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The impact of emissions from aviation on the climate

Content

Please note: Sulphur dioxide (SO_2), nitrogen oxides (NO_x) and soot, which are emitted during take-off and landing in air layers close to the ground, also have direct effects on health and the environment. These non-climatic effects of air traffic emissions are not discussed in this publication. Possible measures to reduce emissions and their effects are also not discussed. The advantages and disadvantages of political measures are described in the fact sheet of the Swiss Academies of Arts and Sciences (2019) on 'Instruments for an effective and efficent energy and climate policy'.

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Key messages

- → In addition to CO_2, air traffic emissions contain various other components that have an effect on the climate, in particular water vapour (H_2O), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and soot. The impact of CO_2 emissions on the climate is meanwhile well known, while knowledge of the climate impact of non-CO_2 emissions is still rather uncertain.
- → According to the current state of knowledge, contrails and the high thin clouds (cirrus clouds) that are induced by them cause the most significant climate impact of non-CO_2 emissions, significantly higher than the effect of CO_2. Nitrogen oxide emissions cause both warming and cooling effects in total about half as much warming as CO_2 emissions. The effects of sulphur dioxide and soot emissions are likely to be relatively small.
- → In order to stabilize the climate impact of aviation emissions, CO_2 emissions must be reduced to net zero, while non-CO_2 emissions must not increase further. For a reduction in climate impact (in line with the 1.5 °C target), a reduction in non-CO_2 emissions – compared to today's level – or net 'negative' CO_2 emissions is needed.
- → The conversion metric used under the United Nations Framework Convention on Climate Change (UNFCCC) agreements (Paris, Kyoto) to CO_2 equivalent emissions (the Global Warming Potential) is not suitable for short-lived substances. An alternative, suitable for all issues, has not yet been established. It is recommended to use the most appropriate metric depending on the problem or the perspective.
- → The choice of metrics in connection with political measures depends on the perspective or the weighting of different effects and thus on (socio-)political values. Technical measures on aircraft usually have different effects on CO_2 and non-CO_2 emissions.

For the calculation of the climate impact of aircraft emissions, the factors recommended for use depending on the issue or the perspective (multiplication with CO_2 emissions for the calculation of CO_2 equivalents as a measure of the total climate impact) are summarized in the table below.

Please note: These factors are subject to a high degree of uncertainty and are estimates based on current knowledge. These factors can change over time and may need to be adjusted. The reasons for this are the accumulation of CO_2 in the atmosphere (the factors become smaller as a result), CO_2 reduction measures (the factors can increase or decrease depending on the type and scope of the measure, see Table 5) or changes in the rate of increase in emissions of short-lived substances (in the Equivalent Warming Potential, GWP*).

Question/Perspective	Factor
Present climate impact of past emissions (basis: Radiative Forcing or Effective Radiative Forcing), status 2018 (calculation of the share of flight emissions in past warming)	3
Impact on the remaining emissions budget or for emission reduction paths for the achievement of temperature targets (basis: GWP*)	3
Compensation payments or political intervention on the consumption side, depending on the perspective:	
– Consideration of the temperature effect over time. Emphasis on short-term or short- and long-term or long-term effects, respectively (basis: GWP; time horizon 30 / 50 / 100 years)	3 / 2.3 / 1.7
– Focus on the effects in terms of compliance with emission budgets or emission paths; suitable for mitigation scenarios (basis: GWP*)	3
– Temperature effect of current emissions at a time in the future, depending on the time horizon (30, 50, 100 years, respectively; basis GTP)	1.3 / 1 / 1.1
Political (steering) instruments to promote measures at the operator (Recommendation for the consideration of non-CO_2 emissions: Use GWP* approach)	consider seperately
(Same treatment as greenhouse gases according to the UNFCCC/Kyoto Protocol [GWP_{100}])	[1.7][1]

1 Comparison with the greenhouse gas inventory: For information, the factor resulting from the application of the metric currently used in the UNFCCC protocols and greenhouse gas inventories (GWP_{100} on basis RF) is also listed. This is slightly lower than most other metrics.
If the CO_2 equivalent emissions of the likewise rather short-lived greenhouse gas methane were calculated on the basis of the GWP* approach, this would result in a small reduction in overall emissions in Switzerland, as methane emissions have fallen slightly in the last 10–20 years. In the greenhouse gas inventory, on the other hand, methane emissions are currently equated with around 4 million tonnes of CO_2 emissions, which corresponds to about 8.5% of total emissions.

