Evaluation of KLM's Climate Plan

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Centre for Sustainability, Tourism and Transport

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[1] This refers to the document titled: Afspraken over de communicatie en woordvoering m.b.t. onderzoek voor Milieudefensie "Evaluation and risk assessment of KLM's climate plan".

Executive summary

KLM is one of only three airlines in the world to have a dedicated Climate Plan and one out of 13 with a Science Based Target initiative (SBTi) approved climate target. This situation enables a unique option to assess what such a plan means with respect to setting targets, the scope and effectiveness of measures, and the underlying assumptions of such a plan. It also allows to inform a discussion of a just mitigation of climate change.

Air travel has become part of modern life for the richer 10% of the global population. Also, it has brought benefits and connectivity to many people and supported economies. However, the fast growth of the sector also has its issues. The disadvantages of air travel have been highlighted by many scientists, policymakers and even some within the sector. To illustrate this, the CEO of Airbus, Guillaume Faury, told the audience during an Airbus Summit in November 2022, "that the aerospace industry is not moving fast enough to address climate change and promote its drive toward emission-reductions targets" (Flottau, 2022, p. 1).

Our client, Vereniging Milieudefensie, asked us to assess KLM's Climate plan, its targets, its measures, and the climate justice aspects of both. The main research question was *how does the KLM climate plan realistically relate to the emission reduction targets of a general 1.5°C climate scenario, Dutch policy, principles of climate justice, and legal climate obligations?*

In our research, we applied a mixed methods approach consisting of a literature study (both scientific and professional), data analyses (including data from FlightRadar24, OAG, CH-Aviation and several statistical offices at international and national level), an analysis aiming to find the outcomes and assumptions of aviation climate mitigation scenarios and policies, and a qualitative analysis of the mitigation of aviation through developing and applying an 'airline climate justice framework'.

The KLM Climate plan is built around a 'science-based' – in the language of the SBTi - short-term target of a carbon intensity improvement by 30% between 2019 and 2030. SBTi registered KLM's target and added it to its list of companies. SBTi does not require an absolute emission target, even though climate science does recommend one. The logic behind this is that SBTi determines a sector emission reduction scenario and deducts the carbon intensity for 2030 from this. The assumption is that if all airlines would stick to this target, the overall emissions of the pathway will be reached. This is mathematically only true if all airlines in the world on average stick to SBTi's assumed (moderate) growth path.

KLM combined their growth ambitions with the 30% intensity target to arrive at an absolute emission reduction of 12% between 2019 and 2030. The latter is in contrast with reductions of between 40% and 55%, deemed necessary by climate science and the IPCC for all sectors, and agreed upon in Paris in 2015. Therefore, KLM's statement that its target is 'Paris-compliant' might be true within the SBTi scenario, but is at odds with the wider climate science. This discrepancy is mainly caused by the idea that aviation is a 'hard-to-abate' sector, thus requiring a higher share of the world's remaining carbon budget. However, the hard-to-abate status does not consider wider considerations of climate justice both in terms of utilitarian and sufficientarian justice. Taking account of these forms of justice challenges the SBTi and sector air transport growth ambitions.

In short, the outcome of our research is that aviation sector climate targets, including those of KLM, are unable to provide the absolute emission reductions deemed necessary by the IPCC scenarios. These targets cause aviation to overshoot its carbon budget share by 200% to 300%. Furthermore, KLM's 30% carbon intensity target and related 12% reduction of total emissions in 2030 with respect to 2019 is, also according to KLM's Climate Plan, difficult to achieve. KLM's emission reduction strategies comprise three main measures ('activities' in KLM's language): sustainable aviation fuels (SAF) blending, efficient operations & logistics, and technological development mainly through fleet renewal. This research found that the actions KLM proposes will realise two-thirds of the carbon intensity target and hardly reduce absolute emissions. The contracted, thus certain, measures will enable only half of the intensity target and cause a growth of KLM's overall emissions by almost 6%. The only way to achieve climate just, absolute emission reductions, is by reducing the growth of or degrow the transport volume in 2030 by up to about a quarter of the 2019 volume, with probably further necessary reduction after that year.

One important reason for the growth of KLM is its strategy to further develop its hub & spoke network, now already showing a high share (60%) of transfer passengers. Transfer passengers use Schiphol Airport as a place to switch between flights, but they do not come from or stay in the Netherlands. We found that an average transfer passenger causes more than double the CO_2 emissions compared to an OD-passenger, which is a passenger travelling to or from the Netherlands. KLM's pricing policy is aimed at attracting large volumes of transfer passengers. Combined with the fact that even passengers themselves report substantial shares (18-31%) of their flights to be 'non-essential' shows that there is ample room for a strategic change and make transport volume development a fourth pillar of the mitigation strategy. KLM's current pricing strategy aims at expanding the transfer market and its economic growth and turn-over, which reduces the overall passenger route efficiency by some 11-12% and adds to overall emissions of the travel. Our tentative analysis shows opportunities to substantially reduce the number of transfer passengers while retaining most of the current OD-connectivity and the viability of KLM's OD-network.

On the more positive side is the fact that KLM has a climate plan. Also, KLM's efforts to be a frontrunner in sustainable aviation fuels and the fact that they performed a risk analysis of not being able to achieve the 30% carbon intensity target are positive contributions, as is acknowledging the challenges caused by the limitations of acquiring sufficient SAF. However, looking at the current performance and policies, the picture is more nuanced. For instance, the fuel efficiency of KLM's current (2019) fleet is rather average. Also, we found the fleet renewal policy to be rather moderate. KLM is generally not an airline that buys the first aircraft coming from the production line of a new type. KLM is relatively often one of the last customers of an existing type, sometimes while newer types already entered the market. In this way KLM missed an additional 6% efficiency gain in 2030, out of the 12% fleet-renewal-related gains claimed in KLM's Climate Plan. An important aspect of fleet renewal to combat emissions is that the current fleet renewal, when finalised by about 2035, will represent a one-off gain in efficiency. After 2035, it is unlikely that another major fleet renewal programme will be fully delivered before 2050, when, according to climate science, emissions should be reduced to zero.

Another issue exists in difficulties to produce enough SAF. KLM is aware that biomass-based SAF will run into ever more severe resource issues. Therefore, KLM proposes to switch to the environmentally superior alternative of SAF-E (e-fuels) as soon as possible, but is aware of the high renewal energy demand for producing these. KLM frames these limitations as an economic issue of supply and demand, but fails to discuss them in terms of climate justice and equity. Though KLM is aware of the difficulties in securing sufficient SAF to achieve its 2030 target and to become zero-emissions by 2050, it does not draw conclusions regarding the obvious limitations to its growth potential because of this. Therefore, KLM might also discuss the supply-driven part of the rise in demand for flying from the vantage point of a for-profit business, for instance by being clear about possible efforts to decouple volume growth from the company's revenue and profit.

Finally, KLM has no specific non-CO_2 climate impacts reduction policy, though it is involved in some research on this topic. Non-CO_2 climate impact mitigation could be accomplished in straightforward ways by means of reducing transport volume. The application of SAF leaves most non-CO_2 emissions as they currently are, though flights with 100% SAF would create opportunities to more substantially reduce non-CO_2 impacts.

One commonly mentioned frame is that of aviation being a ‘hard-to-abate’ sector. This means that given a certain air transport growth, the technical means to reduce emissions are more limited compared to other sectors, and thus aviation should be eligible to get a higher share of the remaining carbon budget. However, this ignores a just balance towards the other side of the equation: how important is every passenger-kilometre flown compared to the devastating impacts climate change is already causing. In a climate just world, lack of technology should be weighed against the possibility to remove the most harmful and least essential parts of demand and supply.

Based on existing climate justice science, we developed an airline climate justice framework. From this framework, we identified that procedural justice and distributional justice are at play. Of distributional justice, both utilitarian and sufficientarian justice are considered. As regards utilitarian justice, we analysed the distribution of the shares of the remaining carbon budget, renewables (for e-fuels) and resource/land use (for other SAFs). Regarding sufficientarian justice, we identified the share of essential flights and demand growth assumptions as useful metrics to discuss. By providing the various arguments, we inform the political discussion. Therefore, we do not draw further conclusions from this part of the analysis.

The overall conclusion is that, though KLM’s Climate Plan is rather unique in the world of airlines, the mitigation actions it proposes do not enable the airline to achieve a true and equitable mitigation strategy that is aligned with the 1.5 °C target recommended by science and IPCC. The climatic effectiveness and credibility of KLM’s Climate Plan might gain from a discussion about volume growth, network structure, and hub & spoke strategy, which would have to be removed out of the taboo sphere.

Contents

List of abbreviations and definitions

Abbreviation/term	*Definition*
ATC	Air Traffic Control
BAU scenario	'Business-as-usual' scenario, a scenario assuming all policies remains they are and other influencing factors develop as 'normal' or 'expected'.
Carbon intensity metrics	The carbon intensity metrics show the CO_2-missions per unit of an activity. For aviation, three definitions are used: kg/pkm kg/skm and kg/rtk. Units can vary as sometimes not kg but grammes or pounds are used for the emissions part and the distance can be in km, nautical miles, statue miles or just miles. The difference between pkm and skm is the seat occupation rate: pkm=sor*skm. The difference between pkm and rtk is in the assumed weight equivalent of freight versus a passenger. In IATA statistics the ratio appears to vary between some 80 to 100 kg per revenue ton kilometre (IATA, 2020).
Climate justice	Climate justice is "justice that links development of human rights to achieve a human-centred approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" (Al Khourdajie et al., 2022, p. 2913).
CO_2 emissions	In this report we only look at direct CO_2 emissions of burning fuel to fly aircraft
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation, developed and implemented by the ICAO.
Direct flight	A journey that comprises only one flight segment.
ICAO	International Civil Aviation Organisation, Montreal, Canada.
Indirect flight	A journey that comprises two or more flight segments.
Journey	A full journey is the travel between two airports, regardless of the number of flight segments. For instance, a trip from Amsterdam to Madrid, both the direct flight from AMS to MAD as the indirect flights through Paris (AMS-CDG-MAD) are considered as a 'journey' in this report
KLM group as applied in this study	This comprises KLM and KLM CityHopper. So, it excludes KLM UK, Transavia and Air France.
KLM-passenger	A passenger that makes use of KLM as operator for at least one segment of the whole journey.

Non-CO_2 impacts	The non-CO_2 impact of aviation involve "nitrogen oxides (NO_x), water vapor (H_2O), soot and sulphate aerosols, and increased cloudiness due to formation of linear contrails and subsequent cirrus clouds" (Fuglestvedt et al., 2023, p. 5).
OD-passenger	Origin Destination passenger. Each passenger taking a journey that starts or ends at Amsterdam Schiphol Airport (AMS)
Pkm	Passenger-kilometre
Rtk	Revenue ton-kilometre
SAF	Sustainable aviation fuels
SBTi	Science Based Targets initiative
Scenario	A scenario is "a coherent, internally consistent and plausible description of a possible future state of the world" (IPCC, 2007a, p. 145).
Segment	A part of a journey involving a direct flight
skm	Seat-kilometre (unit for the of capacity an airline)
Skm	Seat-kilometre
Tourist	"A visitor (domestic, inbound or outbound) is classified as a tourist (or overnight visitor) if his/her trip includes an overnight stay" (UNWTO, 2016).
Transfer passenger	Each passenger taking a journey that only makes a transfer at Amsterdam Schiphol Airport (AMS), but flies from and to another airport.

1 Introduction

Key Findings

1. The main research question of our study is: how does the KLM climate plan realistically relate to the emission reduction targets of a general 1.5°C climate scenario, Dutch aviation policy, principles of climate justice, and legal climate obligations?
2. The creation of just distributions of global aviation consumption and procedures for mitigating its environmental impacts is to be decided within political arenas, and not by scientists.

1.1 Context of the study

Aviation is widely considered an economically and socially (Klöwer et al., 2021b) beneficial sector. This positive contribution of aviation is undisputed, but it must be weighed against its averse environmental impacts relating to human health, ecosystems, and climate. Particularly, the justice implications in relation to the distribution of aviation production and consumption and the related environmental impacts, and the procedural arrangements shaping its environmental governance, are rarely discussed. Most studies and policies contain implicit assumptions about these. What our report intends to provide is to shed light on key distributive and procedural justice elements relevant to aviation. It informs and contributes to debates about current aviation-related environmental policies in the light of the anticipated (future) growth of the aviation industry and the mitigation methods it proposes.

KLM is rather unique to have a climate plan as we identified only two other airlines with a comparable document: JetBlue and Lufthansa. The fact that an airline drafts such a plan, means it sees the issue of climate change is real and of importance for the airline's strategy. However, the value of such plans depends on the validity of the analyses and the effectiveness of the mitigation measures it proposes. The fact that KLM has a Climate plan, provides us with a unique opportunity to critically assess it ideas, impacts, assumptions and outcomes. Of course, we tried to be as objective as possible, to assess the climate plan, and the SBTi (Science Based Target initiative) target setting it is based on. By doing so, we hope to contribute to a more fact-based dialogue about airlines roles in (mitigating) climate change and to extend the scope of ongoing discussion with elements of climate justice and equity both with respect to the growth of air travel as well as the resource demand of proposed mitigation solutions.

We analysed KLM's Climate Plan, second version (KLM, 2023a), with a specific focus on the stated 2030 intensity target of 30%, the absolute emission reductions in 2030, and with a long-term outlook to 2050, required to fit in a 1.5 °C climate scenario. KLM's target is based on guidelines from SBTi (SBTi, 2023a) and accredited by SBTi. In its Climate Plan, KLM claims that because of the intensity improvement of 30% and a continued moderate growth of 1.95%, their total emissions will reduce by 12% by 2030 compared to 2019. Recently, KLM (2024) made this 12% absolute reduction an additional target, not required by SBTi. The KLM-proposed 12% absolute emissions reduction contrasts with a range of Paris Agreement-compatible emission reductions following from recent climate litigation lawsuits, for instance, the 45% emissions reduction imposed on Shell by the court of justice in The Hague (May 26, 2021).

The Dutch aviation policy has set a CO_2-ceiling or cap, in which 2030 emissions become equal to those in 2005 (Ministerie van Infrastructuur en Waterstaat, 2020), which implies a reduction of 8% compared to 2019. After 2030, emission reductions should accelerate and reach half of the 2005 emissions by 2050 and zero by 2070. Because almost all other sectors need to reach zero by 2050, this shows the legislative exception aviation is currently granted. In section 6.4, we further analyse this aspect of target setting. Given this situation, it is important to evaluate the facts that may feed political discussions about whether the aviation industry's longer term emission reduction/net-zero pathway and KLM's corresponding emission reduction goals and actions towards 2050 are reasonable, adequate, and trustworthy.

1.2 Goals and research questions

Our study has three aims: (1) to evaluate KLM's goals for emissions and emissions intensity, which are based in SBTi, against a range of 1.5 °C scenarios; (2) assess the (realism and adequacy) of emission mitigation measures KLM (2023a) proposes and if these 'reasonably'[2] enable their goals for 2030 and 2050; and (3) look at the equity and climate justice implications of stated goals.

We examine the feasibility and effectiveness of KLM's proposed climate mitigation plans considering the remaining emissions budget and its current business model, integrating aspects of distributional and procedural justice in our analysis. And that is what science can ultimately deliver. **The creation of just distributions of global aviation consumption and procedures for mitigating its environmental impacts is to be decided within political arenas, and not by scientists.** We therefore recommend all readers of this report to take full responsibility for their opinions about the (in)justice of current distributional and procedural aspects of the production and consumption of aviation and its governance.

The **main research question** is: ***how does the KLM climate plan realistically relate to the emission reduction targets of a general 1.5°C climate scenario, Dutch aviation policy, principles of climate justice, and legal climate obligations*?**

This question can be divided into the following sub-questions:

1. What are the emission pathways and emission reduction targets of a 1.5 °C future and how do these relate to the aviation specific targets as proposed by the sector, governments and SBTi?
2. How adequate are KLM's proposed measures? What do they mean for KLM's total emissions and carbon budget up to 2050?
3. How do KLM's climate target and climate plan relate the Dutch aviation and climate change policy?
4. What are the climate justice implications of KLM's climate plan?

Chapter 7 lists the answers to these questions and provides some general conclusions.

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[2] Reasonable describes how likely it is or 'in accordance with reason'.

1.3 Guide to the reader

This report consists of seven chapters and a couple of Annexes. Section 2 gives some background to the methods applied. These involve the scenario method (2.2) as background for the discussion of scenarios in chapter 3, the method to assess climate justice (2.3), the scope of the assessment (2.4) and the data models used (2.5).

Chapter 3 explores the climatic impacts of aviation and shows the main mitigation options in aviation (3.1), followed by a description of aviation in climate policy at the global, European and Dutch level (3.2). In 3.3 aviation climate mitigation scenarios are investigated. Section 3.3.1 provides an overview of the scenarios and section 3.3.2 plots their pathways including one recommended by climate science. The goal-setting scenario published by SBTi (2023b) and the scenarios this one is based on are discussed in 3.4, including the division of responsibilities between industry and government (3.4.1), the ICCT Vision 2050 Breakthrough Scenario (3.4.2) and its underlying IEA scenarios (3.4.3). Section 3.5 discusses the policy choices assumptions in the scenarios.

Chapter 4 dives into the target setting by KLM for SBTi. The quality of the target with respect to the overall climate mitigation goals is discussed in section 4.2. Then we will assess whether KLM has followed the SBTi pathway (4.3.1), compare KLM to other SBTi-accredited airlines (4.3.2), and finally discuss the role of the hard-to-abate principle of KLM's targets (4.3.3). The 'feasibility' of a target and the arguments for politically discussing feasibility are discussed in section 4.4.

In chapter 5 we evaluate the climate plan of KLM. Section 5.2 describes KLM's climate plan and its assumed effects, the following sections assess the three main elements of KLM's Climate plan: fleet renewal (5.3), operational efficiency gains (5.4) and SAF (5.5). Section 5.6 discusses the consequences of the way in which KLM handles non-CO_2 impacts.

Chapter 6 assesses the KLM climate plan against an aviation climate justice framework. It provides data about inequalities regarding KLM's current business model, current emissions budget and proposed mitigation in terms of how the benefits and burdens are distributed. After presenting the airline climate justice framework (6.1), we first describe the distributional utilitarian aspects of justice (6.2), including the share of the remaining carbon budget (6.2.1), how essential flying is (6.3.2), the provision of air travel to the least developed countries (6.3.3) and general considerations of demand generation (6.3.4). Section 6.4 provides some insights regarding procedural justice, and particularly the hard-to-abate principle. Finally, section 6.5 provides an overview of these issues with respect to KLM's Climate Plan.

Finally, chapter 7 gives the conclusions and answers to the research questions of this study.

2 Methods

Key message: this chapter describes the methods used, which comprise literature study, scenario assessment, data analyses, justice assessment and the scope of the study.

2.1 Introduction

This chapter shortly explains the methods we used in this research. The study is based on a literature review exploring both scientific and professional (grey) literature. This literature covers both theories and the application of the scenario method (see section 2.2 and chapter 3), climate justice (section 2.3, and 6.1 and chapter 6) and more general literature about the relationship between aviation and climate change and its mitigation. The scope of our study is highlighted in section 2.4. Furthermore, we analysed data (2.5) from a range of data sources, the most important ones being OAG Traffic Analyzer data (OAG, 2024) for the analysis of markets served by KLM and journeys (multiple leg trips) travelled by KLM's passengers, aircraft fleet data (CH-Aviation, 2024), and 2019 flights through Schiphol Amsterdam airport from Flight Radar (FlightRadar24 AB, 2021).

Overall, we applied a mixed method comprising literature study, scenario assessment, data analyses, and a justice assessment method. Section 2.4 gives some details about the scope of the study.

2.2 Scenario method

The scenario method is commonly used to explore the future. The IPCC defines a scenario as "a coherent, internally consistent and plausible description of a possible future state of the world" (IPCC, 2007a, p. 145). In other words, based on a set of assumptions and a systematic description of the system you develop a scenario for, a consistent and logical future state of that system can be developed and described. There are several groups of scenarios. For example, scenarios can be 'exploratory' versus 'normative', or 'quantitative' versus 'qualitative' (Gordon, 1992; van Notten et al., 2003).

