but could also be needed to implement weight-reduction programmes or further route optimisation.

In the legislative proposals put forward by the European Commission as the ‘Fit for 55’ package (European Commission, 2021a), a proposed increase in the linear reduction factor in the EU ETS is likely to raise CO_2 cost and thereby directly contribute to the attractiveness of decarbonisation investments, at least for the intra-European flights that are included in the ETS. Moreover, the European Commission proposes an EU blending mandate for sustainable aviation fuel (5% by 2030). Aviation fuel suppliers would be required to ensure that all aviation fuel made available to aircraft operators contains a minimum share of sustainable aviation fuel, including a minimum share of synthetic aviation fuel. This directly reduces net CO_2 emissions from flights departing from each EU airport. A provision in that same proposal aims to limit tankering by requiring operators to tank at least 90% of the fuel required for a particular flight at the airport from which that flight starts. This could provide an interesting opportunity for decreasing the potential for tankering when introducing a CO_2 emission ceiling in the Netherlands, and could be explored further.

Last, it is relevant to note that increases in alternative fuel use and related cost reduce the attractiveness of tankering. Given the fact that such cost increases are indeed likely, the use of tankering may decrease. Box 1 further explains this relationship.

Box 1: Tankering in relation to oil prices

Variations in global oil prices affect the ‘business case’ for tankering. To understand this, it is relevant to note that the kerosene price partially depends on the feedstock cost (i.e. crude oil) and partially on the production and transportation cost. If feedstock costs rise, the kerosene price will also rise — but relatively more so at airports for which the transportation costs are limited, such as Amsterdam Airport Schiphol (see Section 2.1). This reduces the relative difference in the price of kerosene between airports, affecting the economic attractiveness of tankering. At high oil prices, the difference in fuel prices at Amsterdam Airport Schiphol compared to the EU average, assumed to be USD 16.5 ct/kg in the table below, remains the same as at low oil prices. As such, price savings from tankering remain the same per kg of fuel. But the additional costs of tankering, i.e. the costs of burning more fuel because of the additional weight of the tankered fuel, will increase at high oil prices. Therefore, tankering becomes less attractive at higher oil prices, to the point where, in the example for the long haul (Boeing 787-9) flight in the table below, tankering is only attractive at low oil prices, and results in net additional costs at high oil prices. By this logic, increases in oil price are likely to lead to a decrease in tankering by flights outbound from the Netherlands.

Table 4
Example of costs benefits of tankering, at low and high oil prices

	Unit, source	2011 (high oil price)	2015 (low oil price)
Average fuel costs difference between Schiphol and other airports (assumption)	Eurocontrol (2019)	n/a	30%
Fuel costs average airport (baseline)	USD ct/kg (Easa et al., 2019)	116.7	55.0
Fuel costs Schiphol	USD ct/kg	100.2	38.5
Logistic transportation costs	USD ct/kg	16.5	16.5
Example 1: Boeing 787-9 (5300 km flight)			
Fuel use without tankering	tonnes	26.0	26.0
Fuel use with tankering	tonnes	29.9	29.9
Fuel costs without tankering	USD (*1000)	28,1	12,1
Fuel costs with tankering	USD (*1000)	30,0	11,5
Cost advantage with tankering	USD (*1000)	-1.82	0.62
Example 2: Fokker 70 (635 km flight)			
Fuel use without tankering	tonnes	1.97	1.97
Fuel use with tankering	tonnes	2.03	2.03
Fuel costs without tankering	USD (*1000)	2.13	0.92
Fuel costs with tankering	USD (*1000)	2.03	0.78
Cost advantage with tankering	USD (*1000)	0.1	0.14

4 Monitoring CO_2 emissions

There are a number of advantages and disadvantages related to the use of bunker-fuel-derived or modelled fuel consumption and related CO_2 emissions in setting a CO_2 emission ceiling. As a CO_2 emission ceiling derived from historical bunker-fuel data is likely to include some component of tankering, it would provide the aviation sector with a way of realising notable reductions in CO_2 that would count towards complying with the ceiling (namely by reducing outbound tankering), while realising a significantly smaller reduction in actual global CO_2 emissions. Moreover, a bunker-fuel-derived emission ceiling may incentivise airlines to apply inbound tankering (i.e. taking part of the fuel required for an outbound trip from the Netherlands on board at a non-Dutch airport). That too would reduce accounted CO_2 emissions while actually contributing not only to carbon leakage, but to an actual, albeit relatively small, increase in fuel consumption and associated CO_2 emissions.