1. Introduction

Carbon dioxide (CO_2) emissions from global aviation account for 2 to 2.5 percent of global man-made fossil CO_2 emissions (IEA 2018). In Switzerland, national and international air traffic in 2019 accounted for approximately 132.5 percent of the total CO_2 emissions recorded and around 11 percent of all greenhouse gases (CO_2 equivalents) according to the greenhouse gas inventory.[1] Due to the strong growth in air traffic, this share is increasing steadily, despite technical and operational measures to increase efficiency, which, nevertheless, cannot compensate for the sharp rise in demand. By 2018, CO_2 emissions from air travel were already half as high as those from private motorized transport. With the same growth in air traffic and lower emissions from passenger cars, these shares will continue to converge rapidly. The climate impact of air travel is therefore receiving increased attention. However, the impact of the COVID 19 pandemic brought the growth of air traffic to an abrupt halt in 2020 and it is unclear how its extent will develop in the near future and whether the previous growth rates will be achieved again.

In addition to CO_2, air traffic emissions contain various other components that have an effect on the climate, in particular water vapour, nitrogen oxides (NO_x), sulphur dioxide (SO_2) and soot. While CO_2 emissions and their impact on the climate are well known, information on the climate impact of these non-CO_2 emissions is subject to great uncertainty and is based on estimates from comparatively few studies.

The climate impact of non-CO_2 emissions from aviation is not covered by the greenhouse gas inventory, as these are not greenhouse gases (in the greenhouse gas inventory, aviation emissions are virtually identical to CO_2 emissions). The impact takes place over a relatively short period of time ranging from hours to several years. A comparison with CO_2 is therefore arduous. The Global Warming Potential (GWP)[2] used in the greenhouse gas inventory to calculate the CO_2 equivalents of other greenhouse gases (methane, nitrous oxide, etc.) is not adequate for the short-term effects of such non-CO_2 emissions, but is often used nonetheless due to the lack of alternatives and the desire for a uniform method of calculation.

A recently published, comprehensive study (Lee et al. 2021), which also serves as the basis for the IPCC's 6th Assessment Report, has analysed the effect of the various components in detail. According to cthis, the contrails formed as a result of the emission of water vapour and particles and the resulting persitent cirrus cloud cover cause by far the greatest climate effect of non-CO_2 emissions from air traffic, sa significantly higher effect than that of CO_2, followed by the effects of nitrogen oxides.

Hereafter, the effects of the most important emission components on the climate are briefly described and their quantification and the use of comparative values are discussed.

1 According to Switzerland's greenhouse gas inventory, emissions in 2019, including international aviation, were 42.5 million tonnes of CO_2 or 52 million tonnes of CO_2 equivalents. Emissions from national and international air traffic were approximately 5.8 million tonnes of CO_2 (of which approx. 0.11 million tonnes were national ones) or 5.9 million tonnes CO_2 equivalents. These figures are estimated from the sale of kerosene and aviation fuel at Swiss airports. They roughly represent the emissions from flights from Swiss airports (excluding Basel-Mulhouse) until the next landing. According to the Kyoto Protocol (departures from Switzerland), the CO_2 emissions of air traffic in 2019 were around 13.5% of total CO_2 emissions or 11% of total emissions of greenhouse gases (CO_2 equivalents) relative to the total including international air traffic. By comparison, motorized private transport accounts for 25.5% and 21% of CO_2 and CO_2 equivalent emissions, respectively. According to surveys on traffic behaviour by the FSO (microcensus), the Swiss population travelled approximately 9000 km by airplane per inhabitant per year in 2015. At 90 g CO_2 per passenger and kilometre (average for flights from Switzerland), this corresponds to approximately 810 kg CO_2 per inhabitant per year, or an estimated 6.9 million tonnes of CO_2 for the Swiss population. The 'grey' CO_2 emissions from air travel by the Swiss population thus amount to around 2 million tonnes, compared with the emissions from air travel in the GHG inventory of 5.1 million tonnes in 2015.
If the 'grey' greenhouse gas emissions (caused by the production abroad of goods consumed in Switzerland) and the non-CO_2 effects of aviation are also taken into account, the share of aviation in total emissions is also in the range of 10-15%..