Exploratory scenarios, also called 'what-if' scenarios, describe plausible coherent futures based on a set of assumptions. Often, future studies start with describing a 'business-as-usual' (BAU) scenario, which basically assumes that policies remain as they are now, and no other disruptive external developments will occur. Such scenarios come closest to a projection of a future. Yet, while people often understand them as being 'the most likely', this is not the case. Policies always evolve and external forces always develop in an unexpected way thus changing the scenario outcome.

By contrast, **normative scenarios** describe 'desired futures', for example a world without any CO_2 emissions left. Subsequently the scenario is described in terms of assumptions, for instance about technological developments and policy measures needed to reach the desired future. Often, the term 'backcasting' scenario is used (Prideaux et al., 2003). Backcasting is a powerful approach in environmental studies of complex systems (Dreborg, 1996).

Another scenario division is quantitative versus qualitative. Qualitative scenarios are purely based upon qualitative reasoning and can be useful to describe certain storylines (Riahi et al., 2007). Quantitative scenarios generally use models to describe a system and assess what happens when assumptions change. As most scenarios describe the dynamics – the changes - of a system over time, such models often constitute simulations (Peeters, 2013).

In socio-economic studies, the time horizon of scenarios tends to be short to medium (up to a couple of decades), while in climate scenario studies, centuries are not uncommon. Most of the climate mitigation scenarios for aviation have a time horizon of 2050 (ATAG, 2021; EASA et al., 2023; Van der Sman et al., 2021). ICAO (2022b) has developed their LTAG (Long-Term Aspirational Goals) scenarios until 2070 and Peeters and Papp (2023) until 2100. For aviation, it is important to look at longer-term time scales, because of the very slow penetration of new technology in the global aircraft fleet (Kallbekken & Victor, 2022) and because CO_2- and non-CO_2-effects have very different timescales (Klöwer et al., 2021b). These are centuries for CO_2 and sometimes only days for non-CO_2. In sum, it is important to emphasise that scenarios are planning tools for the future that make assumptions and their implications explicit.

In their capacity as planning tool, scenarios can be technically assessed, for example to evaluate their feasibility with the purpose of informing policy debates, etc. (see section 3.3.2). But scenarios are also often used as political devices. Important choices about the scope of the system described in the scenario and many assumptions make certain futures seem achievable. However, these scope choices may obscure, for instance, potential disablers of the scenario because of a too narrow scope, or leave potential solutions out of the scope. In such way, certain political solutions may look grave, while they would be more palatable in a system with a wider scope (Andersson, 2020).

For example, a too narrow scope might ignore the availability of certain resources, e.g. renewable energy. In such a case mandating more sustainable aviation fuels (commonly referred to as SAF) might seem a perfect policy, whereas in reality these SAFs may suffer from a lack of renewable energy resources needed for their production at the required scale (see section 5.5). Also, only looking at aviation will make any demand management policy reducing the volume of aviation look extremely undesirable, while deploying a wider scope and incorporating the wider travel and tourism industry may put this in a different perspective. Other parts of this wider industry may take over parts of the economic role of aviation, thus removing most of the socio-economic disadvantages of aviation-related demand management policies.

In this report we will use quantitative results of a range aviation climate mitigation scenarios to show the validity of certain goals in the context of the IPCC scenarios (section 3.3.2). Furthermore, we will assess the storylines behind the scenarios to show the scope and attitude towards technology's solving ability, towards fair resource use and distribution, and with respect to eventual limitations to demand volumes.

2.3 Climate justice assessment method

This section introduces and defines climate justice dimensions. The IPCC defines climate justice as "justice that links development of human rights to achieve a human-centred approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" (Al Khourdajie et al., 2022, p. 2913). Climate justice considers climate change as a moral issue. It pays attention to "how climate change impacts people differently, unevenly, and disproportionately" (Sultana, 2022, p. 118), and seeks to address the resulting injustices in fair and equitable ways, reducing marginalisation, exploitation and oppression. For this report, we conceptualise climate justice for the aviation policy context (hereafter referred to as framework for climate just aviation. Our framework is based on the justice framework designed to guide climate research developed by Zimm et al. (2024) (see Figure 1). This framework supplies five 'policy contexts' of justice the researcher needs to define. These contexts comprise the area, scope, form, metric, and pattern of justice. In section 6.1 we develop a dedicated framework for the aviation industry and an airline (see also Figure 10).

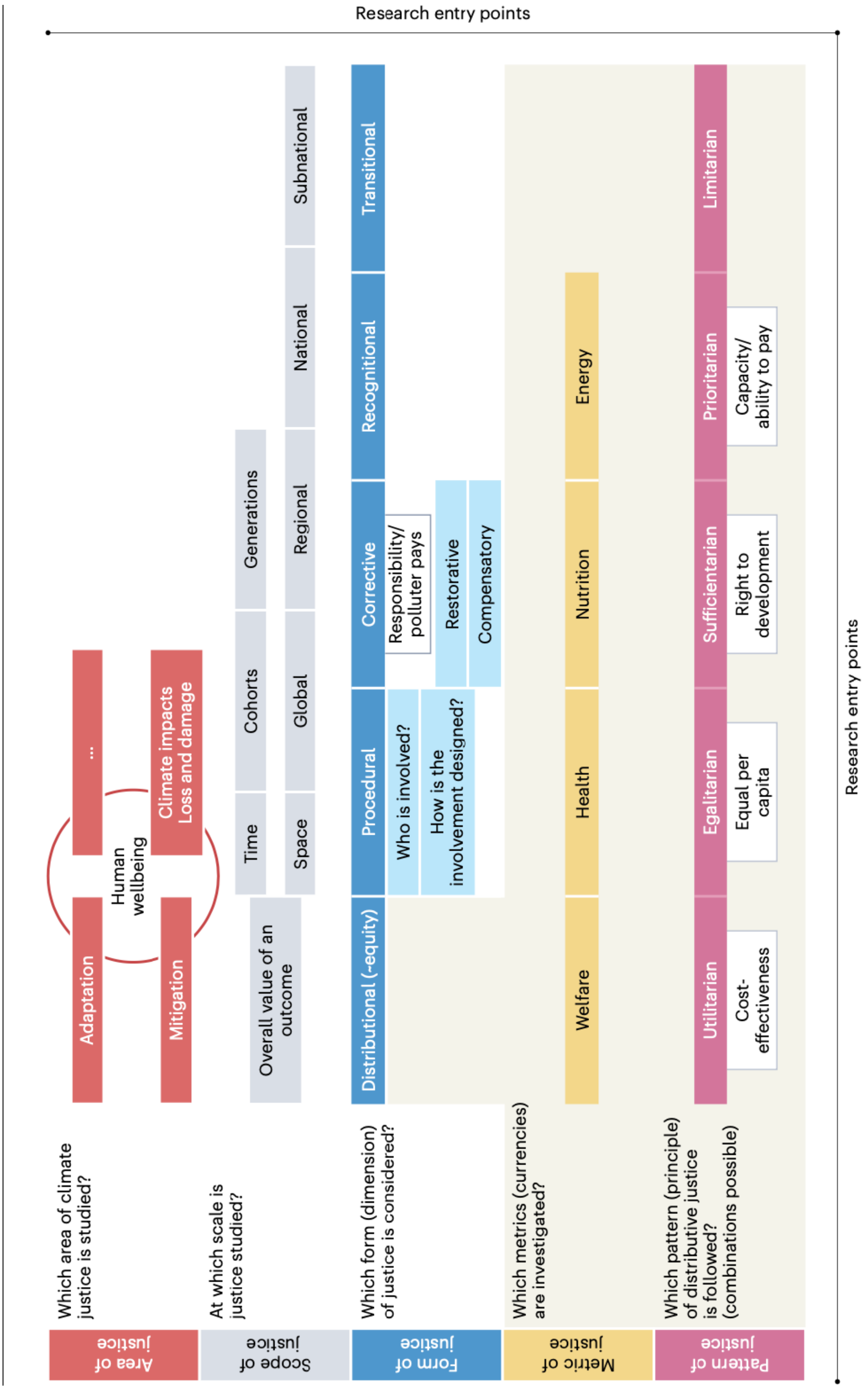

Figure 1: Justice framework for climate research (Zimm et al., 2024, p. 23). Reprinted with the permission (by e-mail of 13-05-2024) by Caroline Zimm.

To analyse the relationship between aviation and climate justice we applied the following main line of assessment:

1. We first draft an aviation climate justice framework based on the general framework developed by Zimm et al. (2024).
2. We determine a general mitigation pathway for all sectors together delivering the Paris temperature goal of 1.5 °C and extract the ‘remaining carbon budget’ (RCB) for the world from this pathway.
3. We then assess global aviation and the shares of RCB, and emissions policymakers assign to aviation and why they chose to do so.
4. An important argument to set relatively mild goals for aviation is the assumption that aviation is hard-to-abate (Bergero et al., 2023). However, in this fourth step we analyse what role climate justice aspects play a role in the hard-to-abate argument, which generally takes business-as-usual demand growth and pure economic values as their starting point
5. We then assess the equity dimensions of the solutions in terms of renewable energy and resource use and consider whether the mitigation measures suffer from the rebound effect (increasing demand rather than reducing total emissions) or consumes large amounts of resources and renewable energy.

A final important note is about what science ultimately can deliver. Whether observed distributions of benefits and costs (in all social and economic terms) are ‘just’, is clearly something to decide within societal and political arenas. Scientists cannot give a final judgement to these. Therefore, we recommend all those readers and users of this report to take the full responsibility for opinions about the justice of certain inequalities and only refer to this report regarding the information the opinion is based on.

2.4 Scope of the assessment

We defined a certain scope for the assessment. The main choices were (unless mentioned otherwise in the text):

- With KLM we mean all activities of KLM and KLM CityHopper, but excluding KLM UK, Transavia and Air France.
- We do not consider other emissions than scope 1 from burning aviation fuel. The scope 3 (lifecycle) emissions from burning jet fuel add between 17.5% (IAEG, 2023), up to 28% (based on data in Table 35 by Klein et al., 2021). The difference is caused by the LCA methods, not by different fuels.
- Furthermore, we ignored the scope 2 and other non-fuel scope 3 emissions. The reason is the relatively small share of these as shown by KLM’s CDP report (CDP, 2024a). This report shows scope 2 to be almost zero and the non-fuel scope 3 to be less than 10%. Furthermore, there is much uncertainty about such numbers as shown by Gössling et al. (2024).
- Also, we do not multiply the direct emissions by a multiplier to arrive at so-called CO_{2e} (CO_2 equivalents) to account for non_CO_2 emissions (see section I.IV in Annex I).
- We consider only passenger transport. The reason is the complexity of adding freight as well. First, the detailed data we have access to does only provide passenger data. Second, the impact of adding the changes in the full-freighter aircraft (only three will be available

in 2030) has no significant impact on our carbon intensity and total emissions calculations. Third, The qualitative descriptions we give regarding the KLM’s business model can hardly be affected by omitting freight because the share of freight in KLM’s yield for passengers plus freight, vary between 8.8% (in 2019) to 10.2% in 2023 and with the note that freight yields rates strongly declined between 2021 and 20234, while those for passengers substantially increased, making it likely the freight share in total yields will further decline.

- Regarding the justice issues, we focus on distributional equity issues for (renewable) energy and resources, which are manly connected to the production of sustainable aviation fuels.

2.5 Data models

In our study we made use of three main data sources:

- Aircraft data from ch-aviation GmbH (CH-Aviation, 2024), which provides current and historic world fleets data, providing many properties from aircraft and engine type to seat numbers per cabin class. The data were primarily used for the analyses presented in section 5.3 about fleet renewal.
- Flight data for all flights to and from Schiphol Airport from FlightRadar (FlightRadar24 AB, 2021), that were acquired for another study (Peeters & Reinecke, 2021), which helped to assess the aircraft kilometres, transport flows and emissions as applied in section 5.3.
- OAG Traffic Analyzer data (OAG, 2024) provide the quantitative base for the analyses regarding passenger behaviour and ticket pricing by KLM passengers. The data were mainly used in section 6.3.1.

Particularly, the data taken from OAG were sometimes rather large. To reduce the complexity and computation power and computational times involved in the analyses, we removed data with only 1 or less passengers per month. This comprised 2.12% of all passengers, but removed 50.6% of all records, thus halving the size of the databases.

3 Aviation and mitigation scenarios

Key Findings

1. None of the aviation scenarios studied achieve the absolute emission reductions as deemed necessary by the IPCC scenarios.
2. Setting only a near-term carbon intensity goal cannot guarantee to keep absolute emissions to stay below a 1.5 °C pathway.
3. SAF, efficient operations and logistics, technological development and, in rare cases, transport volume management are proposed in aviation sector mitigation scenarios as the three main mitigation options for reaching the near term (2030) target. Revolutionary technology like hydrogen/electric propulsion is generally considered to play no major role in 2030.
4. Most aviation scenarios delay emission reduction by 6-10 years, and do not achieve zero-emissions by 2050, because they assume the hard-to-abate principle, while not paying much attention to climate justice issues. Also, other transport modes, transport volume growth and non-CO_2 impacts are generally omitted.
5. The legal obligation to mitigate the risk of climate change is not explicitly addressed: most scenarios are based on assumptions of self-regulation by industry actors and reliance on market-based measures.
6. Most scenario studies fail to integrate arguments of equity and justice.
7. The Breakthrough Scenario, underpinning the SBTi goal-setting scenario, acknowledges that de-growth is necessary to achieve 1.5 °C emissions pathways, but the ultimate SBTi scenario follows industry-projected demand trends. When SBTi would have taken demand as an outcome of climate justice compliant carbon budget limitations, we expect that global air transport volume growth would be substantially restricted or even have to decline in 2030 compared to 2019.
8. The SBTi's interim pathway relies on scenarios that put technological innovation central and does not directly assume demand management measures.
9. From the aviation mitigation scenarios, the SAF blending obligation comes forward as the most well-placed instrument to effectively reduce emissions within the sector up to 2030.

3.1 Introduction

A main research question of our study is to show to what extent aviation climate goals and mitigation strategies are aligned with emission pathways developed by the IPCC. In this chapter, we will try to find answers to that question. Therefore, we explore the aviation's impact on the climate, how to mitigate these and to what level of emission goals. We do so by analysing a set of aviation mitigation scenarios and confronting these to what the IPCC considers to be necessary for all sectors together. In the introduction (3.1) we explore the climatic impacts of aviation and show the main mitigation options in aviation. We then describe in section 3.2 aviation in climate policy at the global (3.2.1), European (3.2.2) and Dutch (3.2.3) levels. This part shows what mitigation measures policymakers aim at. We then investigate aviation climate mitigation scenarios in section 3.3. Section 3.3.1 provides an overview of the scenarios and section 3.3.2 then proceeds with plotting the scenario pathways including one recommended by climate science (the IPCC). We then zoom in to the goal-setting scenario published by SBTi (2023b) and the scenarios this one is based on (3.4). Against this context we discuss the division of responsibilities between industry and government (3.4.1), the ICCT Vision 2050 Breakthrough Scenario (3.4.2) and its underlying IEA scenarios (3.4.3). Finally, section 3.5 discusses the policy choices assumptions in the scenarios.

Environmental concerns about air travel date back to the 1960s and 1970s, particularly regarding noise (Wheatcroft, 1991), caused by the introduction of faster, cheaper and more comfortable jet aircraft. But global warming was another issue triggering debate in the late 1980s. A milestone in understanding of the problem of aviation and climate change was published in an IPCC Special Report on aviation and the atmosphere (Penner et al., 1999). This report provided an overview of a myriad of ways in which aviation affected the atmosphere and climate change, and the size of the problem. The IPCC report showed that next to CO_2 emissions, aviation also impacted the atmosphere because of other greenhouse emissions, because of emissions that change the composition of the higher atmosphere (around 10.000 km), and because aircraft cause condensation trails (‘contrails’, the white stripes in high the sky), and even additional warming when these contrails spread to create contrail-induced cirrus clouds. The cloudiness may seem to have a cooling effect, but that is only true during the day and when no other clouds are in the air, while during clear nights, any cloud has a strong warming effect. The effect of these non-CO_2 effects is considered by most scientists to be significant, but the estimates of the size also vary significantly. See further section I.IV about ‘non-CO_2’ impacts.

Currently, aviation caused a total of about 1034 Mton in 2018, which was almost seven times the amount in 1960 (Fuglestvedt et al., 2023), and which is 2.4% of global CO_2 emissions (Klöwer et al., 2021b). In terms of total contribution to global warming, aviation’s share is 4% (Klöwer et al., 2021b). When aviation continues to grow like in pre-COVID times, roughly half of the total aviation caused warming in 2050 would have been added after 2019, the other half being the remains of current warming (Klöwer et al., 2021b). An important further finding by Klöwer et al. (2021b) is that a decline of aviation volume by 2.5% per year between 2024 and 2050 would result in no net increase of global warming. The reason is that the reduction of the non-CO_2 impacts in 2050 would more than compensate for the additional warming caused by the additional CO_2 emissions between 2019 and 2050. However, the impact of the CO_2 emissions will continue for centuries and still be increasing after 2050, because in 2050 the emissions are halved, meaning they will still continue after 2050 and add to climate change. Lee et al. (2023, p. 1) conclude in their abstract that if “aviation is to contribute towards restricting anthropogenic surface warming to 1.5 or 2 °C then reduction of emissions of CO_2 from fossil fuels remains the top priority”.

While Penner et al. (1999) provided several options for mitigation of the climatic impact of aviation (both CO_2 and non-CO_2), these were all based in reducing the emissions. The problem of such an approach is that a reduction of CO_2 emissions does not reduce the impact on climate change, but only the speed with which the climate is changing. Only zero-emissions can stop the climate changing but cannot reduce the temperature back to pre-industrial levels.

Table 1: Overview of mitigation option and their impact on zero-emissions.

Category	Mitigation option	Kind of impact	Zero CO_2 possible?
Efficiency	Improve air traffic control (ATC)	A one-off reduction of 2-10% as ATC is 90-98% efficient.	No
Efficiency	Improve directness of passenger flights	Currently, the pricing system invites passengers to fly indirect. Provides a one-off opportunity to reduce emissions	No
Contrail avoidance (non-CO_2 impacts)	Fly routes where less or no contrails develop	Avoids contrails and contrail-induced cirrus clouds; increases CO_2.	No
Technology	Conventional aircraft technology	Up to 15% efficiency improvements per new generation of aircraft every 15-25 years	No
Technology	Revolutionary technology	Requires full new design around hydrogen and either jet engines (non-CO_2 not solved) or fuel cell-electric (non-CO_2 potentially solved)	Yes
Fuel (SAF)	Biofuel (SAF-B)	Large environmental and land-use issues	No
Fuel (SAF)	Fuel from waste (SAF_W)	Issues with feedstock availability in a zero-emissions economy, which has little waste; means at best temporarily available until about 2040	Maybe
Fuel (SAF)	E-fuel (SAF-E) from direct air capture of carbon	Issues with renewable energy availability	Yes
Volume reduction	Reduced volume of flight by improving business models and removing least relevant flights	Volume reduction reduces the speed of climate change and improves opportunities for zero-emissions of CO_2 in a climate justice way	As stand-alone measure only when flying is fully abandoned

Table 1 shows the different options and what these can do with respect to zero-emissions of CO_2. In general, efficiency improvements do help to reduce the mitigation challenge, but can in themselves never achieve zero emissions. The only two options for zero are sustainable aviation fuels

(SAF) and revolutionary technology. The advantage of SAF is that it can be used in current aircraft (Schäppi et al., 2022). There are three main types of SAF: biofuel, waste-based SAF and e-fuel. Only e-fuel can theoretically deliver zero-CO_2 emissions if it is based on direct air capture of CO_2 and 100% renewable energy. E-fuels are the only opportunity for zero-emissions, but only when the volume of aviation is no longer growing, because of energy constraints (Peeters & Papp, 2023). The second option, revolutionary technology, is taking shape (Warwick, 2023) but even Airbus CEO Faury says the development goes too slow (Flottau, 2022). The reasons for this are that conventional aircraft will dominate the fleet until 2050 because over ten thousand are on order to be delivered in the coming decade and because such aircraft have an operational lifetime of decades. Furthermore, developing new conventional aircraft types already takes ten years from the development decision to the first delivery. Developing revolutionary new aircraft designs with hydrogen, fuel cells and electric engines for all major range-capacity classes of aircraft is a task that simply cannot be accomplished before 2050. That is, from 2050 onwards, there is some chance that conventional aircraft will start to be replaced by those new types, a process that will take until 2080-2090 to be fully accomplished. The technology is necessary to remove some of the constraints caused by e-fuels, but it comes far too late for zero emissions in 2050, a prerequisite for any reasonable climate scenario (Peeters & Papp, 2023).