4.1 Potential of advanced modelling

A CO_2 emission ceiling based on modelled fuel consumption is insensitive to tankering, but has other downsides. The two models used in this study (the Combined Model and the Eurocontrol Model, which both use the SET model (Eurocontrol, 2020) for calculating fuel consumption per flight) are relatively simple and do not accurately capture specific influences on per-flight fuel burn; for example, due to variations in exact aircraft type–engine type used, including retrofits with fuel-saving devices (e.g. winglets), weather effects, detours, weight reduction schemes, and subtle differences in fuel consumption between airlines. Both approaches do include the most relevant determinants of total CO_2 emissions: the flight network, fleet composition and total number of flights.

That is not to say that the limitations associated to these particular models will hold for any model-based approach. In a wider context of aviation sustainability, Peerlings and Van der Sman (2021) provide an overview of various pathways that can be used to assess environmental performance, ranging from expert judgement to various forms of modelling and measuring. We used their overview as inspiration to outline a more advanced model versus the relatively simple models we used in this study, thereby addressing the limitations of our modelling approach as identified in Chapter 2. Therefore, we added an additional column to Table 5 showing what we believe would be possible to achieve with a more advanced modelling approach. The main elements of such an Advanced Model are:

- Flight data taken from real flight paths as registered by Eurocontrol: this includes exact flight paths, altitudes and airspeeds. Also, services such as those from FlightRadar24 (2021) can provide detailed altitude and speed profiles for the real flight.
- Data on types of aircraft can be taken from national aircraft registers (e.g. the Dutch 'Luchtvaartuigregister'), or international aircraft databases such as those from Jet Inventory Services[7], which include information on engine and aircraft type for every aircraft registered. Some may include a designation of retrofits.
- Weather data from, for example, the Aviation Weather Center of the NOAA National Weather Service[8]. This can be added to the flight profile.
- Data about the operating empty weight would cover modelled fuel-burn savings from weight savings programmes. This type of data is proprietary with airlines. A way to gather such data is to use a default, relatively high OEW, and update that default when an airline can prove to have done better for each aircraft in its fleet.
- The exact fuel consumption per flight can be calculated on the basis of the above three data sources and using BADA 3 (Eurocontrol, 2021). Variations in the aircraft types given by BADA 3 can be added to the Advanced model with small corrections for the known differences in for instance fuel consumption between engine types for the same type of aircraft.

It should be noted that a modelling approach to determine CO_2 emission levels is used for other CO_2 regulation, such as the EU emission standards for heavy-duty vehicles. In order to determine

---

[7] website 'Jet Inventory Services'

[8] website 'Aviation Weather Center'

fuel consumption and CO_2 emissions related to heavy-duty vehicles under this regulation, a standardised simulation tool is used: VECTO (Vehicle Energy Consumption calculation TOol). VECTO is used for determining the compliance with the EU targets for CO_2 emissions from new heavy-duty vehicles.

4.2 Comparison of monitoring options

Four monitoring options are compared in Table 5: the use bunker-fuel data, the Combined Model, the Eurocontrol Model and a possible future Advanced Model. From this comparison of methods can be concluded that using bunker-fuel data is generally the most complete option and applied most often internationally, but also the most vulnerable to tankering. Limitations of the models used in this report can likely be addressed by an advanced model, one that would not be vulnerable to tankering.