2 The Global Warming Potential (GWP) is calculated from the radiative forcing integrated over time due to a single emission pulse of a certain gas after a certain time, in relation to the radiative forcing of an emission pulse of CO_2 of the same amount. The GWP depends on the time horizon, which is usually set at 100 years (GWP_{100}).

2. The emission components and their mechanism of action

Emissions of sulphur and nitrogen oxides as well as soot lead on the one hand to a direct radiative forcing[3] by reflecting solar radiation or absorption of thermal radiation. On the other hand, these components cause changes in the ozone concentration or – together with water vapour which is also emitted or water vapour from the ambient air – lead to the formation of contrails and high clouds and thus have an additional, indirect influence on the climate. In order to quantify the various climate effects, knowledge and detailed analysis of the numerous chemical and physical processes under different weather conditions in the atmosphere are necessary.

Table 1: Substances emitted by the combustion of kerosene and their effect on radiative forcing or climate.

Emitted substance	Mechanisms of action
Carbon dioxide (CO_2)	• Greenhouse gas effect (warming effect)
Water vapour (H_2O)	• Greenhouse gas effect (warming effect) • Promotes the formation of contrails and can lead to the formation of additional cirrus clouds (causes H_2O saturation and condensation; has an overall warming effect)
Nitrogen oxides (NO_x)	• Increases ozone formation in the short term, ozone acts as a greenhouse gas (warming effect) • Decomposes the greenhouse gas methane (has a cooling effect); decomposition of methane in the long term reduces ozone formation and the water vapour concentration (has a cooling effect) • Leads to aerosol formation (cooling effect) and indirectly influences cloudiness
Soot	• Radiation effect (absorbs solar radiation; warming effect) • Leads to aerosol formation and formation of contrails (warming effect) and indirectly influences cloudiness
Sulphur dioxide (SO_2)	• Radiation effect (reflects solar radiation; cooling effect) • Leads to aerosol formation (cooling effect) and indirectly influences cloudiness

The current state of knowledge on the most important processes and effects varies significantly and the quantitative statements are consequently subject to varying degrees of uncertainty (including ICAO 2016; Lee et al. 2021; EC report 2020; see Table 2).

Table 2: Substances emitted by the combustion of kerosene and the corresponding radiative forcing relative to pre-industrial conditions (in brackets the 90% uncertainty range). Radiative Forcing[4] is increasing from year to year as long as emissions continue to rise.

Component	Radiative forcing for the year 2005 [mW/m^2][4]	Radiative forcing for the year 2018 [mW/m^2][4]
CO_2	+25 (+21 to +29)	+34 (+28 to +40)
Contrails (persistent contrails and cirrus formed from contrails)	+35 (+10 to +160)	+57 (+15 to +100)
NO_x (net)	+13 (+2 to +20)	+17.5 (0 to +30)
by		
• ozone increase	+33 (+21 to +51)	+49 (+32 to +76)
• methane degradation	-13 (-9 to -25)	-21 (-15 to -40)
• ozone degradation via methane	- 7 (-4 to -13)	- 11 (-7 to -20)
• water vapour decomposition via methane	-2 (-1 to -4)	-3 (-2 to -6)
H_2O (emission)	+1.5 (+0.5 to + 2.5)	+2 (+1 to +3)
SO_2 (direct aerosol effect)	-5 (-2 to -13)	-7 (-2 to -19)
Soot	+0.7 (+0.1 to +3)	+1 (+0.1 to +4)
SO_2 (via aerosol formation) and soot via cloud formation	Quantification very uncertain	Quantification very uncertain
Total non-CO2 impacts (net)	**+42 (+14 to +69)**	**+67 (+21 to + 110)**

Source: Lee et al. 2021.

The non-CO_2 effects are strongly dependent on the flight altitude, geographical location, time of day and weather situation. This makes it very challenging to calculate the climate effect. The most important components and effects are (see also Table 1):

The direct radiative forcing or the greenhouse gas effect of CO_2 can be calculated relatively accurately from the fuel consumption and the carbon content of the fuel.