For the aviation sector, this leaves SAF, efficient operations and logistics and reducing air transport volume as the three main mitigation option for reaching intermediate climate targets. For zero-emissions, revolutionary technology, and hydrogen/electric propulsion, will not be able to play a major role.

3.2 Aviation in climate policy

3.2.1 Global climate policy

Global climate policy is currently based on the Paris Agreement (UNFCCC, 2015). In the Paris Agreement, the signatory countries (the parties), are only responsible for emissions within their territorial borders. International aviation and international shipping emissions are not directly mentioned. However, Article 4 of the Paris Agreement, states “the Parties aim to achieve a balance between anthropogenic greenhouse gas emissions and sinks – in other words, complete decarbonization and climate neutrality – in the second half of this century. Since emissions from aviation and maritime transport are clearly anthropogenic, they fall within the scope of the Paris Agreement goals even without being explicitly mentioned” (Cames et al., 2023, p. 5).

The omission of a direct reference to international aviation or ICAO in the Paris Agreement does introduce ambiguity as to what part it should play in achieving the global goals (Fuglestvedt et al., 2023). This is problematic as studies show that the goals of the Paris Agreement cannot be achieved without aviation contributing to emission reduction (Cames et al., 2015). International aviation represents some 65% of the current annual CO_2 emissions from the entire sector (Fleming & de Lépinay, 2019), the remaining 35% being domestic air travel, which falls under the responsibility of nations. Next to the unclear role of ICAO in the Paris Agreement, the complexity of the physical impacts of aviation is challenging for policymaking (Fuglestvedt et al., 2023).

In 2016, ICAO introduced two policies to mitigate aviation’s contribution to climate change: a carbon standard for new aircraft types (ICAO, 2017)and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA; ICAO, 2023). The carbon standard has set a limitation on the CO_2 emissions per one km flown as a function of the aircraft’s certified maximum take-off weight. Aircraft manufacturers desiring to certify a new aircraft type, need to show compliance through a series of test flights. The standard is a constant for a longer period in the future and because new aircraft will always be substantially more fuel efficient, is not expected to have any substantial impact on the future emissions of aviation (Peeters, 2017). The CORSIA global market-based measure aims to facilitate ‘carbon neutral growth’ for international aviation from 2020 (Larsson et al., 2019; Scheelhaase et al., 2018). Under CORSIA, airlines are obliged to offset their increase in emissions after 2019 by purchasing credits from emission mitigation projects outside the sector. Between 2020 and 2027 the system is voluntary, but after that it becomes mandatory for most countries. CORSIA has been found to be insufficient to get (international) aviation to develop in a Paris-aligned manner, see section I.I of Annex I and Grewe et al. (2021).

3.2.2 EU climate policy

The EU has not installed specific emission reduction targets for aviation, but regulates domestic and international aviation emissions through several instruments (e.g. Grebe et al., 2024). The Emissions Trading System (ETS) requires airlines to submit emission allowances for all intra-EEA flights. Free allowances are to be phased out over the period 2024-2026. The cap of allowances made available will decrease annually and reach zero around 2040 (Grebe et al., 2024).

Another EU measure regulates the introduction of SAF. For this purpose, the European Commission developed ReFuelEU (European Parliament, 2023). This deal includes a blending obligation for SAF for all departing flights from EU airports. The minimum share of SAF starts with 2% in 2025. From then the share should gradually increase to 6% (2030), 20% (2035), 34% (2040), 42% (2045), and finally 70% in 2050. SAF-E is mandated to a specified share of the fuel mix rising from 1.2% in 2030 through 2% in 2032 and 5% in 2035, until it reaches 35% in 2050 (European Parliament, 2023). SAF types that are allowed to contribute to the blending obligation are renewable synthetic fuels, renewable hydrogen, certain categories of biofuels, and recycled jet fuels produced from waste gases and waste plastic. Biofuels which are based on feed or food crops, or derived from palm and soy materials, are not considered sustainable (Grebe et al., 2024).

The revised Renewable Energy Directive (RED3). RED3 includes a target for renewable energy in transport, including aviation, and a sub-target for Renewable Fuels of Non-Biological Origin (RFNBOs) and advanced biofuels.

The Energy Tax Directive (ETD). In the revision of the ETD it is proposed to include aviation fuels into the scope, introducing a minimum tax rate for intra-EU passenger flights, but agreement on this proposal is not expected in the short-term. Grebe et al. (2024) consider the **SAF blending obligation the most well-placed instrument to effectively reduce emissions within the sector**, although it has its limitations due to the small share of SAF blending required in the coming years.

3.2.3 Dutch aviation climate policy

The current (outgoing) Dutch cabinet policy plans for aviation include the stimulation of SAF through blending and investments in the development of synthetic kerosene production, and for example the discouragement of flying short distance and stimulating rail travel in Europe as alternative (VVD et al., 2022). They also intended the implementation of a number of proposals from the long-term policy document on aviation, the Luchtvaartnota (Ministerie van Infrastructuur en Waterstaat, 2020), such as an increased passenger ticket tax and the introduction of an aviation CO_2 ceiling for departing aircraft from Dutch airports (I&W, 2020). The Luchtvaartnota intends to adopt the Sustainable Aviation Agreement’s (Sustainable Aviation Table, 2021) absolute CO_2 emission targets – the ceiling - for the Dutch aviation sector: equal 2005 emissions in 2030, halving 2005 emissions in 2050, and zero emissions in 2070. The SAF shares proposed for the Netherlands are more stringent than those of ReFuelEU but may not be allowed by the European Commission.

3.3 Aviation and climate scenarios

3.3.1 Introduction to scenarios

A main subject of this report is to show to what extent aviation climate goals and mitigation strategies are aligned with emission pathways developed by the IPCC. Starting point for this reasoning is the emissions pathway the natural sciences tell us is required to stay below 1.5 °C during the current century. From the five 'Illustrative Mitigation Pathways' for 1.5 °C given by the IPCC, we chose the LD scenario which assumes "efficient resource use as well as shifts in consumption patterns globally, leading to low demand for resources, while ensuring a high level of services and satisfying basic needs" (IPCC, 2022b, p. 23). The other four scenarios assume high levels of very uncertain negative emissions (IMP-Neg and IMMP-GS), very high levels of renewables (IMP-Ren), or a strong focus on other sustainability goals (IMP-SP). We made this choice because it is the least damaging, most climate just scenario provided in IPCC 6th Assessment report.

Scenarios are essentially planning tools that are commonly used in corporate environments (Godet & Roubelat, 1996). As we showed in section 2.2, they describe consistent futures based on assumptions. Scenarios are often used to inform business strategy and policymaking. An often-made error is that scenarios 'predict' any future, or that some scenarios are 'more likely' than other scenarios. But that is not the case because it is impossible to 'predict' the range of assumptions scenarios are based on. Correct use of scenarios is to get a sense of what the effect is of certain management measures or policies – these can be anything from legal to economic policies or even assumption about certain behavioural or cultural developments. But the specific assumptions always lead to certain outcomes. By applying inadequate, inconsistent, or incomplete assumptions, scenarios may produce problematic future visions. This makes scenarios also tools for communicating certain desired futures by companies or policymakers (Beck, 2009), and for projecting visions of industry futures which are inherently inconsistent or plainly impossible (Andersson, 2020). **Thus, scenarios also function as political tools: they make certain futures seem realisable and prominent, while obscuring alternative futures.**

Various recent aviation emissions reduction scenarios and reports are currently in circulation. In this analysis (for practical reasons) we focus on six of these that are widely known and cited and that also show a range of different approaches. Four reports present aviation scenarios (ATAG, 2021; Graver et al., 2022; ICAO, 2022b; Van der Sman et al., 2021), one a tourism scenario (Peeters & Papp, 2023), and one an environmental performance overview of the sector (EASA et al., 2023).

Table 2: Overview of some characteristics and assumptions of the six scenarios we considered. Sources: see text.

Title	Type (scope)	Aviation demand	Alternative fuels	Demand management	Are justice aspects included?
Waypoint 2050 **(ATAG, 2021)**	Scenario report (global)	Assumes demand is autonomous. Impacts of transition and climate change not modelled in.	Optimistic. Assumes most economic use of feedstock and energy sectors modification to meet aviation demand.	In-sector only. Calls for full policy support for technological innovation and energy system measures that channel feedstock to aviation. Explicitly opposes demand management.	Marginally

Title	Type (scope)	Aviation demand	Alternative fuels	Demand management	Are justice aspects included?
Long-term aspirational goals (ICAO, 2022c)	Scenario report (global)	Assumes demand responds to transition costs.	Careful concern. Mentions some challenges ahead due to regional variations of supply caused by combination of factors.	In-sector only. Assumes only policy enablers for fuels, technologies and operations. Does not mention demand management.	No
European aviation environmental report 2022. (EASA, 2022)	Sector performance report (EU+)	Assumes demand responds to transition costs and (perceived) effects of climate change.	Concern. Highlights enormous challenges ahead in terms of energy production scale-up and securing renewable electricity also required by other sectors.	Integrated (in-sector and out-of-sector). Considers aviation in terms of EU energy transition policy. Strives for policies addressing both CO_2 and non-CO_2-effects of aviation.	No
Destination 2050. (Van der Sman et al., 2021)	Scenario report (EU+)	Assumes demand responds to transition costs and (perceived) effects of climate change.	Critical concern. Highlights enormous challenges ahead, given current and projected air travel demand, in terms of energy production scale-up and securing renewable electricity also required by other sectors.	Integrated (in-sector and out-of-sector). Problematises current demand levels. Relies heavily on demand management measures until 2030, in combination with other measures (in-sector and out-of-sector).	Marginally
Vision 2050 (Breakthrough Scenario) (Graver, 2022)	Scenario report (global)	Assumes demand responds to transition costs.	Optimistic. Assumes enormous scale-up of production and related policy support.	In-sector only. Assumes full policy support for technological innovation and energy system measures that channel feedstock to aviation. Does not consider demand management but assumes global fuel tax and gradually increasing fossil jet ban starting after 2030.	Marginally
Envisioning 2030 zero-emissions tourism scenario (Peeters & Papp, 2023)	Scenarios report, global, alle travel and tourism	Taxes and subsidies, and cost of alternative fuel affect demand and transport mode choice.	Assumes S-curve introduction to 100% but balanced against renewable availability at global scale.	Assumes demand measures, particularly an UN-governed global airport slot cap.	Yes

Four reports are global in scope (ATAG, 2021; Graver et al., 2022; ICAO, 2022b; Peeters & Papp, 2023), two mainly focus on Europe (EASA et al., 2023; Van der Sman et al., 2021). Three reports marginally address justice aspects, one more in-depth (see Table 2). Furthermore, Table 2 shows that demand management is virtually absent in the aviation industry- and sector-initiated scenarios, but shows in the broader tourism scenario (Peeters & Papp, 2023).

3.3.2 Aviation scenarios compared to the IPCC baseline

The aviation sector and science have developed a range of scenarios exploring ways to fit into the Paris Agreement emission pathways for a 1.5 °C future. This means, the scenarios described below are all intended to show how aviation can be Paris compatible, with the exception of the EASA scenario (EASA et al., 2023) and the ICAO LTAG scenarios (ICAO, 2022b). Important features of the scenarios are the near-term (2030) and long-term (2050) reductions, the reference year for reductions, the total accumulated emissions until 2050, and the policies assumed to achieve the emissions pathway. To assess whether aviation scenarios follow the Paris Agreement pathway for all sectors together, we take the most ‘climate risk-free’ scenario given by the IPCC. This scenario is one of the series of “C1” scenarios that limits warming to 1.5°C (>50% certain) “with no or limited overshoot” from (Figure 3.6 in IPCC, 2022b, p. 311) as the benchmark. Also, it assumes “efficient resource use as well as shifts in consumption patterns globally, leading to low demand for resources, while ensuring a high level of services and satisfying basic needs (IMP-LD)” (IPCC, 2022b, p. 23) or “strong emphasis on low demand for energy” (IPCC, 2022b, p. 77). However, this scenario still does assume some negative emissions, mainly from land-use change. Its basis is the SSP1-1.9 scenario also depicted ‘very low emissions’, for which an overall CO_2 emissions pathway is given by IPCC (2021, p. 88). This scenario comes at 42.3% reduction in 2030 compared to 2019. Note that the IMP-LD scenario assumes a sectoral approach in which the overall transport sector is given a lower reduction of 37%. The reasons for allowing a lower reduction for transport is not entirely clear from the IPCC AR6 reports but seems to be based in a mix of the perceived lack of technical solutions and the higher cost of abatement compared to other sectors, a way of assessment developed by Nordhaus (2008). As we consider this an argument that is not based in climate science, we will take the CO_2 emissions, and not the negative emissions corrected net-emissions, as the reference for our analyses. It is based in the IPCC special report about 1.5 °C (IPCC, 2018, pp. SPM-15): “In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range)”. Legally there is support for a 45% net-reduction (over 2019) from the reasoning by the lawyers of a group Dutch NGOs in the case against Shell (Milieudefensie c.s., 2022). This figure is between the two IPCC scenarios shown in Figure 2. In this case 2019 rather than 2010 was chosen as reference, because of a data gap for 2010.

Taking this IPCC scenario as a baseline, we assessed a range of aviation dedicated scenarios and plotted the index (2010=1.0) of the absolute emissions pathway between 2010 and 2050 in Figure 2. Clearly, all aviation scenarios follow a less stringent pathway than IPCC, except the ‘Envisioning 2030’ scenario (Peeters & Papp, 2023). Generally, emissions are hardly reduced by 2030 (with respect to 2019). Also, the global aviation scenario developed by SBTi (2023b), which forms the basis for KLM’s and other airlines’ claims to be Paris-aligned, follows a delayed emission reduction scenario, which stay roughly at 2019 levels up to 2030, after which it starts to decline to close to zero in 2050. We show that two scenarios - LTAG-IS1 (Long-Term Aspirational Goal Integrated Scenario number 1) and LTAG-IS3 – published by ICAO (2022a) and a scenario published in the 2022 Environmental Report of the European Union Aviation Safety Agency (EASA et al., 2023) - fail to achieve zero emissions by 2050. The scenario provided by the Air Transport Action Group, the Waypoint 2050X scenario (ATAG, 2021), and the Destination 2050 scenario (Van der Sman et al., 2021), calculate moderate emissions by 2050.

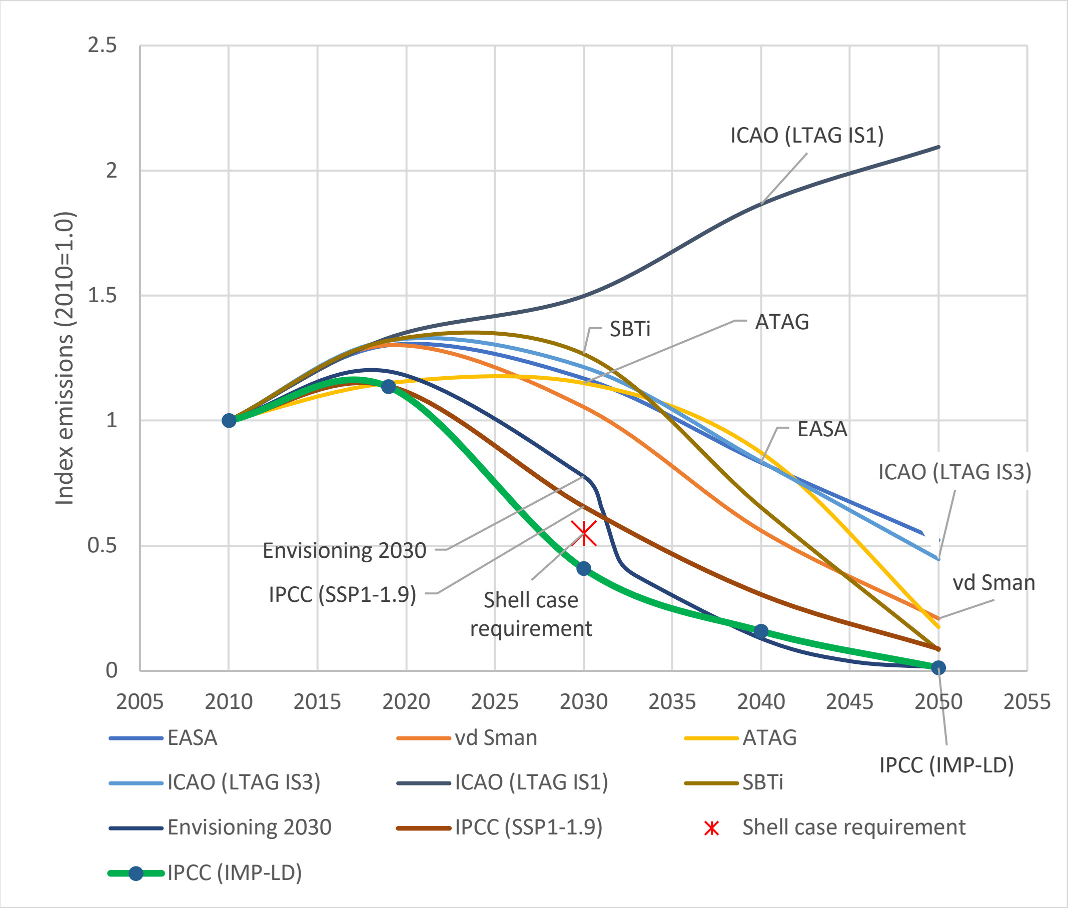

Figure 2: Indexed (2010=1.0) emission development for a range of aviation scenarios as compared to the IPCC 1.5 °C scenario accounting for all sectors. Notes:

1. *IPCC (SSP1-1.9) assumes substantial negative land-use emissions, while the IPCC (IMP-LD) shows only the CO_2 emissions, not the negative land-use equivalents.*
2. *All aviation scenarios are intended to show Paris compatibility, except for the ICAO LTAG IS1 scenario. Sources, see main text.*
3. *The Envisioning 2030 data have been slightly smoothed for 2030, 2040 and 2045.*

The conclusion is that **none of the aviation mitigation scenarios follows a 1.5 °C IPCC pathway for all sectors as provided from science**. All assume that aviation is hard-to-abate, and that, because of that reasoning, it is justified to assign a relatively high carbon budget to aviation as compared to other sectors. This reasoning ignores the argument of the necessity of demand, and the UNFCCC equity and Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), which is not deliberately influenced with measures in any of the scenarios except in Envisioning 2030 (Peeters & Papp, 2023). In most other scenarios the cost changes due to mitigation, allowing for some negative impact on growth rates.

SBTi (2023b) defined only one specific target for airlines, which is a 30% improvement of the carbon intensity (kg/pkm) in 2030 compared to 2019. Figure 3 shows the carbon intensity for the same scenarios as presented in Figure 2. EASA and LTAG IS1 show a relatively shallow improvement, while the ATAG, SBTi and Destination 2050 scenarios reach improvements of over 90%, but not zero. The Envisioning 2030 scenario shows a strong improvement between 2019 and 2030. This has mainly to do with the combined restriction of airport capacity and the availability of e-fuel. The reduced growth of air travel enables higher shares of e-fuel for the same given development of e-fuel production facilities resulting in higher shares of fuel being replaced.