Table 5
Comparing the use of bunker-fuel data and model calculations as a basis for emission monitoring under a CO_2 emission ceiling

	Bunker-fuel data	**Modelling approaches**		
Model type	Not applicable	Combined model	Eurocontrol model	Advanced model[a)]
Internationally accepted standard	Yes	No	Yes (EU ETS)	Possible
Benchmark unaffected by tankering	No	Yes	Yes	Yes
Including operational efficiency	Yes	Partially	Yes	Yes
Including weather effects	Yes	On average	On average	Partially in detail[b)]
Including network changes	Yes	Yes	Yes	Yes
Including fleet renewal and retrofits	All	Most	Most	Yes
Robustness of emission ceiling[c)]	Vulnerable	Robust	Robust	Robust
Incentive to fly more efficiently	Yes	No	No	Partially in detail[b)]
Incentive to optimise network for fuel efficiency (more direct flights)	No	No	No	No

a) This column shows the possibilities of an (as of yet theoretical) advanced model. Such a model would be based on detailed fuel consumption calculations using existing datasets from air traffic control and for instance Flightradar that provide full flight-paths in terms of place, speed and altitude and including the precise aircraft type.

b) Partially in detail means that the flight data are at the highest detail possible, but weather data a bit less so. Flying to make advantage of weather is common and is rewarded as far the details allow it.

c) Potential effectiveness in relation to the avoidance of tankering

4.3 Other data sources

The use of other forms of data measurements (e.g. as reported for EU ETS or CORSIA) has not been considered here, but could be used for monitoring purposes. Due to the lack of such data on 2005, which is the benchmark year proposed for the CO_2 emission ceiling and applied in the agreement on sustainable aviation (*Akkoord Duurzame Luchtvaart*), it cannot be used for setting a baseline.

Another possibly upcoming data source might be found in reports for the ReFuelEU Aviation initiative. The proposed ReFuelEU Aviation initiative is presented as part of the European Commissions “Fit for 55”-package of measures (European Commission, 2021b). If that proposal is accepted, aircraft operators are required to report independently verified yearly quantities of fuel uplifted (tanked) and required at each Union airport[9] from the year 2023 onwards. This data should be available after March 31st following the year of the reporting period at the competent authorities of Member States. This would provide the Ministry with independently verified data on the amount of fuel used on flights departing the Dutch airports (except those departing Groningen Airport Eelde, a small share). Although no data for the benchmark year 2005 will be available, the data could improve monitoring of a potential CO_2 emission ceiling.

5 Conclusions

Tankering is the process where more fuel is taken on board than would be necessary for the save operation of a flight. There are multiple reasons why tankering is currently being applied. This report focuses on both the economic incentive created by kerosene price differences between airports and tankering in relation to a potential CO_2 emission ceiling in the Netherlands. Because the aircraft weight increases due to tankering, CO_2 emissions during the flight also increase. This report assesses what share of the current bunker-fuel uptake and associated CO_2 emissions in the Netherlands can be related to tankering and explores the potential for future tankering, if demand would cause higher CO_2 emission levels than would be allowed under a bunker-fuel-based CO_2 emission ceiling.

Low fuel prices are likely to induce outbound tankering from Amsterdam Airport Schiphol

Based on the literature on tankering and fuel-price differences observed between Amsterdam Airport Schiphol and other European airports, the hypothesis is that intra-European flights departing from Schiphol are applying tankering. We made a comparison between modelled CO_2 emissions (insensitive to tankering) and bunker-fuel-use data on CO_2 emissions (sensitive to tankering) which indeed indicated differences, ranging between 3% and 15%, with an average of 9% and with bunker-fuel-sales data indicating higher CO_2 emission levels than were calculated in the modelling approaches. These differences could not be quantitatively attributed to a number of possible factors, one of which being tankering. As such, the average amount of current outbound tankering was estimated at between 1% and 5%.

---

[9] ‘Union airport’ means an airport as defined in Article 2(2) of Directive 2009/12/EC of the European Parliament and of the Council, where passenger traffic was higher than 1 million passengers or where the freight traffic was higher than 100000 tons in the reporting period, and is not situated in an outermost region, as listed in Article 349 of the Treaty on the Functioning of the European Union;”. Of the six (future) airports of national interest, only Groningen Airport Eelde does not classify as a ‘Union airport’ by this definition.