3 Radiative Forcing (RF) is the change in the net radiation flowing towards the Earth's surface at an altitude of about 10 km above sea level (tropopause) due to internally or externally induced changes in radiation conditions in the Earth's atmosphere (see IPCC AR5 WGI Box 8.1, www.ipcc.ch).

4 The values given correspond to the Effective Radiative Forcing (ERF), which takes into account adjustments in the lower atmospheric layer (troposphere), in contrast to Radiative Forcing (RF), , which only allows for adjustments in the stratosphere. In this paper, the ERF is used to represent the radiative forcing, which takes into account the different effect of the RF of the different components on temperature. ERF values were also used for the calculation of GWP.

In the formation of contrails, a distinction is made between the effects of persistent linear contrails and of high cirrus clouds that are induced by them. Both have a warming effect, the latter having a much greater impact. In recent years, it has been possible to simulate the coupling and feedback effects more and more accurately in climate model calculations.

Nitrogen oxides (NO_x) influence the concentrations of ozone and methane, with various effects, both cooling and warming. These effects depend on the location of the emission and the existing background concentrations of NO_x. The warming and cooling effects are similar in magnitude but occur at different times and therefore do not simply cancel each other out. Estimated values for the individual effects and the overall effect are available here.

Sulphur-containing aerosol particles and soot have – in addition to their influence on the formation of contrails – a direct radiation effect: soot causes heating, sulphur causes cooling. The magnitude of the respective climate effect is known.

Possible effects of sulphur dioxide and soot on the change in general cloud cover (in addition to contrail effects) have hardly been investigated and are poorly understood. The data in the literature vary widely and there are no integral estimates yet.

As can be seen from Table 2, the contrails and induced cirrus clouds are considered by far the most important effect of non-CO_2 emissions.

3. Different characteristics make comparative calculations difficult

Different life span

The various emission components of air traffic cause disturbances of varying duration. While the climate impact of contrails and the emission of nitrogen oxides, soot and sulphur fades after a few hours up to several years, a substantial part of CO_2 emissions remains in the atmosphere for centuries to millennia.

A significant difference between CO_2 and the other short-lived substances becomes apparent when emissions from aviation are assumed to stabilize: the concentration and climate effect of the short-lived substances remain constant after a few years and subsequently no longer cause additional warming. However, even with constant emissions, CO_2 continues to accumulate in the atmosphere and continues to heat our habitat continuously. In order to stabilize the climate impact of aviation, CO_2 emissions would therefore have to be reduced to net zero. The emissions of short-lived substances, on the other hand, ‘only’ need to be stabilized; a reduction would have a cooling effect compared to today. A reduction of non CO_2 emissions, on the other hand, results in a reduction of the climate impact.

In the case of CO_2 a reduction requires ‘negative’ emissions, e.g. a removal of CO_2 from the air. A reduction in radiative forcing, which is probably necessary to meet the 1.5 °C target, can therefore be achieved both by reducing non-CO_2 emissions – compared to today – or by negative CO_2 emissions.

Spatial differences

A challenge in calculating the climate impact of non-CO_2 emissions is the varying effect of the different emissions depending on environmental conditions such as humidity or background concentration. In addition, there is the different distribution of non-CO_2 emissions. For example, the effect on ozone has a regional to hemispheric distribution, whereas the effect of contrails is concentrated on the main flight paths. Unfortunately, the literature on this issue is limited (e.g. Schumann & Mayer 2017) and results are inconsistent. Nevertheless, a regionally different heating pattern due to spatially inhomogeneous radiation changes is hardly noticeable.

4. Estimation of the overall climate impact of emissions from aviation

Currently, greenhouse gas inventories under the UNFCCC only cover greenhouse gases. Since CO_2 is the only relevant greenhouse gas in aircraft emissions, the CO_2-equivalent emissions practically correspond to CO_2 emissions. The climate impact of non-CO_2 emissions is not accounted for. Efforts are increasing to include these emissions as well.