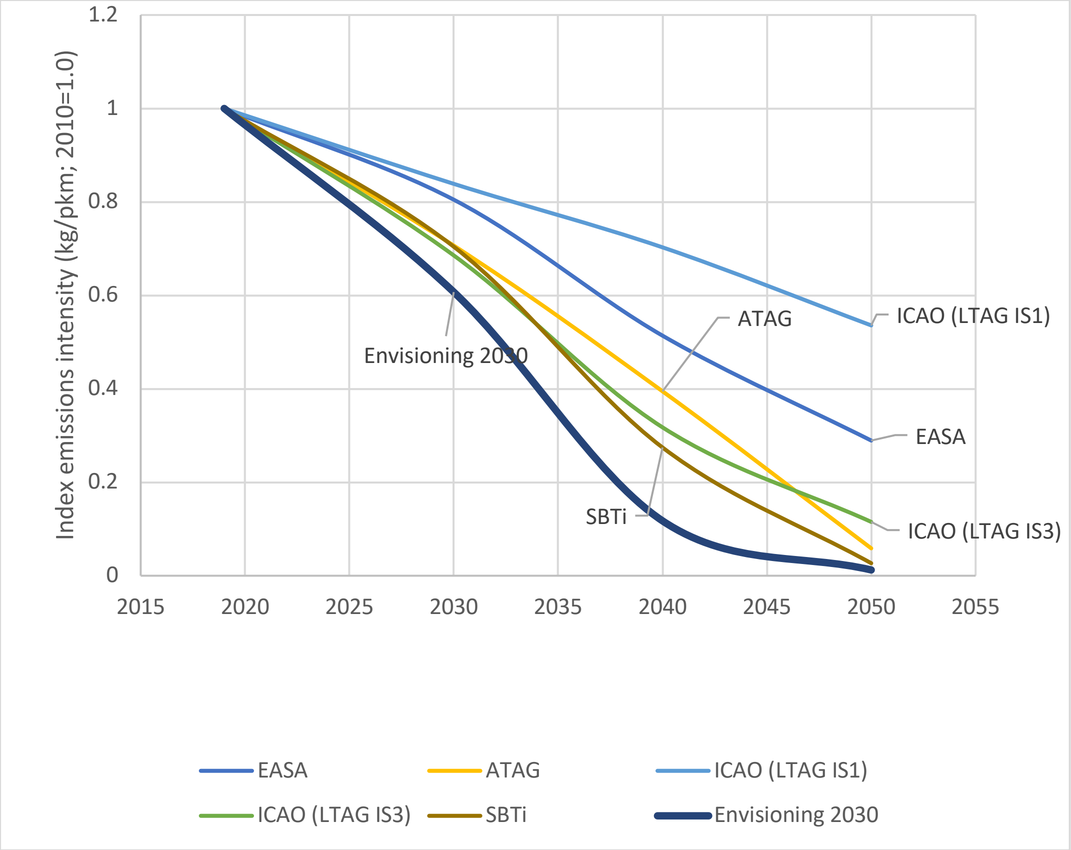

Figure 3: The improvement of the carbon intensity measured in kg CO2 per pkm as index of 2019. Note that the Envisioning 2030 data were slightly smoothed in 2030 and 2040 to avoid some 'spiky' behaviour. Sources, see text.

Formulating a climate goal in terms of efficiency is problematic from a climate science perspective because the temperature is governed by the concentration of CO_2 and other GHGs in the atmosphere, and thus the speed of climatic change is a direct function of absolute emissions, while efficiency only forms part of the equation. The ICAO LTAG (IS1) scenario, which is close to BAU, shows an efficiency improvement in Figure 3, but at the same time a strong increase of the total emissions in Figure 2. **The overall conclusion is that none of the aviation scenarios achieves absolute emission reductions as deemed necessary by the IPCC scenarios and setting only a near-term carbon intensity goal cannot guarantee to keep absolute emissions to stay below a 1.5 °C pathway.**

3.4 SBTi's interim pathway and underlying scenarios

3.4.1 Responsibilities for industry and government

Because the SBTi scenario plays such a prominent role in company target setting, we now discuss a bit deeper what the underlying assumptions of the SBTi scenario are. The SBTi takes businesses as unit for science-based target (SBT) setting and, when possible, SBTi first determines the target for an individual business via sector targets (Andersen et al., 2021). A question is how the responsibilities are divided between governments and industry. From a recent legal analysis, it appears that **industry actors also have a legal obligation in mitigating the risks of climate change** (A Dehon, 2021; Armstrong, 2022). SBTi might play a role in this process. The SBTi focuses on SBT setting and related communications and not on (guidance for) SBT implementation. Instead, it presents SBTs as a low-threshold corporate communications tool for firms to demonstrate climate leadership in the face of increasing societal pressure and, potentially, to delay more ambitious public climate policies (Peeters, 2023). The current SBTi aviation scenario is the 'interim 1.5°C sector pathway for aviation' (SBTi, 2023b). Key underlying scenarios of the interim 1.5° C sector pathway are the Vision 2050 Breakthrough Scenario of the International Council on Clean Transportation (ICCT) (Graver, 2022), and two scenario reports of the International Energy Agency (IEA): the Net Zero Emissions (NZE) scenario (IEA, 2021) and the Sustainable Development Scenario (SDS) (IEA, 2019). We therefore take a closer look at these documents below.

3.4.2 ICCT Vision 2050 Breakthrough Scenario

The SBTi interim pathway states that it is derived from the Breakthrough Scenario of ICCT Vision 2050 (Graver, 2022). SBTi highlights that this Breakthrough Scenario is institutionalised (has global aviation industry support): in a footnote it explains that this scenario supported the development of a 2050 net-zero CO_2 goal for international aviation, agreed upon by ICAO in 2022 (SBTi, 2023b). The Breakthrough Scenario is highly ambitious (hence the name). It assumes, among others, a peak in fossil jet fuel use in 2025 and an elimination of fossil jet fuel by 2050; projected demand and technology changes that are sufficient to align with a net-zero CO_2 by 2050 goal with limited removals, but that are also deemed plausible according to industry air traffic forecasts (SBTi, 2023b). It brings aviation to 1.75° C of global warming by the end of the century. The remaining emissions reductions should thus come from out-of-sector measures that are not modelled in.

Examining the interpretations and assumptions relating to air travel demand, feedstock supply, and policy enablers, we find that air travel demand is indirectly addressed. It uses traffic demand forecasts plausible to industry trends as model input but assumes what it calls an annual 'demand response' because of carbon price changes that are largely driven by a cost increase of alternative jet fuels. It subsequently anticipates 7% less air traffic because of this and modal shifts (plane > train) on short-haul routes in Europe, resulting in a 4% air travel demand decline.

Similar to Waypoint 2050 (ATAG, 2021), the Breakthrough Scenario is optimistic about feedstock supplies, but simultaneously acknowledges that the scaling of SAF has been slow to date and that there are supply constraints for biomass feedstock. But it nevertheless assumes an acceleration because of proposed fuel mandates. It recognizes that (uncertain) renewable electricity supply is key to accomplishing the scenario (see Van der Sman et al., 2021), but simultaneously caps biofuel supply at 100 million tons (equivalent to IEA NZE 2040 supply) and assumes all subsequent alternative fuel supply comes from e-fuels.

In terms of policy enablers, the Breakthrough Scenario is again closest to Waypoint 2050 (ATAG, 2021). It also limits itself to policies that mainly serve aviation industry interests through in-sector measures. Current air traffic growth is considered as a problem but not directly addressed. Curbing growth is considered as a by-product of fuel price increases that generate the funds necessary to promote alternative fuel uptake and production. Alongside, it places the ball in the court of policymakers. It argues that "out of sector actions and significant curbs to direct traffic growth would be needed to align aviation with a 1.5°C temperature goal" (Graver et al., 2022, p. iii), but "activity growth for the sector under the Breakthrough scenario is consistent with aviation traffic projections developed by the industry" (Graver et al., 2022, p. 3) such as described by ATAG (2021). **The Breakthrough Scenario acknowledges that de-growth is necessary to achieve 1.5 °C emissions pathways, but the SBTi scenario simply follows industry-projected demand trends.**

3.4.3 IEA scenarios the ICCT Vision 2050 Breakthrough scenario

The second scenario inspiring the SBTi interim pathway is the IEA's Net Zero Emissions (NZE) scenario (IEA, 2021). NZE sets out what needs to happen to transform the global economy from fossil fuel-based to renewable energy-based. Under NZE, SBTi states, aviation is treated as hard-to-abate, "therefore qualifying it for a larger share of future emissions under that framework" (SBTi, 2023b, p. 3). NZE indeed accepts – given that most of the technologies needed to reduce aviation emissions are still in prototype phase – that fossil fuels are still used in aviation in 2050 (it anticipates that just over 10% of total unabated global emissions come from aviation that year) and expects that these emissions will be offset by negative emissions elsewhere (IEA, 2021). Other than the ICCT Vision 2050 Breakthrough Scenario, NZE explicitly assumes that aviation growth "is constrained by comprehensive government policies that promote a shift towards high-speed rail and rein in expansion of long-haul business travel, e.g. through taxes on commercial passenger flights" (IEA, 2021, p. 135).

The Breakthrough Scenario and SBTi's interim pathway stay below the NZE scenario (with lower cumulative emissions) and are stated to be consistent with limited global warming to 1.5°C, without overshoot. The Breakthrough scenario shows a more gradual decrease of emissions in the period 2025-2030 than the NZE scenario. To compensate for this and set a higher near-term ambition level, the SBTi interim pathway adopts the Sustainable Development Scenario (SDS) for the period 2023-2031, and the Breakthrough scenario for 2032-2050. The SDS puts technological innovation central. Main trajectories for decarbonisation are electrification of end use sectors; use of CO_2 Capture & Storage (CCS); the use of low-carbon hydrogen; and the use of bioenergy. 35% of cumulative emissions reductions come from technologies in prototype or demonstration phase; 40% come from technologies not yet commercially deployed at the time of publication (IEA, 2019).

Consequently, the SBTi's interim pathway relies on scenarios that put technological innovation central and does not directly assume demand management measures.

3.5 Policy choices in aviation scenarios

To understand the policy choices underlying scenarios, we drafted Table 21 (see Annex II). This table assesses eight policy assumptions or dogmas. Four scenarios (ATAG, 2021; EASA et al., 2023; ICAO, 2022b; Van der Sman et al., 2021) delay emission reductions until after 2030 and true zero-emissions until after 2050, one scenario (SBTi, 2023b) achieves net-zero by 2050 but minor reductions until 2030 and the last scenario (Peeters & Papp, 2023) manages about 50% reduction by 2032 and true zero by 2050. The attitude towards technology is rather mixed but directly connected to the emission reductions outcome. Two scenarios (EASA et al., 2023; ICAO, 2022b) are hesitant to technological development, two are optimistic (ATAG, 2021; Van der Sman et al., 2021) and two medium optimistic (Peeters & Papp, 2023; SBTi, 2023b). In general, some 20-40% reduction is expected from technology, though it is often unclear what technology baseline development is assumed. It seems that most scenarios assume a baseline with fixed-technology, which is not a fair baseline, because the trend-wise growth is to a large extend generated by the trend-wise emission improvements. Most scenarios show concern about resources (EASA et al., 2023; ICAO, 2022b; Peeters & Papp, 2023; SBTi, 2023b; Van der Sman et al., 2021), but one

(ATAG, 2021) assumes that the demand for SAF-B/W feedstocks will generate enough economic power to get that available for aviation. There is no mention of the impacts of such a development for other sectors. Unequal renewable energy use for aviation shows no equity constraints in three scenarios (EASA et al., 2023; ICAO, 2022b; SBTi, 2023b; Van der Sman et al., 2021), and only one applies a renewable constraint by reducing air travel volume development (Peeters & Papp, 2023). Finally, ATAG (2021) reverses the equity argument by claiming that aviation has a right for a larger share of SAF in the world as compared to other transport modes, because the other modes are less difficult to abate. Three scenarios apply the hard-to-abate principle (ATAG, 2021; ICAO, 2022b; SBTi, 2023b), two apply it with some consideration of other sector's needs (EASA et al., 2023; Van der Sman et al., 2021) and one Peeters and Papp (2023) treats aviation as a 'normal' sector. The lean-to-lose principle concerns the option to reduce less-valuable demand for air travel. Only one scenario applies it (Peeters & Papp, 2023). None of the scenarios offer an integrated approach to non-CO_2. Regarding other transport modes the picture is scattered. Two scenarios (Peeters & Papp, 2023; SBTi, 2023b) see a promising role for rail travel, one (EASA et al., 2023) takes into account a trend-wise rail development, two scenario (ATAG, 2021; Van der Sman et al., 2021) propose to shape rail travel such that it better serves transfer passengers (calling it 'rail-air integration'), and one fully ignore other transport modes as part of the solution (ICAO, 2022b). Because rail systems are particularly good at city-to-city centre connections, adapting them to city-centre to airport or even airport-to-airport would seriously impair the quality for non-flying rail-travellers.

The overall outcome is that **most aviation scenarios delay emission reduction by 6-10 years, do not achieve zero-emissions by 2050, assume the hard-to-abate principle paying not much attention to equity issues, cover only CO_2 and do not see air travel demand reducing role for rail travel**.

4 Evaluation of KLM's targets

Key Findings

1. SBTi accreditation is voluntary and does not include an evaluation of the feasibility of the company achieving its accredited target. Also, it only requires a carbon intensity target, not an absolute reduction target.
2. KLM's short-term target (-30% carbon intensity in 2030 with respect to 2019) is in line with the SBTi targets. Additionally, KLM has presented the outcome of their emissions assessment, an overall emissions reduction by 12%, as an additional target.
3. Compared to all airlines publishing their emissions on the Carbon Disclosure Project website and having an SBTi target, KLM is an average airline when it comes to the carbon intensity of its air transport.
4. Quantitatively, KLMs promised performance (the -30% carbon intensity) leads to a 1.9 times higher overall emissions index (2010=100) than the IPCC/Shell required reduction, and 2.2 times for KLM's sure (contracted) emissions index.
5. To achieve IPCC aligned emission reductions, KLM has either to improve carbon intensity by about 56% in 2030 (baseline 2019), which is not feasible, or to reduce its transport volume by at least 21% in 2030 compared to 2019, pending the success of other mitigation measures.

4.1 Introduction targets

In this chapter, we will dive in the target setting by KLM for SBTi. Targets are an essential first step towards mitigation of emissions. But targets in themselves cannot guarantee effective mitigation, which is to be supported by a reasonable, manageable climate plan. The KLM climate plan is subject of chapter 5. Here, we only look at the target. The value of targets depends on the feasibility of the target. A target to achieve zero-emissions next year would, for KLM, only be possible when KLM would end its activities and be dismantled. That is clearly not a feasible target. But the balance between what is achievable and what is not depends on a range of factors. For an airline the main parameters are efficiency (fleet renewal, operational and logistic efficiency, cabin seat layout), application of SAF, particularly SAF-E, and the volume of traffic. The latter is a clear function of the business model of an airline. Apart from this 'internal' feasibility of the target, one should also look at the quality of the target with respect to the overall climate mitigation goals. We discuss this matter in section 4.2. Then we will assess whether KLM has followed the SBTi pathway? (4.3.1), compare them to some other SBTi-accredited airlines (4.3.2), and finally discuss the role of the hard-to-abate principle of KLM's targets (4.3.3). The 'feasibility' of a target is typically a political outcome, which cannot be derived from science. But science can bring forward the arguments for politically discussing feasibility. Such arguments we will discuss in this chapter and summarise in section 4.4.

Hassan et al. (2018) assessed the likelihood of a set of strong targets to become reality. They assessed, running an aviation sector model thousands of times, that achieving the strong IATA targets has a low likelihood to be reached. The main option appeared to be, as we have described above, SAF, technology and operational efficiency, but only 0.3% of all scenarios reached the targets set by IATA. Therefore, **in general one could question what the value of target setting is when the targets seem impossible to achieve given the growing demand for air travel**.

4.2 Targets from the Science-Based Targets institute

Following the Paris Agreement, voluntary science-based targets emerged, including the involvement and nudging of industry actors in the pursue of international climate targets (Giesekam et al., 2021; Walenta, 2020). Emerging service providers, with SBTi being a leading organisation, primarily support corporate clients in establishing and developing their objectives and goals (Bjørn, Tilsted, et al., 2022; Rekker et al., 2022; Tilsted et al., 2023). See further discussion in the textbox

Science-based targets

Science-based targets are defined as "Science-based targets provide companies with a clearly-defined path to reduce emissions in line with the Paris Agreement goals" (SBTi, 2023a, p. 1). The procedure is that SBTi defines sector-specific targets for a global, Paris-aligned, emission reduction pathways and extracts from these pathways - and a growth assumption - the carbon intensity per unit of product (SBTi, 2023a). Then companies who want to create science-based targets, must use an Excel model provide by SBTi. The one for aviation is the SBTi Aviation Tool (SBTi, 2024b). The model helps them to determine the precise development of intensity ad total emissions when they set a science-based target. This target is 30% better carbon intensity in 2030 with respect to the base-year, for KLM, that was chosen to be 2019. SBTi checks the model and accredits it. That means that the target setting is accredited. However, the feasibility of achieving these targets is not part of the accreditation.

These voluntary science-based targets have triggered increased (communication about) climate action, but still display inconsistencies and doubtful proof regarding their effective alignment with the 1.5°C goal of the Paris Agreement (Bjørn, Tilsted, et al., 2022). SBTi has created mitigation pathways for various sectors ranging from cement, through apparel and footwear, ground transportation, and housing to financial institutions (SBTi, 2024d). Aviation currently has an interim target document (SBTi, 2023b) based on an interim 1,5 °C scenario (see also section 3.4). From this scenario, only one goal is derived:

- A 30% carbon intensity (kg CO_2/pkm or rtk)[1] improvement in 2030 with the base year 2019.
- Offsetting and SAF were not allowed according to the original target guidelines (SBTi, 2021).

There are methodological issues and jurisdictional constraints in SBTi's target setting and validation process, including, but not limited to, the freedom companies have in choosing their targets and target setting methods, the common allocation principle of the SBTi, as well as the lack of validation of how realistic targets are, limited transparency in emission accounting, disclosure and reporting and allowed use of problematic means to meet science-based targets calls the effectiveness of the use of voluntary science-based targets into questions, raising serious concerns (Bjørn, Tilsted, et al., 2022; Cames et al., 2023; Giesekam et al., 2021; Ruiz Manuel & Blok, 2023).

Among others, Bjørn et al. (2021); Bjørn, Lloyd, et al. (2022); Chang et al. (2022) fiercely debated science-based targets including the freedom of choice companies have in relation to target setting and regarding target setting method selection; the rigour of the SBTi's target validation process, the common emission allocation principle of the SBTi and the verifiable Paris-alignment of validated science-based targets. And in terms of implementation of emission reductions against validated targets, these issues include, but are not limited to, the allowed use of problematic means for meeting science-based targets, and non-transparent emission accounting and disclosure. SBTi (2024b) provides an Excel tool for airlines that enables them to set a target, dedicated to their situation. What the airline needs to provide is the current (2019) transport volume and emissions, and the expected growth rate or volumes in 2030. Based on these, the tool calculates both the absolute emission pathway and the carbon intensity pathways for the airline. A lower submitted volume growth path of an airline, as KLM does, will result in a lower absolute emission target, because SBTi takes the carbon intensity target of 30% improvement as a fixed basis for all calculations.

The calculation is accredited based on a set of criteria (SBTi, 2024c). The accreditation assesses the 2019 emission inventory, checking for instance if emissions are correctly calculated according to the required standards, and it assesses the 2030 absolute emissions, or the carbon intensity targets or, if the company wants to sign for it, the net-zero target in 2050. However, v**oluntary SBTi accreditation does not include an evaluation of the feasibility of the company achieving its accredited target**. This can be considered a serious omission, because basically every company can get an accredited target, even if it is entirely unclear how this target can be reached.

4.3 KLM's targets

This section analyses KLM's Science-Based Targets (SBTs), focusing on KLM's objectives (4.3.1), targets compared to other SBTi accredited airlines (4.3.2), and the claim of prioritized fossil fuel emission allocation in regards to the 'hard-to-abate' classification (4.3.3).

4.3.1 Stated Targets

In 2022, the Science-Based Targets initiative (SBTi), approved KLM's emission reduction strategy (Climate Action Plan) with the target of 30% carbon intensity improvement between 2019 and 2030 (to be supposedly) in alignment with the Paris Agreement and its goal of keeping global temperature increases well below 2°C (KLM, 2022a; 2022b, p. 1). The intensity target combined with KLMs economic perspective results in a 12% decrease in total emissions in 2030 compared to 2019 levels. KLM adopted the SBTi 'hard-to-abate' classification generally granted to the aviation industry. Therefore, the targets are less stringent in comparison to other sectors. Additionally, the choice to not include non-CO_2 emissions targets remains debateable and problematic, though it is wise not to adopt an integrated CO_{2e} (equivalents) target as further explained in section I.IV of Annex I.