Tankering could undermine the effectiveness of a bunker-fuel based CO_2 emission ceiling

Following the above, the volumes of fuel taken onboard at Dutch airports are likely to include some component of tankering, and therefore are an overestimation of the actual fuel consumption by flights departing from the Netherlands. In case a CO_2 emission ceiling would be set at an historical level based on CO_2 emissions derived from bunker-fuel sales for a given year, it would be higher than if it would be set on the basis of modelled fuel consumption and CO_2 emissions.

CO_2 emission ceiling could reduce outbound tankering and induce inbound tankering

Depending on the amount of tankering and the design of the CO_2 emission ceiling, the effectiveness of such an instrument could be undermined. Terminating current outbound tankering could account for 4% to 21% of the required CO_2 emission reduction under the proposed ceiling for 2030. Based on an analysis of the technical potential for tankering, we found that 25% of the fuel required for flights departing the Netherlands could be tankered elsewhere. If that amount of inbound tankering would be applied in response to a CO_2 emission ceiling, than the entire CO_2 emission reduction required by 2030 could be achieved without any actual reductions in CO_2 emissions from outgoing flight from the Netherlands.

European Commission proposals may reduce risk of tankering

There are a number of advantages and disadvantages related to the use of bunker-fuel derived or modelled CO_2 emissions for setting a CO_2 emission ceiling. Merely using bunker-fuel data as a basis for a CO_2 emission ceiling could significantly undermine the effectiveness of such a ceiling. A recent legislative proposal by the European Commission (ReFuelEU Aviation) reduces these risks, as it includes a clause that requires at least 90% of the fuel needed for flights departing a Union airport to be taken on board at that airport. It does not fully mitigate these risks though. The proposal includes a requirement for aircraft operators to report fuel uplifted and required, starting in 2023. Although no data for the benchmark year 2005 will be available, the Ministry could research the potential of these independently verified reported data for monitoring CO_2 emissions under a CO_2 emission ceiling.

Research needed whether advanced modelling could mitigate risk of tankering

A modelling approach is insensitive to tankering and can include other behavioural responses to a CO_2 ceiling as well. More research is needed to investigate whether advanced modelling would improve setting the ceiling and monitoring emissions. Also, a combination of an advanced model with reported data (bunker fuels or ReFuelEU-reported data) could be examined as a way to verify whether the observed trends in reported fuel data are in line with modelled trends.

References

Bouwer J, Saxon S and Wittkamp N. (2021). Back to the future? Airline sector poised for change post-COVID-19. New York.

CBS (2020). Statline: Luchtvaart; maandcijfers Nederlandse luchthavens van nationaal belang. CBS. Retrieved 9 November 2020 from https://opendata.cbs.nl/#/CBS/nl/dataset/37478hvv/table?ts=1605025507458.

CBS (2021). Statline: Luchtvaart; Motorbrandstoffen; afzet in petajoule, gewicht en volume. CBS. Retrieved 9 November 2020 from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83406NED/table?ts=1622820132408.

Daggett DL, Sutkus DJ, DuBois DP and Baughcum SL. (1999). An evaluation of aircraft emissions inventory methodology by comparisons with reported airline data (CR-1999-209480).

EASA, EEA & EUROCONTROL (2019). European Aviation Environmental Report 2018 (ISBN: 978-92-9210-214-2).

Eurocontrol (2019). Fuel Tankering: economic benefits and environmental impact. Eurocontrol.

Eurocontrol (2020). Small emitters tool. Eurocontrol. Retrieved 8 July 2020 from https://www.eurocontrol.int/tool/small-emitters-tool.

Eurocontrol (2021a). CO_2 Emissions by State. Eurocontrol. Retrieved 28 May 2021 from https://ansperformance.eu/data/.

Eurocontrol (2021b). Base of aircraft data. Realistically model the performance of any aircraft. Retrieved from https://www.eurocontrol.int/model/bada.

European Commission (2021a). Delivering the European Green Deal. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en.

European Commission (2021b). Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport - ReFuelEU Aviation 2021/0205 (COD). Retrieved from https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf

FlightRadar24 (2021). About Flightradar24. Retrieved from https://www.flightradar24.com/about.