Until now, the CO_2 emissions were usually multiplied by a conversion factor to estimate the total climate impact of air traffic. This factor can be determined on the basis of different measures of the climate impact of non-CO_2 emissions. The factors for the different measures are listed in Table 3.

The comparison of the climate impact of CO_2 and short-lived non-CO_2 emissions is generally difficult and associated with relatively large uncertainties. The GWP_{100} benchmark used in the Climate Convention and the greenhouse gas inventories is hardly suitable for this purpose, as it is based on greenhouse gases that are fairly homogeneously distributed in the atmosphere with a longer residence time (in the atmosphere) and a long-term time horizon of 100 years. Nevertheless, the GWP and similar measures are used due to a lack of better alternatives.

The commonly used measures Radiative Forcing (RF), GWP and Global Temperature Potential (GTP)[5] describe different aspects of climate impact (Table 3). Therefore, it is important that those measures are chosen which most accurately characterize the problem.

Radiative Forcing describes the momentary effect due to the emissions observed since pre-industrial times. However, this measure is not adequate for comparing the effect of current emissions in the future, since CO_2 accumulates and thus the effect of CO_2 emissions compared to non-CO_2 emissions increases over time. The GWP or GTP are used to compare future effects. The GWP calculates the radiative forcing of a one-time emission integrated over a given period of typically 20, 50 or 100 years. It also takes into account short-lived effects by integrating them over time. The GTP calculates the change in temperature caused by a single emission pulse at a given time in the future. Since only the effect in the distant future is considered, this metric practically does not capture the effect of short-lived substances at all when considering longer time horizons (50 or 100 years). Therefore, the choice of the time horizon of GWP or GTP depends on the issue at hand and on the weight given to the warming over the next few decades. With a time horizon of 20 years, the short-lived effects are heavily overweighted, whereas with a time horizon of 100 years they are underweighted (see Figure 1).

Recently, another variable has been described in the literature, the GWP* (Equivalent Warming Potential) (Allen et al. 2018; Cain et al. 2019), which takes into account the fact that short-lived effects – in contrast to CO_2 – no longer cause a temperature increase when emissions remain constant and the induced temperature change mainly depends on the change in emissions. The GWP* is greater than zero if emissions of short-lived substances increase and less than zero if emissions of short-lived substances decrease. The GWP* is designed to calculate remaining emission budgets for meeting specific temperature targets or the effect of emission reduction paths. The GWP* is relatively independent of the time horizon (see Figure 2).

The metrics and the estimates of the corresponding conversion factors are presented in Table 3.

Table 3: Most common conversion factors in the available literature for calculating the total climate impact of aviation emissions compared to the climate impact of CO_2 alone.

Metrics used	Content	Conversion factor (estimated value)
Radiative Forcing (ERF)	Instantaneous radiation effect due to previous and current emissions	3[6]
Global Temperature Potential (GTP)	Temperature effect of a current emission pulse after x years	20 years: ~ 1.3 50 years: ~ 1 100 years: ~1.1
Global Warming Potential (GWP)	Over the next x years integrated radiative forcing, which results from a current emission pulse	20 years: ~ 4 50 years: ~ 2.3 100 years: ~ 1.7
Equivalent Warming Potential (GWP*)	Global temperature change caused by changes in emissions of short-lived substances.	~ 3

Sources: Lee et al. 2021; Allen et al. 2018.

5 The Global Temperature Potential (GTP) describes the current effect of today's emissions on temperature at a certain point in the future compared to emissions of the same amount of CO_2. The GTP depends on the time horizon under consideration.

6 In the literature often referred to as radiative forcing index..

Hereafter, the most important questions and the choice of the appropriate factor are briefly discussed. It should be noted that the mentioned factors change over time, also depending on CO_2 reduction measures (see Table 5). If current technology is used, the factor will decrease in the longer term as CO_2 is accumulated. However, the factor could also increase with the use of alternative fuels that are partially or completely CO_2-neutral, such as bio-kerosene or synthetic kerosene, since the formation of contrails or cirrus trails does not decrease to the same extent as CO_2 emissions. When using GWP*, the factor must also be adjusted if the rate of change of non-CO_2 emissions changes, e. g. if the increase in emissions becomes weaker.