4.3.2 Targets for SBTi accredited airlines

Currently, 13 airlines have submitted emission targets to SBTi. Table 3 provides an overview of these airlines, their goals and in which country they are registered. Only two airlines filed a 1.5 °C short-term target and five a net-zero target. According to this source KLM fails both targets but tries to achieve '<2 °C'. Most airlines defined a near-term target for 2030, but five did so for 2035.

KLM is rather unique in having a Climate Plan. We could identify such documents only for Lufthansa and JetBlue.

Table 3: Overview of all airlines with a SBTi target. Source: (excel file downloaded from SBTi, 2024a).

Company Name	Near term - Target Classification	Near term - Target Year	Net-Zero Committed	Published dedicated climate plan (Y/N)	Country
Air France - KLM Group	<2°C	2030	No	N (but some elements mentioned in their sustainability reports)	France
Air France Group	<2°C	2030	No	N (but some elements mentioned in their sustainability reports)	France
Air New Zealand	<2°C	2030	No	N (but many elements I n their annual sustainability reports)	New Zealand
American Airlines	<2°C	2035	No	N (States climate actions on website and integrates climate in sustainability reporting)	United States of America (USA)
ANA Holdings Inc.	<2°C	2030	No	N (discloses climate/environmental policies at group level)	Japan
Azul S.A	1.5°C	2030	Yes	N/A	Brazil
Delta Air Lines	<2°C	2035	Yes	N (presents climate actions on website and reports on climate actions as part of ESG reporting)	United States of America (USA)
easyJet plc	<2°C	2035	Yes	N (presents climate actions on website and has sustainability section integrated in annual report)	United Kingdom (UK)
JetBlue Airways Corporation	<2°C	2035	No	Y (presents climate actions on website and annually discloses GHG emissions in dedicated report).	United States of America (USA)

Company Name	Near term - Target Classification	Near term - Target Year	Net-Zero Committed	Published dedicated climate plan (Y/N)	Country
KLM Royal Dutch Airlines	<2°C	2030	No	Y (Climate Action Plan)	Netherlands
Lufthansa Group	<2°C	2030	Yes	Y (Annual climate-related financial disclosure report (reporting on climate risks for business)	Germany
TUI Group	<2°C	2030	No	N (Climate impact addressed as part of CSR/sustainability reporting)	Germany
United Airlines, Inc.	<2°C	2035	Yes	N (Climate impact addressed as part of CSR/sustainability reporting	United States of America (USA)

Several of these airlines publish their annual emission data and targets in the Carbon Disclosure Project (CDP, 2024b). Based on these data and conversion factors between pkm and rtk for these specific airlines given by IATA (2020), we have calculated the carbon intensity in terms of emissions per unit of air transport. Figure 4 shows the results in kg CO_2/RTK. Figure 4 shows that most airlines have published intensities that are above the ones published by SBTi (2023b). KLM is a bit above the SBTi estimates. The goals are all met in percentages, but the absolute carbon intensities vary. This makes sense because of the many parameters that determine the final carbon intensity per rtk. This depends not only on the technology level of aircraft, but also on the cabin layout, the number of seats (a high number reduces emissions per seat-kilometre), the kind of markets served (long-haul, medium-haul, short-haul), etc. From Figure 4, we may conclude that KLM is a rather average airline when it comes to its carbon intensity over time.

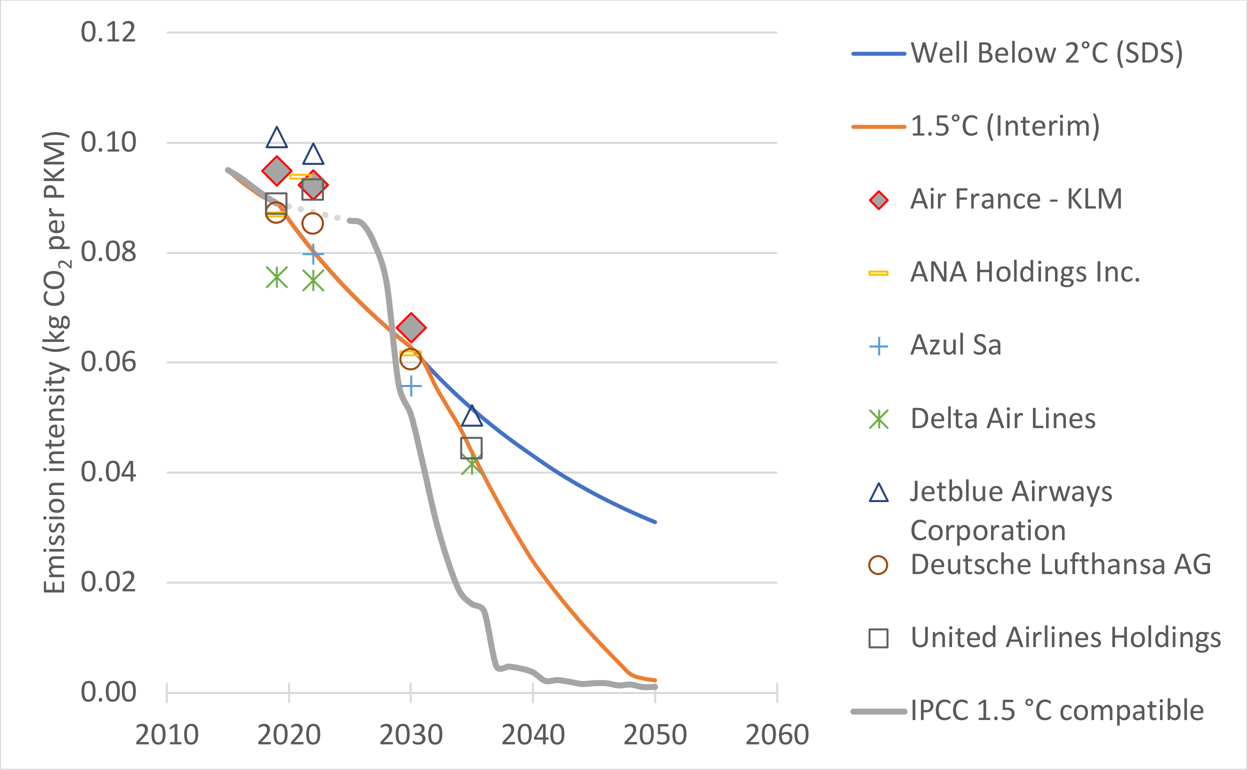

Figure 4: Intensity development for all aviation as required by SBTi (drawn lines) and as published in CDP reports (CDP, 2024b) by several SBTi-accredited airlines. The IPCC 1.5 °C compatible line shows the detailed intensity development in the Envisioning 2030 zero-emissions scenario (Peeters & Papp, 2023).

4.3.3 Hard-to-abate status as applied by KLM

In line with the earlier addressed controversial 'hard-to-abate' assertions (section 5.2.1), the concept of climate justice, including burden-sharing justice (upholding the principle that those who have contributed the most to climate change, who can most afford mitigation measures, or who profit most from activities causing climate change should carry the primary burden) and harm avoidance justice (preventing harm for those who are most vulnerable to climate change impacts) will be further discussed. These concepts stand central in the Paris Agreement and equity discussions (Caney, 2014; UNFCCC, 2015, p. Art.4.1).

Critics argue that this approach may blur important impacts and damages from climate change and dismiss "the importance of a sector for the global population, the share it serves, the necessity of the product for those who make use of it and the distribution of the products of the sector over income classes" (Peeters et al., 2023, p. 26). Especially in the context of aviation, this view on the 'hard-to-abate' prioritization, becomes evident through the disproportional effects of climate change on developing countries through extreme weather events like heat-waves, droughts and floods (Dolšak & Prakash, 2022b), while the population of those countries fly substantially less frequently (IATA, 2020)[3].

KLM states that the aviation industry "is considered a hard-to-abate sector due to a lack of alternatives and a rise in demand for flying. The industry's main obstacle to reducing its impact is the

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[3] Only 2.2% of all air transport volume is consumed by the population of Africa while Africa hosts 18.2% of the world population. Compare with the European population that consumes 26.4% of all air transport while comprising only 9.2% of the population. These numbers show that Europeans fly roughly 25 times more than the average African.

absence of readily-available zero-emission technology, which is likely to persist until at least 2035" (KLM, 2023a, p. 9). KLM ads to this that "a rise in demand for flying" (KLM, 2022a, p. 9) exacerbates the hardness to abate. Interestingly, in these statements KLM says that the rise in demand is something outside of their power. Therefore, the hard-to-abate argument is only valid when the demand, which at least partly, is generated by the aviation sector, is kept out of the consideration as we have seen in section 3.5. We will show how KLM generates additional transport volumes because of their hub-and-spoke network business model (section 6.3.1). Though such a network provides high flexibility in terms of OD[4]-relations that can be achieved when one or two transfers are included, it regularly also causes long detours and additional CO_2 emissions for passengers that would also have a more direct alternative are tempted by the low fares of KLM for such indirect connections. Furthermore, KLM is justifying the higher share of carbon emissions allocated to the aviation industry, as stated in KLM's Admissibility Defence Sections, suggesting that airlines cannot achieve the same reduction rates as other sectors due to the stated slow processes in finding and developing adequate technical solutions (Katan & van 't Lam, 2023, pp. 5, par. 20). This (cost-optimal abatement) approach prioritizes sectors with higher abatement costs and seems to be accepted by amongst others SBTi, IEA and IATA (Ekins et al., 2011).

4.4 Evaluation of KLM targets

To understand the position of KLM in the target setting 'arena', Figure 5 is based on Figure 2 that showed the emission development according to a range of scenarios and what is needed to become 1.5 °C compatible. Figure 5 now shows the position of KLM with respect to the most typical scenarios. Clearly, KLM's contracted plans (fleet renewal and 3% SAF and some operational improvements) bring KLM almost onto the SBTi global scenario. But the KLM had a much lower growth between 2010 and 2019 than KLM, which makes it 'easier' for KLM to stay below SBTi. Furthermore, only KLM's goals follow the start of a decline as required by SBTi, but the concrete measures will fail to accomplish that goal. Finally, **KLMs promised performance is 1.9 times higher than the IPCC/Shell required reduction, while is 2.2 times for the sure (contracted) emissions index**.

From the above we may conclude that KLM's stated target for the carbon intensity improvement in 2030 over 2019 of 30% is in line with SBTi's target. However, the SBTi scenario fails to come close to the general IPCC pathways. In 2030, KLM's absolute total emissions in 2030 will be 12% lower than in 2019, which is a strong shortfall of what the IPCC requires for all sectors, which is in the range of 40% to 50%. If KLM wants to stick to its growth rate of 1.9% per year up to 2030, it should improve its carbon intensity by 56%, which cannot be feasible. Another option would be, assuming the 30% carbon intensity improvement is successful, to reduce the volume in 2030 by 21% compared to 2019 (or 37% compared to KLM's intended growth). Though this may seem not feasible either, when the constraint of the current transfer-passenger-based business model would be exchanged for another business model, for instance more point-to-point and aiming at the highest direct economic impacts for the Dutch economy (Peeters et al., 2024), feasibility will substantially improve.

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[4] OD means origin-destination, so the relationship between the point of departure (e.g. home) and the destination (e.g. a holiday destination), regardless of the number of flight segments and transfers.

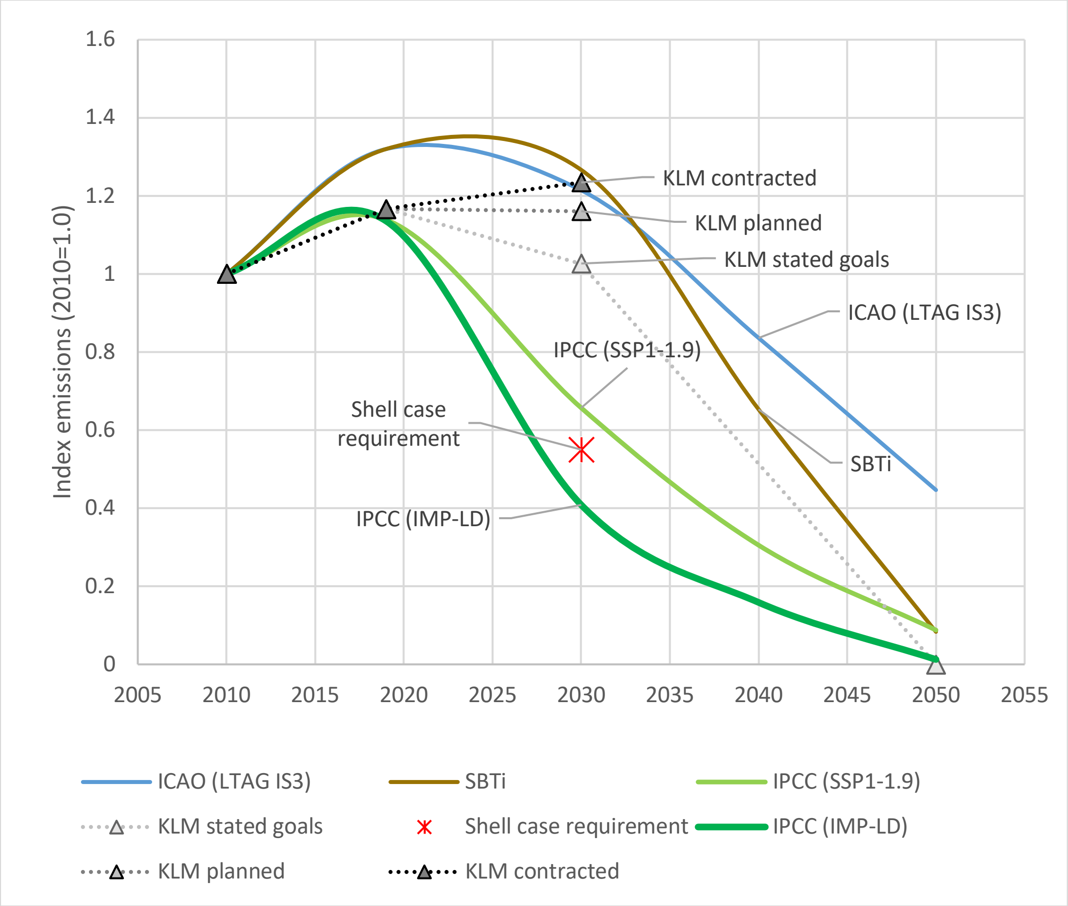

Figure 5: The indexed (1990=100) development of a selection of scenarios and the position of KLM as promised by its SBTi target (corresponding to 30% improved carbon intensity in 2030), as covered by plans (20.6% improvement) and as covered by concrete contracted plans (-15.8%).,

KLM takes the 'hard-to-abate' argument as the baseline to argue aviation can reduce its emissions at a substantially slower pace than other sectors do, without considering equity or justice aspects of such a position. Though KLM acknowledges it should take its responsibility, this effort is within the hard-to-abate paradigm. Current performance of KLM in terms of carbon intensity is average, not particularly advantageous as compared to a range of competing airlines. The conclusion is that, **KLMs promised performance (the -30% carbon intensity) leads to 1.9 times higher overall emissions index (2010=100) than the IPCC/Shell required reduction, and 2.2 times for KLM's sure (contracted) emissions index.** To achieve IPCC grade emission reductions, **KLM has either to improve carbon intensity by 56% in 2030 (baseline 2019), which is not feasible, or to reduce its transport volume by at least 21% in 2030 compared to 2019.**

5 Evaluation of KLM's Climate plan

Key Findings

1. Based on KLM's concrete plans, the airlines' 2019 emissions would **increase by 5.8%** in absolute terms in 2030.
2. Two-thirds – 20.6% - of KLM's reduction goal of 30% is covered by planned measures.
3. Just over half – 15.8% - of KLM's reduction goal is covered by concrete measures; the difference is in 3% SAF under contract rather than 10% SAF planned.
4. The process of fleet renewal is driven by economics, not environment, and does not simply result in the lowest fuel consumption and CO_2 emissions.
5. KLM has a history of a relatively conservative fleet-renewal policy, meaning that it also has an average fleet with respect to fuel efficiency and CO_2 emissions.
6. By publishing acquisition instead of design age in the context of climate change mitigation, KLM suggests a 6 to 9 years younger fleet than technically is the case, implicitly suggesting 10% to 14% too optimistic fuel efficiency and carbon intensity.
7. In 2019 KLM was an average airline with respect to fuel efficiency per seat-kilometre. The recent introduction of new cabin classes providing more space to passengers (e.g. World Business Class and Premium Comfort Class) may reduce KLM's fuel efficiency and increase its CO_2 emissions per passenger-kilometre.
8. As KLM's fleet renewal policy has been hesitant, the company missed an additional 6% of efficiency gain in 2030, out of the 12% they claim based on their current fleet renewal as assumed in their Climate Plan.
9. KLM has no specific non-CO_2 reduction policy, whereas a reduction of non-CO_2 emissions could be accomplished in a straightforward way by means of reducing volumes and growth of transport volume. The use of sustainable aviation fuels leaves most non-CO_2 emissions as they currently are.
10. KLM describes and affiliates itself with the development of zero-emissions aircraft but does not seem to take much risk in their development, for instance by taking options on Universal Hydrogen fuel cell aircraft currently in development.
11. Achieving an IPCC compatible goal of -45% absolute emission reductions would require a reduction of KLM transport volume between about 21% and 35%. This fact illustrates the importance of discussing volume growth in the outcome of the total emissions in 2030.

5.1 Introduction and aspects of evaluation

In this chapter we evaluate the climate plan of KLM. The main problem of aviation for the climate is that aircraft burn fossil fuel (kerosene, generally Jet-A) and emit CO_2 because of this. Furthermore, the burning causes a range of other non-CO_2 emissions like hydrocarbons, nitrogen oxides and water vapour (Klöwer et al., 2021b). Particularly at the high altitudes of about 10,000 m a modern aircraft cruises at, these emissions cause a range of impacts like contrails, which may even generate layers of high-level cirrus clouds (Klöwer et al., 2021b). All these processes can lead to an additional heating effect that is very significant (see section I.IV of Annex I).

Section 5.2 describes KLM's climate plan and its assumed effects. The following sections assess the three main elements of KLM's Climate plan: fleet renewal (5.3), operational efficiency gains (5.4) and SAF (5.5). Section 5.6 discusses the consequences of the way in which KLM handles non-CO_2 impacts.

The main ways proposed by science to mitigate the climate impacts from aviation are the following:

1. Improving energy efficiency:

   Using less fuel per passenger-kilometre or revenue-ton-kilometre will, ceteris paribus[5], reduce the emissions. Efficiency can be improved by using more efficient aircraft (section 5.3), by flying an aircraft more efficiently and by more efficient logistics (flying shortest routes as described in section 5.4, and offering passengers/freight the shortest or least-emissions routes as shown in section 6.3.1). However, regarding more efficient aircraft technology, the laws of physics, particularly aerodynamics and thermodynamics, prohibit flying at zero energy (Peeters, 2010). Hence, you will never be able to reduce emissions to zero by more efficient aircraft that still use fossil fuels as energy source. An additional issue forms the 'ceteris paribus' assumption: when you improve aircraft efficiency, you will reduce the cost of fuel and thus of flying. This means that the demand for flights will increase and, through the so-called 'rebound effect', a part up to almost all the emission reductions will leak away into higher demand for air transport. In section I.II of Annex I, we show a graph that combines the strong fuel efficiency improvements of jet aircraft since their introduction in the 1960s and the even stronger increase in total emissions because of the cost reductions involved with improved aircraft designs in the same period. While more fuel-efficient aircraft have a direct rebound effect of at least some 30% because 30% of current direct operating costs of an aircraft is fuel cost, the rebound for operational efficiency might be up to 100%. The reason is that flying shorter routes, for instance, will also reduce the flight-hours of an aircraft, which determine almost all other direct operating costs one-to-one. We discuss the rebound effect further in Annex I , section I.III.