ICAO (2020). 2019 Environmental Report. Destination Green, the Next Chapter. ICAO.

IATA (2021). IATA Reference Manual for Audit Programs (IRM). Edition 11. Montreal

Lissys Limited. (2021). Lissys Ltd is proud to present PianoX and Piano 5.0. Lissys Ltd. Retrieved 3 March 2021 from https://www.lissys.uk/.

Ministry of Infrastructure and Water Management (2020a). CO_2-plafond internationale luchtvaart (CO_2 emission ceiling international aviation) (IENW/BSK-2020/238729). Ministry of Infrastructure and Water Management, The Hague.

Ministry of Infrastructure and Water Management (2020b). Verantwoord vliegen naar 2050. Luchtvaartnota 2020-2050. Ministry of Infrastructure and Water Management, The Hague.

PBL, TNO, CBS & RIVM (2020). Klimaat- en Energieverkenning 2020 (Climate and Energy Exploration). PBL Netherlands Environmental Assessment Agency, TNO Netherlands Organisation for Applied Scientific Research, Statistics Netherlands (CBS) & National Institute for Public Health and the Environment (RIVM) The Hague & Bilthoven.

Peerlings B and Van der Sman ES. (2021). Verkenning milieuscores voor de luchtvaart. Analyse van mogelijke doelen en toepassingen en consultatie van betrokken partijen (NLR-TR-2021-223). Amsterdam.

Peeters PM. (2018). Carbon footprint emissiefactoren; versie 2017 en trends 2002-2017.

Rutherford D, Zheng XS, Graver B and Pavlenko N. (2021). Potential tankering under an EU sustainable aviation fuels mandate. ICCT, Washington D.C.

Ruyssenaars PG, Coenen PWHG, Rienstra JD, Zijlema PJ, Arets AJMM, Baas K, Dröge R, Geilenkirchen G, 't Hoen M, Honig E, van Huet B, van Hui EP, Koch WRR, te Molder RM, Montfoort, JA, Van der Zee T, van Zanten MC. (2021). Greenhouse gas emissions in the Netherlands 1990–2019. National Inventory Report 2021, National Institute for Public Health and the Environment (RIVM), Bilthoven.

Swartz KL. (2020). Great Circle Mapper. Karl L. Swartz. Retrieved 22 March 2020 from http://www.gcmap.com/.

Tabernier L, Fernández EC, Tautz A, Deransy R and Martin P. (2021). Fuel tankering: Economic benefits and environmental impact for flight up to 1500 NM (Full tankering) and 2500 NM (Partial tankering), Aerospace 2201, 8, 37.

Uitbeijerse G and Hilbers H. (2018). Ontwikkeling luchtvaart en CO_2-emissies in Nederland. Factsheet voor de Omgevingsraad Schiphol. PBL Netherlands Environmental Assessment Agency, The Hague.

Van der Sman E, Peerlings B, Kos J, Lieshout R and Boonekamp T. (2021). Destination 2050 – A route to net zero European aviation (NLR-CR-2020-510). NLR.

Verrips A and Hilbers H. (2020). Kansrijk Mobiliteitsbeleid: bijlage 4 Fiches, CPB Netherlands Bureau for Economic Policy Analysis & PBL Netherlands Environmental Assessment Agency, The Hague.

Zijlema PJ. (2020). Nederlandse lijst van energiedragers en standaard CO_2 emissiefactoren, versie januari 2020. Netherlands Enterprise Agency (RVO), The Hague.

Appendix: Modelling approach

Method

FEM model

BUAS calculated the emissions from all flights departing from the Netherlands on 7 days in 2019 using the FEM model. All departing flights from Amsterdam Airport Schiphol (AMS), Rotterdam-The Hague Airport (RTM), Eindhoven Airport (EIN), Groningen Airport (GRQ) and Maastricht-Aachen Airport (MST) were taken into account. These add up to 5,951 flights.