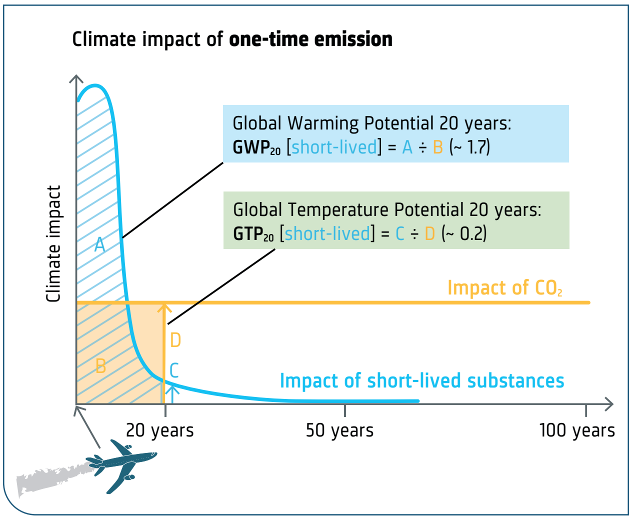

Figure 1: Illustration of the calculation of the climate impact of a one-time emission: Calculation using the Global Warming Potential (GWP) and Global Temperature Potential (GTP) for short-lived and long-lived climate-relevant substances (for the long-lived CO_2 is used as an example). The GWP and GTP over 100 years are calculated in the same way as the GWP and GTP over 20 years.

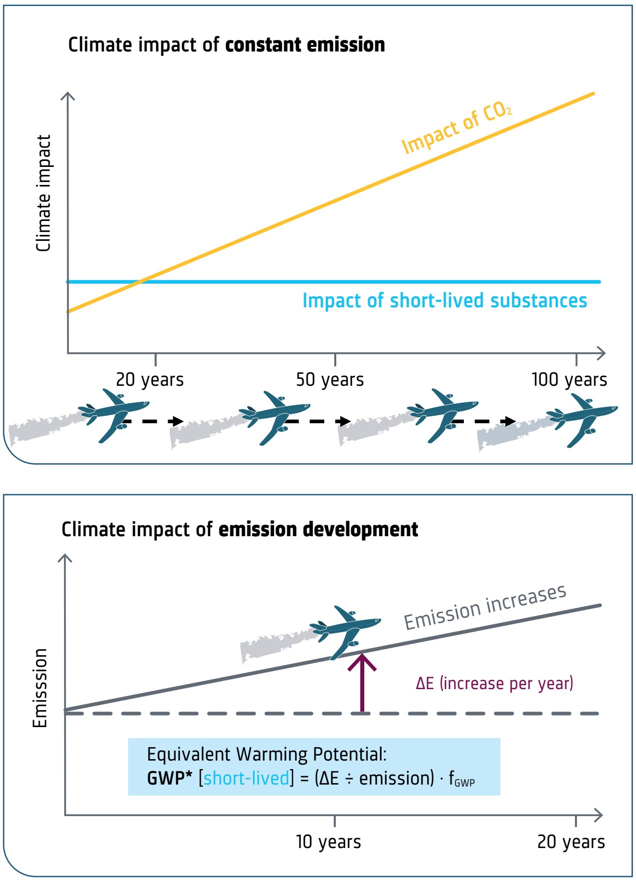

Figure 2: Climate impact of constant emissions:
Above: Climate impact of constant emissions of short-lived and long-lived substances (using CO_2 as an example).
Below: Calculation of the Equivalent Warming Potential GWP* based on the emission development of short-lived substances (ΔE: Development of emissions over the past years; f_{GWP}: Weighting factor, depending on the Global Warming Potential of the short-lived substance).

5. Choice of metric

Current climate impact

The current radiative forcing is a useful measure of the effect of past emissions. Based on current estimates (state 2018), the radiative forcing index is approximately a factor of 3 (see Table 3).

Achievement of a temperature target

For the question of what influence current emissions have on the stabilization of temperature, the temperature influence at the time when this goal is to be achieved is primarily decisive. This is expressed by the GTP.