2. Replacing fossil fuels by non-fossil fuels:

   Another way to remove emissions is by replacing fossil-based kerosene by 'sustainable aviation fuels' (SAF). Three main categories of SAF exist (ICAO, 2022b): bio-based SAF-B, waste-based SAF-W and synthetic e-fuels produced from CO_2 captured from factories, electricity plants or the atmosphere (SAF-E). Due to a range of different reasons, SAF-B will generally remove less than 80% of all emissions (Meerstadt et al., 2021). This also applies to many types of SAF-W feedstocks as these are also bio-based. Furthermore, the resources for SAF-W experience serious resource limitations (Suzan, 2023). The third type, SAF-E has a potential to reach almost 100% reduction of emissions (Schäppi et al., 2022) and use far less space than SAF-B and SAF-W. However, the bottom-line here is energy use, particularly of renewables, which could consume up to 100% of all electricity for aviation only in a country like Germany (Drünert et al., 2020). See section 5.5 for further discussions.

3. Paying someone else to reduce emissions (offsets):

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[5] Meaning 'other things equal'.

Carbon offsetting is the base for ICAO's CORSIA system. With offsetting, one industry pays another (industry, individual) to reduce their emissions in a way to compensate for the paying industry's emissions. The initial emissions will still add to the CO_2 concentration of the atmosphere, so offsetting can never be a way to reduce the climate impact to zero, except when negative emissions are assumed. For a further discussion about the issues with offsets see Annex I section I.I.

4. Applying revolutionary technology:

   Another option mentioned by the aviation industry, including KLM, is to develop aircraft that no longer use fossil fuels, but are driven by electric engines powered by batteries or hydrogen-fed fuel cells, or by jets burning hydrogen (Noland, 2021). This is not a new idea, such aircraft designs were proposed at the end of the 20th century (Brewer, 1991; Peeters, 2000; Snyder, 1998). There is broad consensus that these completely new aircraft types may only become effective after 2045-2050, i.e. too late for the 1.5 °C climate targets of zero-emissions in 2050. Most scientific papers assume that in 2030 only few experimental small aircraft may be on the market (Miller et al., 2023). However, it is also a fact that the two main players in the fuel-cell electric aircraft development, ZeroAvia (Dubois et al., 2023) and Universal Hydrogen (Norris, 2023), have already reached the flight-testing stage of aircraft with around 20-40 seats and are designing and actively building prototypes up to 50 seats.

5. Reducing the volume of air travel and transport:

   In all scenario studies we presented in section 3.3 the demand for air travel was assumed to be a given, even though to some extend affected by the cost of mitigation measures, and the (accumulated) emissions an outcome. Only Peeters and Papp (2023) reverse this way of thinking in making the supply of air transport a function of the effectiveness of mitigation measures and the 2050 zero-emissions goal. This reversed thinking is crucial to achieve the 1.5 °C climate goal according to the IEA, who observe that the "assumption that people's lifestyles and patterns of consumption will continue unaltered in a scenario of net zero emissions by 2050 is arguably unrealistic" (Crow et al., 2021, p. 1).

In our evaluation of KLM's climate plan, we argue, in concurrence with KLM (2023a), that offsets will not be a viable solution. Annex I section I.I provides extensive background on this assumption. In contrast to KLM's climate plan and many aviation sector plans as well as SBTi's scenario, we consider measures to limit the supply of air transport essential in a discussion about climate justice. The reason is that efficiency measures are both limited (see Annex I section I.II) and suffering from serious rebounds (see Annex I section I.III). Ignoring non-CO_2 impacts (Annex I section I.IV) is undesirable because it may currently form the majority of aviation's impact on the temperature rise, but simply multiplying CO_2 emissions by a non-CO_2 multiplier, as is common practice, is not seen as a scientifically defendable approach as further explained in Annex I section I.IV.

5.2 Reduction feasibility of KLM's climate plan

KLM's Climate Action Plan (KLM, 2023a) assimilates the common technology-centric approach found in the aviation industry, integrating measures in regards to fuel-efficiency and fleet advancements, air traffic and operational improvements and the transition to sustainable aviation fuels (SAF), carbon capture and technological-aircraft progresses in regards to battery electric, fuel-cell electric and hydrogen-jet (Bergero et al., 2023). KLM (2023a) gives three quantified improvements of its *carbon intensity*:

1. Planned fleet renewal – most new aircraft are on order – is assumed to deliver 12% improved carbon intensity,
2. Operational improvements may deliver 2-4%, of which about half through measures taken by KLM, and the other half depending on the introduction of the Single European Sky by the European Commission.
3. The mixing of 10% SAF, with an assumed life-cycle emission reduction of 80%, which could deliver another 8%.

Next to these planned measures, KLM also mentions an undefined fourth option as 'other measures'. "Some areas of our decarbonization strategy still need to be finalized, including measures to boost operational efficiency and increase the uptake of SAF" (KLM, 2023a, p. 7). According to KLM, the three improvements, if fully implemented, would reduce the total carbon intensity by 20.6%[6], so **some two-thirds of the reduction goal is covered by planned measures**. However, currently, only 3% of SAF has been contracted up to 2030, reducing the currently implemented *concrete* measures to a carbon intensity improvement of 15.8%[7]. Thus, **these contracted measures cover half of the 30% target**. If KLM wants to fully achieve their 30% carbon intensity target by 2030, they will need another 18% of SAF. This would make the total needed SAF, assuming an optimistic 80% effectiveness, some 28%. This contrasts KLM's current SAF contracts that cover in total only 3% by 2030. Also, the high share of 28% in a tight SAF market (IEA, 2024) in 2030, would limit other airlines to buy their SAF. That would mean, that KLM being a frontrunner, does no longer add to the global CO_2-emission reduction.

It is important to understand the relationship between volume growth, carbon intensity and total emissions to understand the meaning of KLM's 12% overall CO_2 emissions reduction 'target' KLM (2023a). This figure assumes the full 30% carbon intensity improvement will be reached, while the above shows that only 15.8% improvement is covered by planned and contracted measures. The relationship between growth, carbon intensity and total emissions reduction is relatively straightforward:

$$Total\ emissions = (1 + Growth\ rate)^{(target\ year - base\ year)} * Carbon\ int. * Volume_{base\ year}$$

For the KLM base case, in this formula, the base year is 2019, the target year 2030, the growth rate[8] 0.021, the Volume in 2019 (the base year) 92.7 million passenger-kilometres (KLM, 2024), and the carbon intensity index 0.7 (30% reduction) in 2030. We thus get:

$$Total\ emissions\ index = (1.021)^{11} * Carbon\ intensity * 92.7$$

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[6] In this kind of calculation, you have to multiply the index of all the effects: 12% improved intensity through fleet renewal (0.88) * 2% operational measures (0.98) * 8% SAF (0.92) = 0.88*0.98*0.92 = 0.794 and thus a 20.6% improvement.

[7] 12% improved intensity through fleet renewal (0.88) * 2% operational measures (0.98) * 3% SAF at 80% effectiveness (1-0.03*0.80) = (0.88*0.98*(1-0.03*0.8)) = 0.842 and thus 15.8% improvements.

[8] Note that the KLM Climate Report mentions a 1.95% growth rate between 2019 and 2030, but this does not result in 12% reduction of total emissions when 30% carbon intensity is assumed over the 11 years between 2019 and 2030. Therefore, we have recalculated the correct average growth rate which resulted in 2.1%. The reason for this small difference is unknown.

By varying the carbon intensity reduction in 2030 in the formula, we assessed the relationships shown in Table 4. From this table we conclude that currently, certain emission reductions from the KLM Plan (those contracted like ordered new aircraft and SAF-contracts) would lead to a 'worst-case' scenario resulting in a 5.8% *increase* of KLM's global emissions. Note that the 2% carbon intensity assigned to operational measures is not exactly contracted yet and thus still uncertain. KLM's planned, but not fully contracted, climate measures would lead to a small reduction of KLM's total emissions of 0.5%. As was to be expected, the target of 30% intensity improvement would deliver the 12% overall emission reduction, as also claimed by KLM.

Table 4: Overview of the impacts of the volume growth and carbon intensity assumptions for the KLM case.

Case assumptions	Intensity gain	KLM global emissions index with 2.1% growth
KLM Climate Plan contracted (-15.8%)	15.8%	5.8%
KLM Climate Plan planned (-20.6%)	20.6%	-0.5%
KLM SBTi target (-30.0%)	30.0%	-12.0%
High gain (-45.0%)	45.0%	-30.9%
Extreme gain (-60.0%)	60.0%	-49.7%

However, one could use the relationship between growth and emissions also to do a reverse calculation: what volume growth is compatible with the IPCC target reduction (-45% of absolute emissions in 2030) as a function of the carbon intensity improvement.

Table 5: The transport volumes KLM would be able to realise if the emissions would need to reduce to the average IPCC level (-45%) under various carbon intensity assumption cases. Note: the IPCC in fact asks for a reduction compared to 2010, which would further reduce the volumes

Case assumptions	IPCC compatible growth rate	KLM IPCC compatible volume (billion pkm) in 2030	IPCC compatible volume reduction compared to 2019
KLM Climate Plan contracted (-15.8%)	-3.80%	60.5	-34.7%
KLM Climate Plan planned (-20.6%)	-3.26%	64.3	-30.6%
KLM SBTi target (-30.0%)	-2.17%	72.8	-21.4%
High gain (-45.0%)	0.00%	92.7	0.0%
Extreme gain (-60.0%)	2.94%	127.4	37.5%

Table 5 shows the results of this analysis. Only in the impossible case of a carbon intensity improvement of 60% between 2019 and 2030, KLM would be able to grow its volume above the currently expected volume. Even a zero-growth assumption would require a carbon intensity reduction by 45%. This table is important input for any debate about climate justice, because it contains information about a fair share of reductions for aviation (see discussions in chapter 6 about for instance the 'hard-to-abate' principle) and the consequences for transport volume growth.

Figure 6 further illustrates the relationships between volume and carbon intensity cases. The grey lines describe the current (2019) and assumed (2030) passenger transport volumes of KLM. The orange line shows that only the intended carbon intensity reduction by 30% is compatible with the volume growth KLM assumes. When KLM would stick to the 12% absolute emission reductions described by KLM's Climate Plan (KLM, 2023a), the two lower intensity gains would require the volume growth to be substantially reduced as the graph shows. When one assumes IPCC-compatible reduction, the volume will have to be significantly reduced by 2030 compared to 2019.

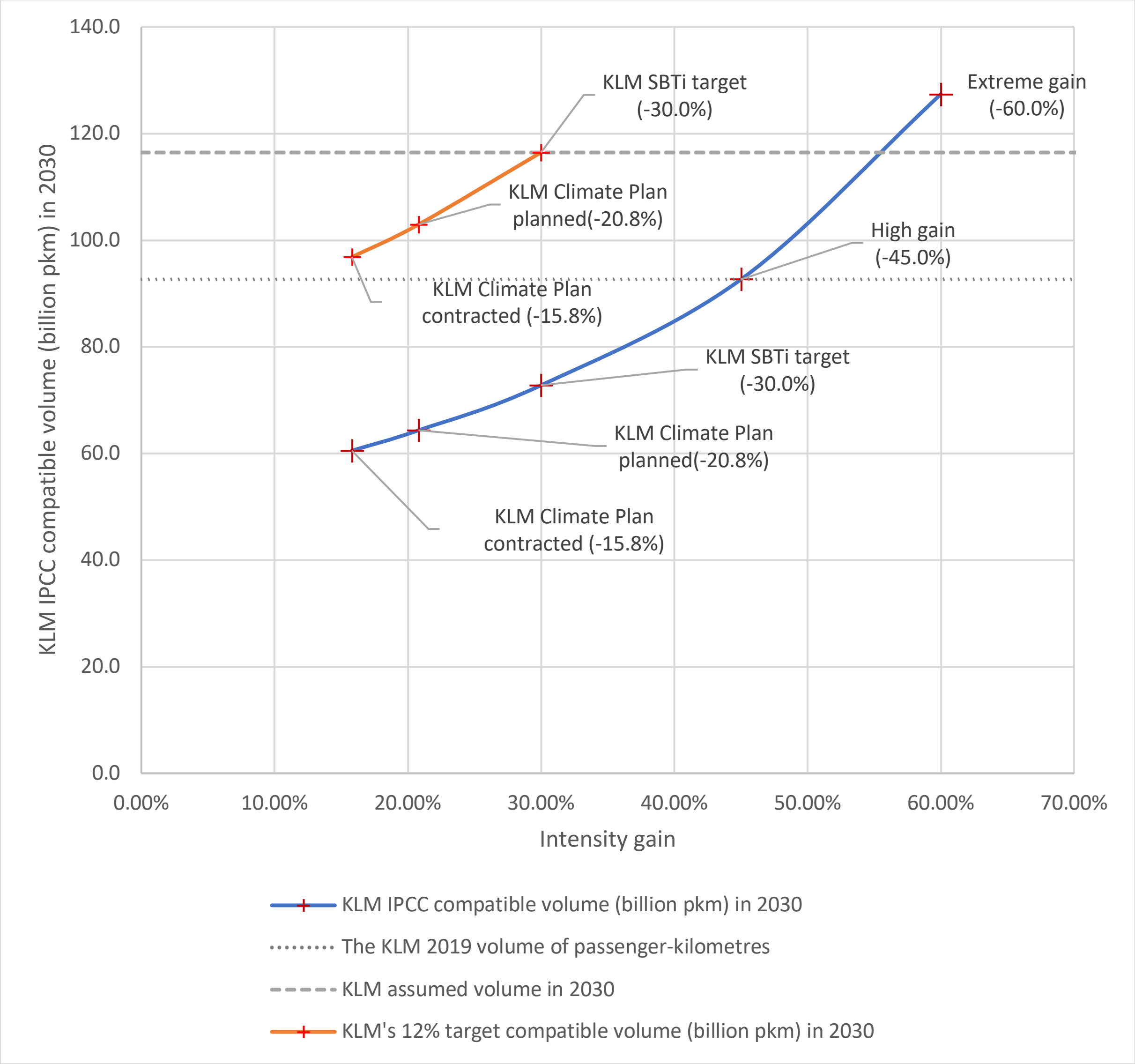

Figure 6: The IPCC compatible (-45% of total emissions in 2030 compared to 2019) volumes for varying assumption cases for the carbon intensity gain. It also indicates the 2019 and assumed 2030 volumes of

passenger-kilometres of KLM. Note: the IPCC in fact asks for a reduction compared to 2010, which would further reduce the volumes.

KLM assumes an increase of transport volume of 25.7% in 2030 compared to 2019. This means that **based on concrete planned measures the outcome would be a 5.8% *increase* of absolute emissions** rather than a decrease by 12% as claimed by KLM. Furthermore, if KLM were to be treated like a 'normal' sector, **achieving an IPCC compatible goal of -45% absolute reductions would require a reduction of the transport volume of between about 21% and 35%.** The 21% refers to the assumption that KLM realises the full 30% carbon intensity target, while the higher volume reduction would be needed if only the currently certain carbon intensity improvement is accounted for. **This fact illustrates the importance of discussing volume growth in the outcome of total emissions in 2030**.

5.3 Fleet renewal

5.3.1 Introduction

Fleet renewal is a common argument from the aviation industry to show their environmental achievements. It is mentioned by all scenario studies we presented in chapter 3. Also, KLM (2023a) mentions it and expects the planned fleet renewal to reduce the carbon intensity by 12%. This raises questions like what part of the intensity reduction target is achieved by replacing old with new aircraft and how pro-active KLM is - and has been – in fleet renewal. An underlying question is whether fleet renewal can be seen as a sustainability measure with some economic advantages or as a necessary economic measure with some environmental benefits?

Table 6: emission factors and index for a representative sample of 5473 international flights from Dutch airports. Sources: (Eurocontrol, 2020; FlightRadar24 AB, 2021; Peeters & Reinecke, 2021).

Airline	**Emissions (kg /skm)**	**Index (all other airlines = 100%)**
KLM-group	0.080	99%
All other airlines	0.080	100%
KLM+Cityhopper	0.083	103%
Transavia Holland[9]	0.064	79%
Legacies (10 largest at Dutch airports)	0.085	106%

We first assessed the 2019 fuel efficiency of KLM at the network level. We gathered data for a sample of seven days of flights in the year 2019 and calculated the average emissions per seat-kilometre considering not only the exact aircraft types and distances flown, but also the cabin layout that determines the number of seats on board and the division over different classes. Table

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[9] Transavia has a relatively low emissions factor because it is a low-cost carrier with a high-density seating, which thus causes relatively low emissions per seat.

6 shows that the KLM-group (KLM, KLM Cityhopper and Transavia Holland) are only 1% more efficient than the average of other airlines at Dutch airports. However, the core KLM group – excluding Transavia - is 3% less efficient, but 3% points better than the ten largest legacy airlines at Dutch airports[10]. **The conclusion is that in 2019 KLM was an average airline with respect to fuel efficiency per skm**. Note that KLM in 2023 introduced new low density seating classes (World Business Class and Premium Comfort Class (KLM, 2023b), **which may reduce the number of seats per aircraft and thus increase the emissions/skm**. To tackle the last question: Bağcı and Kartal (2024) describe models that assist airlines to decide on their fleet renewal policies. They see six main criteria in that process: "purchase cost, fuel capacity, maximum seat capacity, range, maximum take-off weight, and cargo" (Bağcı & Kartal, 2024, p. 1). Furthermore, they define the goal of the fleet renewal process to grant "airline companies a competitive edge and <ensure> the efficient utilization of sectoral, environmental, and economic resources" (Bağcı & Kartal, 2024, p. 2). In other words, environment is only an indirect criterion through the operating cost and may help the airline when environmental constraints – generally noise limitations - are at play at airports in their network. So, fleet renewal is primarily an economic act, optimising the interplay of a range of operational and acquisition costs. **The process of fleet renewal is driven by economics, not environment, and does not simply result in the lowest fuel consumption and CO_2 emissions**.

5.3.2 KLM's fleet renewal strategies

One way to assess an airline's fleet renewal strategy is by investigating whether the airline was often a launching customer for a new aircraft type. Launching customers take a risk as they are the first airline to start operations with a new type, but they also get influence in the detailed design of the aircraft. Competitors to KLM, like Air France (before the merger), Lufthansa, British Airway and Pan American, all have been launching customers for jet aircraft types developed by Boeing or Airbus. KLM was never a launching customer in the jet age, except recently for the Airbus A350 freighter. In 1920, KLM was the launching customer for the Fokker III[11].

Interestingly, KLM recently showed some contrarian aircraft acquisition behaviour. For instance, as late as in 2019 KLM took delivery of four B737NG (Noack, 2023), including the very last that has been build (Hemmerdinger, 2020). The technology level of this aircraft is over 22 years old. A newer type, the B737 MAX, has been on offer since 2011[12] and thus represented a nearly 10 years' old technology in 2019. But KLM failed several times to buy new aircraft from the newest type and technology available. We found similar behaviour when, between 2015 and 2022, KLM took delivery of B777-300ER aircraft, while in the same years the far more efficient B787 was also on the market. Our conclusion is that **KLM does not have a history of buying the newest aircraft with the highest efficiency**.

Another more general way to look at fleet renewal is to calculate the fleet age. The 'age of the fleet' is often mentioned to proof the airline has an environmentally up-to-date fleet. However, this age is generally based on the dates each individual aircraft was added to the fleet. This age may be of interest for the service level and cabin quality to passengers, but it is not relevant for the environmental performance such as the fuel efficiency. The last B737-800NG's KLM bought would in such a calculation be considered brand new, but the efficiency is determined by the time

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[10] These are Aer Lingus, Air France, Alitalia, Austrian Airlines, British Airways, Delta Air Lines, Lufthansa, Scandinavian Airlines, Turkish Airlines, and United Airlines. These airlines were responsible for 18% of all flights, while KLM took 46%.

[11] See http://www.dutch-aviation.nl/index5/Civil/index5-2%20F3.html.

[12] Source: https://en.wikipedia.org/wiki/List_of_Boeing_737_MAX_orders_and_deliveries

the B7370-800NG was designed. And that is a much older age. The environmental performance is mostly determined by the age of the technology of an aircraft type. It is the entry into service (EIS) year that determines the technological age of each aircraft of a certain type.

The technical age is always higher than the age of aircraft based on the year it enters the fleet. The technical age is the factor mainly determining the efficiency of the fleet, because the difference in efficiency between the first and the last aircraft coming off the production line is low. See Table 7 as an illustration.