The flights are assumed to provide a representative set for a year-long operation from the 5 Dutch airports in terms of the distribution over airlines, aircraft types and destinations. This data set includes 96 types of aircraft, 542 origin–destination pairs, 365 destination airports, and 200 different airlines. The most important aircraft types are the B738 (1619 flights), E190 (768 flights) and the A320 (575 flights). The most common destination airports are London Heathrow (LHR, 127), London City (LCY, 118), Barcelona (BCN, 101), Dublin (DUB, 96) and Copenhagen (CPH, 94). The most common airlines are KLM (KLM, 2507), Transavia (TRA, 707), easyJet (EJU, EZY, 382), and Ryanair (RYR, 208). The data set was cleaned up by removing flights for which (a) no aircraft type was given, (b) no destination was given or (c) the aircraft type was not available in the Eurocontrol Small Emitters Tool (SET).

The next actions were:

1. Calculate the great circle distances for each airport pair using Great Circle Mapper (Swartz, 2020).
2. Calculate the real distance by multiplying the GCD by a detour factor that varies per distance class (based on Peeters, 2018).
3. Use the Small Emitters Tool (Eurocontrol, 2020) to calculate CO_2 emissions for each flight.
4. Calculate the average emissions per flight and extrapolate this to the total number of flights for 2019.

Table 6
Overview of days with flights

Date	Day	Number of flights
2019-05-14	Tuesday	844
2019-06-01	Saturday	773
2019-06-06	Thursday	894
2019-07-17	Wednesday	884
2019-08-04	Sunday	850
2019-08-30	Friday	886
2019-10-28	Monday	820
Total		**5951**

CO_2 tool

The NLR CO_2 tool has been designed to model CO_2 emissions of large groups of flights, prioritising flexibility and computational speed over accuracy at flight level. For each airport pair, it computes flight distance based on the great circle distance and a ‘detour factor’ derived from historical data. Then it models a simple flight trajectory, consisting of climb, descent, cruise, and cruise climb segments, in such a way that the entire distance is covered. For each aircraft type, the airspeed, rates of climb and descent as well as resulting fuel flow throughout this flight trajectory are computed using the EUROCONTROL Base of Aircraft Data (BADA; v3.14). Integrating the fuel flow over time results in the fuel burn per flight; multiplication with the CO_2 emission index and summation over all flights in the data set yields the total CO_2 emissions. For the analyses presented here, traffic data has been sourced from NLR's FANOMOS (Flight Track and Aircraft Noise Monitoring System).

Combined model

The FEM model is more detailed and covers all airports in the Netherlands, but only for 2019. The NLR CO_2 tool provides data for Amsterdam Airport Schiphol only, but for all years between 2001 and 2019. Therefore, the two data sets were combined, starting with FEM with respect to the distribution of flights over airports and the average emissions per flight per airport. CBS data provided the number of flights per airport between 2001 and 2019. Emissions were derived by multiplication by the average emissions per flight from FEM. These computed emissions are corrected by dividing them by 0.9394, which is the FEM share of emissions for Amsterdam Airport Schiphol. This resulted in the emissions for all 5 main Dutch airports. Because the network and fleet composition were not constant over this period, the NLR CO_2 tool provided a correction on the emissions with average emissions per flight (index 2019 = 1.0). This delivered the trend for the 'combined model'.

Eurocontrol data

The Eurocontrol database (Eurocontrol, 2021) was directly obtained from Eurocontrol. The model used by Eurocontrol to generate the CO_2 emissions used the SET tool (Eurocontrol, 2020) and the flights database proprietary to Eurocontrol.

Results

Table 7 shows the results for FEM and the combined model. Total modelled emissions are calculated based on overall average emissions per flight and then multiplied by the total flights departing from all 5 airports (using the average emissions per airport, per flight). The latter is more accurate because the average varies rather widely between the airports as Table 7 shows.

Table 7
Modelling results by FEM

	Departures		**CO_2 emissions**	
2019	FEM (5 days)	CBS (full year)	FEM average per flight per airport (kg)	FEM average x CBS flights (Mt)
AMS	5,148	248,420	40,772	10.1
EIN	452	20,117	16,902	0.3
GRQ	42	1,700	10,297	0.02
MST	71	3,598	42,805	0.2
Total Dutch airports	5,957			10.8
Average per flight (kg)			37,699	