However, GTPs and GWPs are not suitable for the question of how emissions must develop in order to achieve this goal, as they are not intended to describe declining emissions or short-lived substances. For this question, the GWP* was developed, which allows the comparison of short-lived and long-lived substances and can capture the effect of different emission paths and, above all, reduction paths or reduction scenarios (Allen et al. 2018). The GWP* approach is also the most suitable metric for calculating emission budgets – e. g. the amount of emissions still available to achieve a temperature targetor the calculation of CO_2 equivalents in the greenhouse gas inventories.

Compensation for current emissions

In the context of compensation measures for current emissions, the choice of the appropriate metric depends on value judgements, e. g. the (socio)political choice of which aspect(s) to focus on. In case of compensation of the future effect of current emissions, GWP and GTP are the most appropriate measures, while in the case of accounting for short and long-term effects, GWP is the most appropriate representation. The GTP covers almost exclusively the future impact, according to the chosen time horizon. The time horizon of 100 years is usual for the long-term view. Here, the main consideration is that some effects disappear relatively quickly, and are therefore less significant in the longer term. If, on the other hand, the focus is on developments in the near future, e. g. the next few decades or the time horizon 2050, this would correspond to about 30 years. A time horizon of 50 years would give roughly similar weight to short and long-term effects.

Table 4: Estimated values of the conversion factors for the calculation of the total CO_2 equivalent emissions from the CO_2 emissions, depending on the time horizon under consideration; calculated on the basis of the Global Warming Potential GWP or the Global Temperature Potential GTP.

Approach (points of view in the foreground)	Time horizon	Factor based on GWP	Factor based on GTP
• Time horizon of the net zero target (2050) • Time horizon relevant for the current population • Disproportionate weighting of the short-term effects of non-CO_2 emissions	30 years	3	1.3
• Similar weighting of the short and long-term effects	50 years	2.3	1
• Disproportionate weighting of the long-term impact • Focused on effects that are irreversible over a long period of time	100 years	1.7	1.1

Source: Lee et al. 2021.

Table 4 shows the corresponding estimated values of the conversion factors for the different time horizons, calculated on the basis of the GWP and the GTP, taking into account the effective temperature impact.

Impact of political interventions

In the case of policy interventions, the application of general conversion factors for the climate impact of non-CO_2 emissions may, under certain circumstances, lead to inappropriate incentives.

Political interventions on the consumption (demand) side, such as a levy on air tickets, are primarily aimed at reducing air traffic. These should lead to a reduction of all emissions and climate impacts and are therefore the most effective measure for reducing emissions. The use of a constant factor (according to Table 4) to calculate the total climate impact makes sense in this case. The choice of metric in turn depends on the weighting of the various aspects, as described in the previous section.

In the case of political interventions at the operator's end (supply side), however, such as an emissions trading system or the global system CORSIA (ICAO 2016), inadequate incentives may also arise under certain circumstances, since the effect of technical or operational measures on the various emission components can vary greatly (see Table 5), thus changing the conversion factor. For example, technical measures that lead to a reduction in fuel consumption can, under certain circumstances, increase NO_x emissions, while more or less CO_2-neutral fuels such as biofuels or synthetic kerosene are used, the CO_2 effect is greatly reduced but the non-CO_2 emissions and their effect may remain similar. Flying around humid air masses or at a lower flight altitude can reduce the formation of contrails, but at the same time it increases fuel consumption and thus CO_2 emissions. Since the effect of measures does not affect CO_2 emissions and non-CO_2 emissions equally, it is advisable to consider CO_2 emissions and non-CO_2 emissions separately. The GWP* approach is probably the most suitable for assessing the effect of non-CO_2 emissions, as it burdens emissions growth and ‘rewards’ reductions in emissions.

Table 5: Effect of technical or operational measures in aviation on the climate impact of CO_2 or non-CO_2 emissions (contrails, NO_x, SO_2, soot).

Group of measures	CO_2 effect	non-CO_2 effects
Use of bio-kerosene or synthetic kerosene	decreases	tending to decrease slightly
Reduction in fuel consumption (per tonne or passenger-kilometre)	decreases	decreases
Avoiding humid air masses	increases	decreases
Hydrogen propulsion (smaller aircraft, short distances)	decreases	increasing
Kerosene-electric hybrid (with renewable electricity; short distances)	decreases	decreases

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