Table 7: Fleet age data for KLM and some other airlines. The fleet age has been weighted for the transport-capacity (seats times normal flight-hours) of each aircraft type in the fleet. Sources: own calculations and (Noack, 2023) as cited in Peeters et al. (2023).

Airline	Aircraft age	Type technology age
KLM (excl. Cityhopper, Transavia)	12.1	19.8
Etihad	7.4	14.1
LATAM	10.4	23.3
Ryan Air	10.7	19.8

Figure 7[13] uses historical fleet data from CH-Aviation (2024) and shows in detail the timing of new aircraft acquisition by KLM, including two of the piston-powered aircraft (Lockheed Constellation L-188 and Douglas DC-6). Of these two, KLM purchased the last aircraft being build, while most other airlines already shifted to the newer and more economic jets. The advantage of this lagging was that those piston-powered aircraft were more fuel efficient compared to the first generations of jet aircraft (Peeters & Middel, 2007). But after those two, KLM has not been a particularly early adopter of new technology and in several cases bought some of the last aircraft rolling off the production lines.

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[13] To these data, we added four Airbus A321NEO's from the current fleet data to the historic list, but only for calculating the dates of acquisition, not the fleet technical age calculations as shown in Figure 8 and Figure 9.

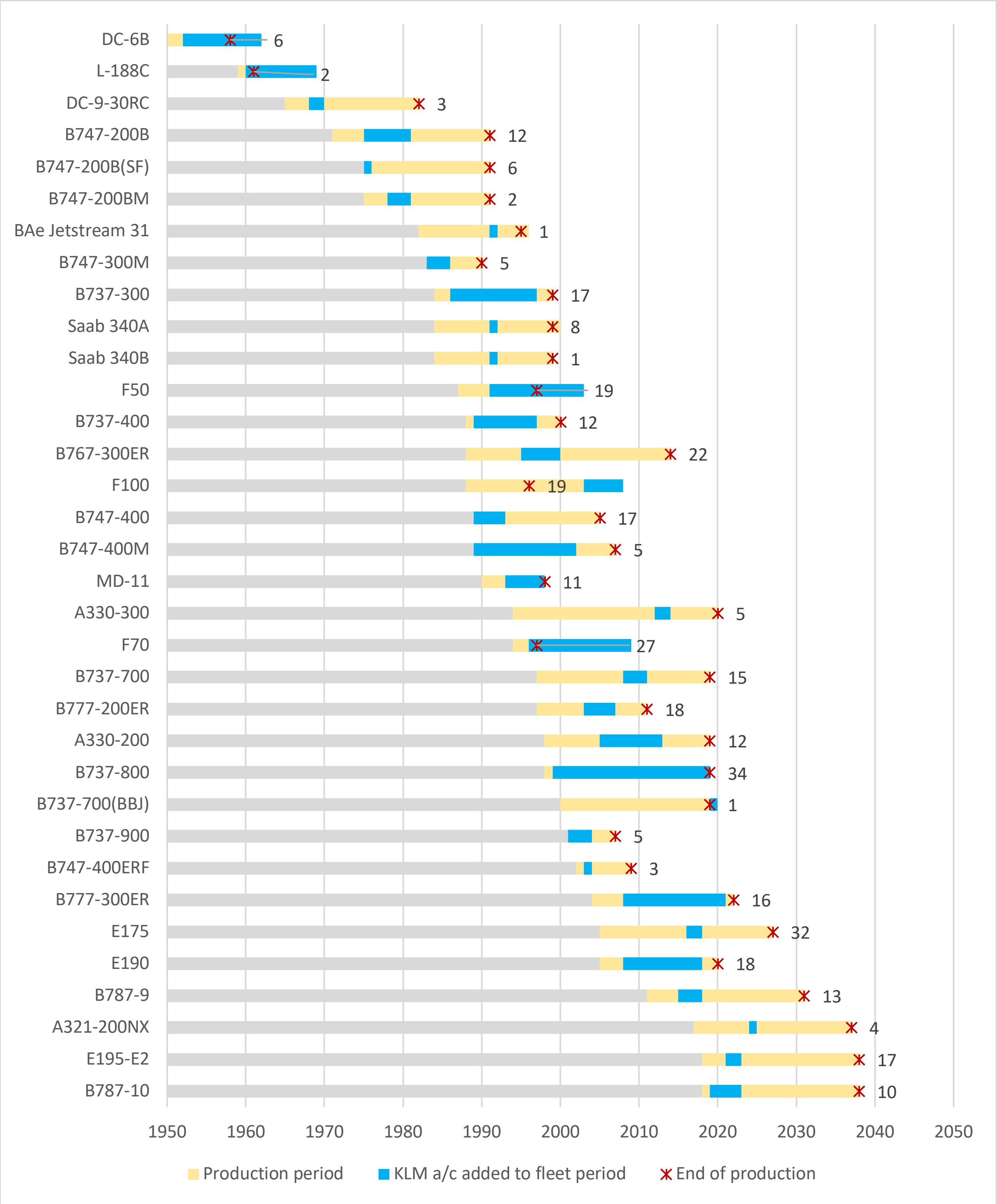

Figure 7: this graph shows how early or late KLM was to acquire aircraft compared to the production period of each of its aircraft variants. The yellow bars show the full production period from first to last delivery. The Blue bar shows the full range of years over which the type entered the KLM-fleet. The 'End of production' indicator shows year in which the aircraft of the type was delivered (estimated for current in production aircraft). Sources: historic fleet from CH-Aviation (2024) and information from several aircraft manufacturer websites and Wikipedia. Note: a/c is 'aircraft'.

Figure 8 is based on a detailed assessment of each aircraft in the historic fleet database (CH-Aviation, 2024) and confirms the impression that KLM is a rather average technology adopter. KLM generally hardly acquired aircraft of types in their first year of production (only 2%), and quite often (16%) aircraft of types in their last year of production. For aircraft types in their 7th year of production (or last seven years of production), the first share is a bit lower than the last share (see last bar in Figure 8.

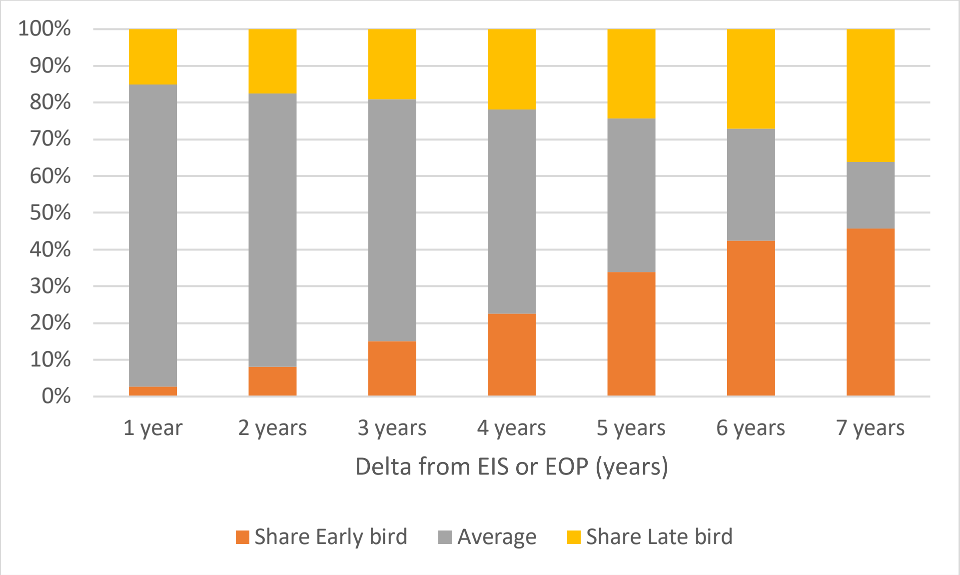

Figure 8: Shares of early and late adoption of new, more efficient aircraft types in KLM's fleet. The vertical axis provides the shares of aircraft acquired within the indicated number of years x from the type's entry into service year (EIS) or end-of production year (EOP). For early birds we calculated the average number of years after EIS Data. Source: historic fleet from CH-Aviation (2024).

Once an aircraft is certified, technically it will not be changed anymore, though often some minor improvements are implemented like some aerodynamic cleaning or engine improvement packages, which may improve efficiency with a few per cent. Figure 9 shows the technology age of KLM's fleet over time. It reveals that the average technical age of the fleet has almost continuously increased since the 1970s from some 5 years to currently close to 20 years' old technology. The early years are based on incomplete fleet data, but from about 1990, the data is more complete. The habit to publish the acquisition age of fleets while communicating about fuel efficiency or climate change, instead of the technical age, means that a too high fuel efficiency is suggested. **By publishing acquisition age in the context of climate change mitigation, KLM suggests a 6 to 9 years younger fleet than technically is the case, implicitly suggesting a 10% to 14% too optimistic fuel efficiency and carbon intensity.**

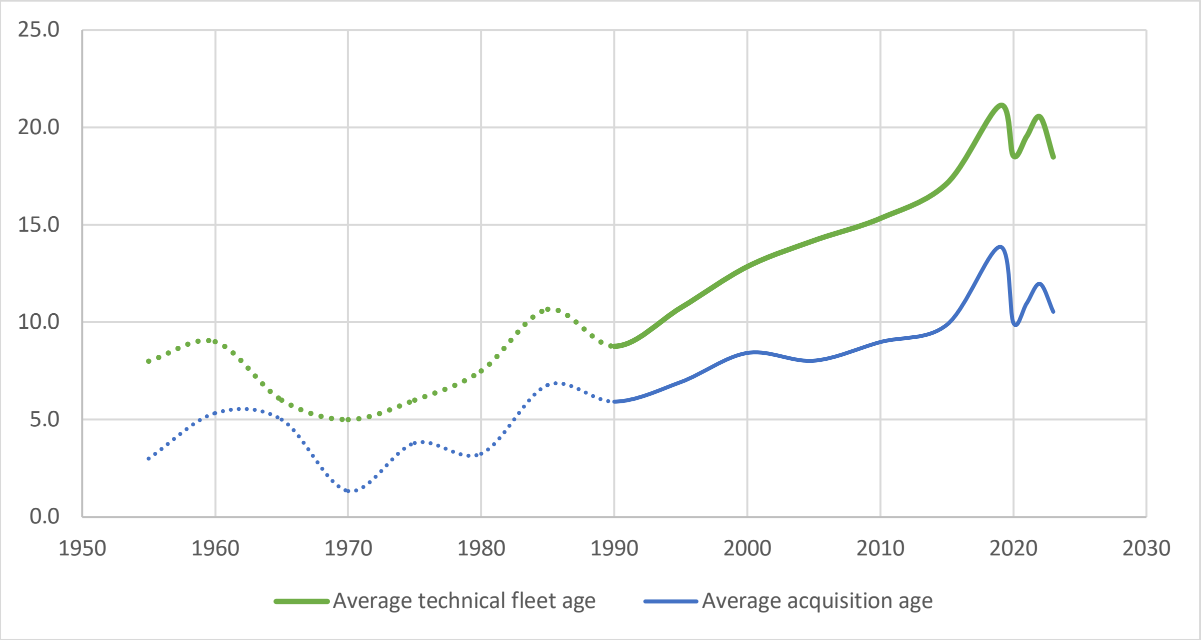

Figure 9: this graph shows the development of KLM's average fleet age (unweighted for the size and productivity of the aircraft). The technical age refers to the age compared to the entry into service (EIS) year of the aircraft type, while the acquisition age is the average of the age compared to the entry into the fleet of each individual aircraft. Note: dotted lines based on incomplete fleet data. Source: historic fleet from CH-Aviation (2024).

5.3.3 KLM future fleet and efficiency gains

KLM (2023a) claims that their fleet renewal plans will improve the carbon intensity by 12%. The data described above (section 5.3.2), allow us to calculate a more optimistic scenario: what if the KLM had been a frontrunner in fleet renewal enabling the KLM to finalise the renewal of the fleet completely by 2030? We assessed this by taking the current (2019) fleet for 2030, but replace all current aircraft with the newest aircraft types that KLM already has in the order book. Table 8 shows our assumed conversion from current to new aircraft types based on (KLM, 2023a, 2024).

Table 8: assumed KLM Group fleet replacements by 2030. 2030 types between brackets mean no change because the best technology is already applied in 2019.

2019 aircraft type	2030 aircraft type
A332	A359
A333	A359
B737	A20N
B738	A21N
B739	A21N
B744	B78X

2019 aircraft type	2030 aircraft type
B772	A359
B77W	A359
B789	(B789)
B78X	(B78X)
E190	E295
E295	E295
E75L	(E75L)

Overall, this hypothesised full fleet renewal scheme would mean that KLM's new fleet would improve its fuel efficiency by 18% between 2019 and 2030, as compared to the 12% resulting from the partly executed fleet renewal published by KLM (2023a). This is the result of a 14% reduction of total emissions, assuming the same flights in 2030 with the renewed fleet as were flown in 2019 with the 2019 fleet, and the fact that the newer aircraft provide 5% more capacity. This additional seat-capacity ignores the new seat classes KLM introduced (KLM, 2023b), which use more space, and thus the capacity may be a couple of per cent lower (see Table 9). Note: these results only show passenger flights for a sample of in total seven days in the year 2019. Total emissions are thus 52 times higher for the whole year 2019, amounting to almost 6 Mton, which covers only the outbound flights. The total is about double this figure, which exactly matches total emissions mentioned by KLM (2023a), showing our sample of seven days to be representative for the whole year.

Assuming the hypothetical completely renewed fleet in 2030, the overall carbon intensity we calculated in section 5.2 of 20.4% improvement would rise to 26.0%, which is still 4% points (13% in relative sense) short of the SBTi 30% goal. We conclude that **KLM's hesitant fleet renewal policy caused KLM to miss one third of the potential fleet renewal induced carbon intensity improvement**.

Table 9: effect of a hypothesised (almost) complete fleet renewal of KLM Group' 2019 fleet assuming a representative set of flights for 2019.

Topic	Total emissions (ton)	Capacity (10^6*skm)	kg/skm
KLM-group 2019 fleet	114,850	1,443	0.0796
KLM-Group 2030 new fleet	98,730	1,520	0.0650

Topic	Total emissions (ton)	Capacity (10^6*skm)	kg/skm
Improvement[14]	-14%	5%	18%

5.3.4 Zero-emissions aircraft

The KLM climate plan pays some attention to revolutionary technology. With this, they mean the development of entirely new, zero-emission aircraft. The basic options for zero-emission technology are all described by KLM (2023a): electric aircraft powered by batteries, electric aircraft powered by fuel cells, and jet aircraft burning hydrogen. Also, hybrids between one of the above options and a conventional jet or turboprop engine are now in development, like some two-engine aircraft with up to 30 seats with one normal and one electric engine (Bjerregard, 2022; Norris, 2023). The three technological pathways provide various opportunities and challenges.

The battery-based solutions suffer from the high weight of batteries and are not likely to serve larger aircraft than those with a short range and only a few seats (Epstein & O'Flarity, 2019), though some see wider opportunities when a hybrid is applied (Pornet & Isikveren, 2015; de Vries et al., 2024).

The second option, based on fuel cells, has far better perspectives as both United Hydrogen and ZeroAvia currently show - with testing aircraft - air transport capabilities of over 1000 km range and up to 50 seats compliant with the short-haul markets. This option, if fuelled with green hydrogen, will not only reduce CO_2 emissions of aviation to zero, but will also avoid all non-CO_2 impacts, because this type of aircraft will not emit anything else than water and will generally not fly at altitudes prone to contrail forming (Noland, 2021).

The final option, burning hydrogen in jet engines, will not emit CO_2 in flight and not in the fuel production process if green hydrogen is used. But there are some technological challenges with this solution. One is the space aboard an aircraft required for the low-density hydrogen, eroding both payload and range performance. Furthermore, burning hydrogen will still generate and emit nitrogen oxides and large quantities of water vapour at altitudes that are prone to contrails. However, as with SAF, detouring such areas could be done at no CO_2 emission penalty. Airbus (2023) arrived at the same conclusion that for transport aircraft, both fuel cells and hydrogen in jet engines are the most promising solutions. A major issue is that most emissions are generated by long-haul flights, while it will be the short-haul zero-emissions aircraft that may first enter the market as KLM acknowledges. Also, ICAO (2022b) expects no significant impact before 2050.

Though KLM spends several pages on these revolutionary zero-emissions aircraft, their role in developing them is restricted to assigning a former pilot to coordinate the development with partners, and some collaboration with Delft University students, the Netherlands Aerospace Centre and the Electric Flight Connection. The latter concerns training KLM pilot-students in electric trainers, avoiding the emissions of initial flight-training. Furthermore, they collaborate with some undisclosed parties in the interest of hydrogen technology. KLM does not seem to collaborate

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[14] Note that Table 9 ignores the freighters in KLM's fleet. KLM will also replace the remaining four B747-400 full freighters with the new A350 freighter. Peeters, P., Buijtendijk, H., & Eijgelaar, E. (2023). *KLM, science-based targets, and the Paris Agreement. Expert Report*. Breda University of Applied Sciences. Peeters et al. (2023) assessed the potential impact of this part of fleet renewal. They found, the improvement for the four aircraft is 28%. But this would not change our overall rounded improvement of 18% for passengers alone.

substantially with one of the aircraft manufacturers like ZeroAvia or Universal Hydrogen, now most advanced in developing short-haul zero-emissions transporters. Other airlines, like United (CDP, 2024c), Japan Airlines (AW&ST, December 11-24, 2023, p. 9) and Universal Hydrogen claim to have collected up to 250 conversion orders for fuel cell retrofit kits (Norris, 2023). KLM does not seem to be one of these clients, so we conclude that **KLM does describe the zero-emissions aircraft situation relatively accurate, but is not taking much of the development risks**, which matches their fleet renewal strategies as described in section 5.3.2.

5.4 Efficient operations and transport logistics

Operation efficiency covers a range of small improvements. Internally, an airline can train their pilots for more fuel saving flying skills, remove unnecessary weight from flights, improve maintenance, etc. Next to these improvements, the aviation sector - KLM included - always mentions the operational inefficiencies caused by air traffic control (ATC) issues. Particularly in Europe, with its small countries with a national ATC sector each, causes some inefficiencies (EASA et al., 2023), averaging around 2-4% in terms of additional aircraft kilometres flown as compared to the shortest distance physically possible. The Single European Sky (SES) plans are being developed to mitigate these inefficiencies and KLM (2023a) expects some 2% carbon intensity improvement can be realised if this SES would be implemented by 2030.

Another efficiency issue, almost ignored by the aviation sector, is the larger distance passengers must cover to travel from A to B as compared to the shortest (great circle) distance possible. In aviation, two basic network types exist: the ‘’point-to-point’ or ‘fully connected’ network, and the ‘hub & spoke’ network. Initially, aviation developed through fully connected networks, meaning that for every line, direct connections are provided, and transfer are uncommon and not designed by the airlines. However, a hub & spoke network provides opportunities for much higher connectivity and frequencies (Brueckner & Zhang, 2001). To understand this, imagine a hypothetical network of five airports: one in the middle and four on the edges around it. In a fully connected network, one would have to provide 10 different direct connections: four between the centre airport, and six between the surrounding four airports. However, one could suffice by just providing the four direct flights between de main airport and the four satellites. By arranging these flights to arrive and depart all around the same hour of the day, one provides all 10 connections, with a maximum of one transfer at the main airport. Given a certain demand, this allows for higher frequencies for the four direct connections than in a fully connected network (when the same aircraft types are used, 2.5 times higher frequencies emerge).

However, already in 1998, Nero and Black (1998, p. 293) concluded “that the problem of externalities is exacerbated by hub development”, a conclusion that was confirmed regularly by several authors: “point-to-point networks have the lowest global environmental impact” (Peeters et al., 2005, p. 151), hub bypass networks would save considerable environmental costs (Morrell & Lu, 2007), fuel burn would be about 12% higher in a full hub & spoke network as compared to a more directly connected network (O’Kelly, 2012).

In section 6.3.1 we further explore the impacts of the hub & spoke model on passenger behaviour, emissions and network, in an attempt to assess whether the large share of transfer passengers (60%) in KLM’s business model provides any opportunities to provide the Netherlands with a reasonable network quality but less traffic volume, and some climate justice consequences of this phenomenon.

5.5 Sustainable aviation fuels (SAF)

Sustainable aviation fuels (SAF) have been proposed since the 1980s to reduce the CO_2 emissions of aviation (Azar et al., 2003). Particularly, biofuels were included in scenario studies. Currently, the aviation industry heavily relies on SAF (Dubois et al., 2023) and KLM is no exemption. ICAO (2022b) distinguishes three basic groups of SAF: biofuel (SAF-B), waste-based fuel (SAF-W) and synthetic e-fuels (SAF-E). Each of these SAFs has its advantages and limitations. The biofuel variant has been increasingly criticised for its large space-use and potential competition with both nature and agriculture (Suzan, 2023; The Royal Society, 2023). Another issue is that the life-cycle emissions of biofuels are between 65% and 80% (Meerstadt et al., 2021). The latter means that even 100% SAF-B use would not enable zero-emissions. The main reason for SAF-B's large land-use is the low energy conversion factor of chlorophyl, the green substance in plants that is responsible for photosynthesis, converting solar energy to biomass, which is the feedstock for producing SAF-B. Barber (2009) shows this conversion efficiency is only 1-2%, while photovoltaic solar panels typically reach 20% conversion (Blankenship et al., 2011). An additional issue with SAF-B is the energy balance. What is the net balance of energy inputs for harvesting and processing biomass and the energy output of the biofuel? O'Connell et al. (2019) show that the balance as units of energy required for producing one unit of SAF-B energy varies from 0.5 (you have a net gain of energy) to 1.5 (you need 1.5 times the energy to produce only one unit of energy for the aircraft).

SAF-W suffers from the same issues as SAF-B, because it is still based on biomass (The Royal Society, 2023) and thus a low solar energy conversion rate, large land-use and the same levels of process energy apply. For instance, SAF-B produced from 'forestry residue' feedstocks haves an energy balance of 1.3, while short-rotation forestry would even show 2.5 (O'Connell et al., 2019). Of course, using wasted biomass has the advantage that it would otherwise have no impact at all. However, The Royal Society (2023, p. 24) notes for the UK "About 250 million litres of used cooking oil is produced in the UK each year. Much of it is not waste, as it is used to feed livestock, and to manufacture soap, make-up, clothes, rubber, and detergents". In other words, there are issues with the definition of 'waste'. Finally, several of the most appropriate waste feedstocks have very limited availability. KLM orders its SAF-W with Nesté (1 million tons), which uses mainly cooking oil and animal fat waste, and DG Fuels (0.6 million tons), using timber waste, corn stover and cotton gin waste.

The synthetic e-fuels, SAF-E, use CO_2 as feedstock. This CO_2 can be taken from the industry or electricity plants or through direct air capture (DAC) from the atmosphere. Because SAF-E does not use biomass, its land-use and water competition with agriculture and nature is low (Schmidt et al., 2018). One issue remains and that is the overall energy efficiency of the production of SAF-E, which is estimated to become some 42% to 54% (Schmidt et al., 2018), but might currently be as low as only 20%, though with a perspective of increasing to some 60% at mid-century (Peeters & Papp, 2023). The energy must be 100% renewable to achieve near 100% reduction of CO_2 emissions.

Despite the range of sustainability issues with SAF, the Ministerie van Infrastructuur en Waterstaat (2021) describes an aggressive pathway to introduce SAF-W and, later, SAF-E and to produce substantial parts of this in The Netherlands or acquire it elsewhere to be tankered into The Netherlands. This latter idea fails to acknowledge that in the early stages of SAF mixing it is far more efficient to produce the fuel at the places with most renewables available and to tanker it close to where it is produced. As long as a SAF-exchange would guarantee that those who claim SAF indeed have paid for it, it is no longer important for the reduction of the emissions where the fuel is exactly used (Peeters & Melkert, 2024).

Most forms of SAF will be ‘cleaner’ than fossil kerosene and this might result in an up to 26% lower chance contrails and aircraft-induced clouds (AIC) will develop (Märkl et al., 2023). As contrails and AIC are responsible for about two-thirds of the non-CO_2 effects, 100% SAF-mixing may reduce non-CO_2 impacts by 17%. A first step could be to use hydrotreated Jet A as proposed by KLM (2023a), but not yet implemented. The cost of such a fuel would be just a few per cent more than of the currently most used Jet A (Faber et al., 2022).

KLM mixed 0.8% SAF in 2022 and increased this by 50% to 1.2% in 2023 (KLM, 2024). Based on data provided in the annual report of 2023 (KLM, 2024), this added some 2.9% to KLM’s fuel cost. Apparently, SAF is 2.5 times more expensive than fossil fuel. KLM has contracted a total of 1.6 million tons for the period 2023-2036. SAF from Neste and DG Fuels typically use feedstocks like renewable waste and residue raw materials such as used cooking oils and animal fat waste[15] and agricultural waste like sugarcane waste[16]. A full list of feedstocks used for the SAF acquired by KLM does not seem publicly available, but Neste claims to follow the RED II European regulations for eligible fuels.

KLM assumes their SAF to remove 80% of carbon from the lifecycle of the fuel, which is in line with numbers published by the two factories. This means that the goal to use 10% SAF by 2030 would remove 8% of the CO_2 emissions.

5.6 Non-CO_2 in KLM’s climate plan

The climate impact of non-CO_2 is large but difficult to weigh against CO_2 impacts (see section I.IV of Annex I). The methodology of SBTi does not require a goal for non-CO_2. Still, a failure to address non-CO_2 impacts by 2050 would mean a failure to comply with the Paris agreed 1.5 °C goal. KLM’s climate plan does not integrate non-CO_2 impacts, because “actions to limit non-CO_2 climate effects often result in increased CO_2 emissions, and because of a lack of scientific pathways” (KLM, 2023a, p. 9). Therefore, the “non-CO_2 climate effects that may also contribute to aviation-induced warming are not included in this target, but we will find ways to discover opportunities for mitigating them” (KLM, 2023a, p. 17).

KLM (2023a) announces two actions that may contribute to reduce non-CO_2 impacts: switching to more pure fuel like hydro treated Jet A-1 and SAF, and participation in the SATAVIA project (SATAVIA, 2024). As section 5.5 shows, a 100% replacement of fossil kerosine with SAF has the potential to reduce the non-CO_2 impacts by some 17%. A similar improvement might be achieved with hydrotreated Jet A (Faber et al., 2022). Note that there is ample evidence that current aviation transport growth projections are incompatible with 100% SAF mixing when aviation is allocated reasonably available feedstock resources and renewable energy (see section 6.2).

The SATAVIA project aims to experiment with the idea that applying flightpaths along low contrail-prone routes may reduce the forming of persistent contrails and aircraft-induced clouds (AIC) (van Manen & Grewe, 2019; Molloy et al., 2022; Simorgh et al., 2022). The problem with SATAVIA is not so much the attempt to experiment with avoiding contrails, but the idea to create a business case by selling the avoided contrail impacts as carbon credits is worrying for the following reasons (Peeters et al., 2023, p. 33):

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[15] Sources: https://www.neste.com/products-and-innovation/sustainable-aviation/case-stories/how-delta-and-neste-are-working-toward-making-flying-more-sustainable and

[16] Source: https://louisiana.dgfuels.com/.

1. “The effect of contrails and cirrus clouds is about equal to the accumulated amount of aviation’s emissions since 1945, which means that per avoided contrail, a very large amount of CO_2 credits can be claimed at extremely low cost (Klöwer et al., 2021a).
2. The simple exchange of contrails versus CO_2 ignores the large impact of intra- respectively the inter-generation effect (see explanation section I.IV of Annex I). Actually, in this way aviation would swap intra-generational problems by inter-generational climate impacts, which may partly last for over a thousand years (Alonso et al., 2019).
3. Compensation is not credited by SBTi.”

Still, experimenting with contrail avoidance is a just investment, but better without the offsetting business case as in the example of Boeing and NASA (Gates, 2023). In general, avoidance techniques cause a fuel burn penalty which is problematic if fossil kerosene is used. But as soon as 100% e-fuels are used, the CO_2 emission penalty becomes zero and contrail avoidance highly viable. Overall, KLM only reduces non-CO_2 emissions through its efficiency measures and slightly through the SAF mixing. **KLM has no specific non-CO_2 reduction policy.**

6 Climate justice in KLMs climate plan

6.1 Introduction: the airline climate justice framework

Key Findings

1. In general, aviation is aware of the limitations of its proposed mitigation options, particularly for SAF and e-fuel, and renewables and resource availability. But this is framed as an economic issue, questioning how to safeguard access to sufficient resources to cover aviation's demand, rather than in terms of just and efficient use of those resources.
2. Aviation assumes to be eligible to take a higher-than-average share of the remaining carbon budget because of their assumed hard-to-abate status.
3. This argument is difficult to defend when curbing air transport volume is also a viable and equitable option to achieve zero emissions.
4. Instead, KLM, by its pricing strategy, expands the transfer market and its economic growth and turn-over, a strategy which reduces passenger route efficiency and adds to overall emissions of the airline.
5. The average distance and emissions of a transfer passenger more than double those of the average OD-passenger, making KLM's business model at odds with its climate targets.
6. Though KLM is aware of the difficulties in securing sufficient SAF to become zero-emissions by 2050, it does not acknowledge this in terms of limitations to its growth potential.
7. This analysis shows opportunities to substantially reduce the number of transfer passengers while retaining most of the current OD-connectivity. This would help to cope with the limitations of the mitigation measures proposed by KLM and the subsequent failure to reach climate just targets.

This final chapter assesses the KLM climate plan against the airline climate justice framework shown in Figure 10 based on Zimm et al. (2024). It is important to understand the realm of this chapter. We will provide data about inequalities regarding KLM's current business model, current emissions budget and proposed mitigation in terms of benefits and burdens distribution, but we will not judge whether any of these is 'just' or not. This chapter is to inform the political, societal and scientific debate about climate justice with all kinds of information, data, and considerations.

According to KLM's Climate Action Plan and 2023 Annual report, emissions reduction scenarios play a central role in KLM's stated climate objectives and actions. In this chapter we will discuss in section 6.2 the distributional utilitarian justice issues like shares of the remaining carbon budget (6.2.1), shares of land-use and resources (6.2.2), and renewable energy (6.2.3). The next section (6.3) discusses sufficientarian justice particularly in terms of the effects of detours passengers are made to make due to the hub & spoke networks (6.3.1) and the individual necessity of air travel (6.3.2), the role of aviation in the development of least developed countries (6.3.3), and assumptions about the role demand for air travel projections play (6.3.4). Section 6.4 discusses elements of procedural justice related to the ‘hard-to-abate’ argument. The final section (6.5) provides an overview of how KLM’s Climate Plan is related to the climate justice issues raised.

Based on the climate justice framework provided by Zimm et al. (2024) given in Figure 1, we developed an airline climate justice framework, see Figure 10.

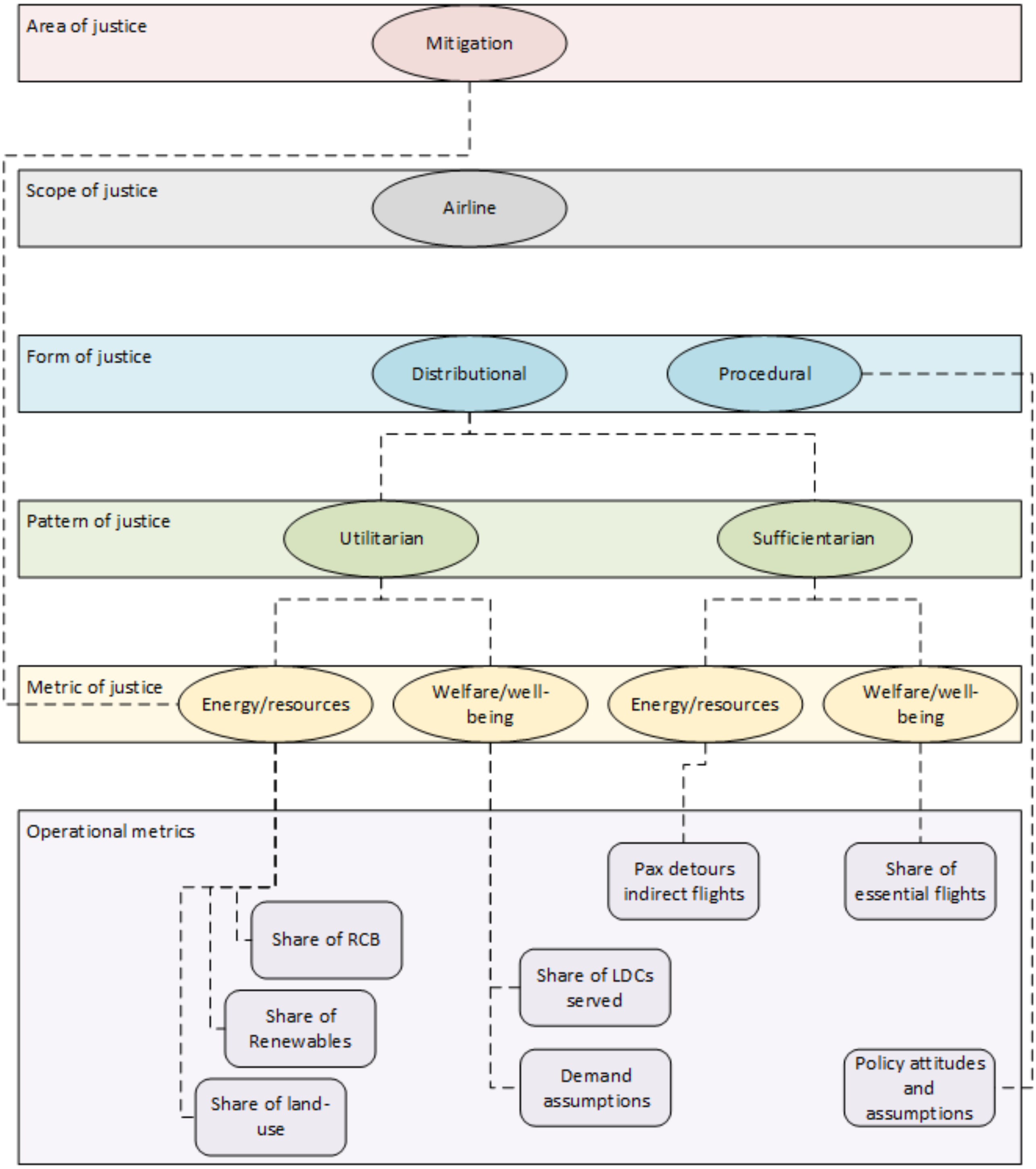

Figure 10: The airline climate justice framework. Inspired by (Zimm et al., 2024).

For the five dimensions of justice, we made following choices (see Figure 10):

- As the ***area of justice***, we have chosen **climate mitigation** as the focus point for an airline. In tourism and travel, of which aviation is a substantial part, one can define climate mitigation policies as policies regarding mitigating emissions, adaptation (of destinations, transport systems) to climate change and of adaptation of both the industry (destinations, tour operators, airlines) and tourists to climate mitigation policies (Dubois & Ceron, 2006). Adaptation is mainly a problem in destinations (Dubois & Ceron, 2006; Scott et al., 2023), though airlines do suffer from atmospheric changes caused by climate change (Ryley et al., 2020), including extreme weather events, flooding and heavy clear-air turbulence[17]. The damages from climate change are unequally distributed over the world, as those who contributed least are likely to be hit hardest (Millward-Hopkins & Oswald, 2021). We will include adaptation to climate mitigation policies, but ignore adaptation to the impacts of climate change itself. So, the increase of for instance severe weather and high-clear skies turbulence on the safety and reliability of air travel (Chen et al., 2021; Koetse & Rietveld, 2009) is not part of our study.
- The ***scope of justice*** for our study is an **airline**, the KLM, but we will derive arguments at both global and national scopes and even on some generational issues, particularly regarding the balance between policies addressing CO_2 and non-CO_2 impacts of air travel.
- The ***form of justice*** chosen is both **Distributional** and **Procedural**. *Distributional justice* – historically at the core of the environmental justice debate (Schlossberg, 2007) – looks at how (scarce) resources should be distributed. Distributive considerations are more often implicit than explicit in climate policies (Zimm et al., 2024). In climate mitigation of aviation, distributive justice considerations revolve around the question of who can claim or use what share of the remaining emissions budget and available energy stock until 2050. *Procedural justice* looks at the fairness of processes. In this form of justice, questions about involvement of different actors, the implications of the decisions of those who have (not) been involved, and the common assumption by policy-developers that aviation is a hard-to-abate sector play a role in determining the set of policies recommended. Distributive and procedural justice considerations can be considered relevant for climate mitigation policies of aviation. The current distribution of emissions from commercial air transport is highly uneven and resembles in part historically rooted inequalities of a geopolitical order that can be traced back to Western colonialism (see e.g. Ghosh, 2021). Gössling and Humpe (2020) for instance find that in 2018 at most 1% of the world population caused more than half of the commercial air transport emissions and that until 2050 most of these emissions will come from Western countries (North America and Europe), petrostates in the Middle East, and China.
- The metrics of justice only apply to the distributional form of justice. For the ***metric of justice*** in aviation both the **welfare effects**, and **energy** are relevant. Travel is typically a hedonic behaviour for increasing the well-being of the traveller and welfare of the travel-providers. Though energy is the bottom-line of the resources for climate mitigation policies, we have also added resources to the distributional issues, because to produce SAF or hydrogen solutions may require large stretches of land, feedstock resources and even rare metals. For each of these metrics, the ***pattern of justice*** can be chosen. We identify that **utilitarian** and **sufficientarian** are most relevant for airlines and aviation.

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[17] This type of turbulence is dangerous, because it is invisible and difficult to predict.

The *utilitarian* pattern of justice, and particularly the limited economic variant of it[18], is important because it is the dominant principle of global aviation emissions reduction policies. Utilitarianism does not directly question consumption growth as we have seen in section (3.5). As explained by Zimm et al. (2024), the economic variants of utilitarianism seek maximalisation of total welfare by means of selecting economically optimal pathways assuming that consumption contributes to welfare. Utilitarianism applies the cost-effectiveness principle to prioritise least cost emission reductions over high-cost reductions and does not distinguish between essential and non-essential emissions. In contrast, the *sufficientarian* pattern of justice seeks to define a threshold of consumption that still meets basic human needs and living standards (Zimm et al., 2024). In economic utilitarian analysis, the willingness to pay is generally leading and therefore does not distinguish between emission reductions essential for survival and human decency and emissions inessential for human survival or decency (Shue, 1993). The sufficientarian pattern of justice is relevant here as air travel consumption growth has outpaced beneficial effects of technological innovation (see section I.II in Annex I). As low, middle- and high-income segments of the world population expand, technological solutions have to reduce impact but also compensate for the effects of increasing affluence (Wiedmann et al., 2020). This is particularly relevant for aviation, as mobility related consumption disproportionately increases with income (Wiedmann et al., 2020).

6.2 Distributional utilitarian justice

6.2.1 Share remaining carbon budget

The remaining carbon budget (RCB) is defined as “the amount of remaining allowable CO_2 emissions that is consistent with limiting global warming to a specified temperature target (such as 1.5 °C warming above the pre-industrial) with a given probability” (Dickau et al., 2022, p. 91). Dickau et al. (2022) find some general conclusions consistent for RCB calculating methods: (1) the RCB for 1.5 °C is small, and on the order of several hundreds of Gt CO_2 (best estimate in IPCC, 2023 is 500 Gt CO2), (2) the RCB for 2 °C is expected to be in between 1000 and 1500 Gt CO_2 (best estimate in IPCC, 2023 is 1150 Gt CO2), (3) the RCB for 2 °C has a wider range of uncertainty than 1.5 °C RCB, and (4) there is a low (but non-zero) probability that the RCB for 1.5 °C has already been exceeded. An additional factor is that each RCB is accommodated by a chance for staying within the goal temperature. Generally, these chances vary between 50% and 66%, meaning that there is 34-50% chance the budget does *not* prevent the envisioned temperature rise. RCB estimates need to be updated regularly, following scientific understanding, RCB exhaustion by continued annual emissions and mitigation progress (Damon Matthews et al., 2021).

A main issue is how to distribute the RCB over countries, sectors and companies. Nationally determined contributions’ (NDC) goals were initially determined by each country, but then later added and reshaped to still reach the overall global goal (van den Berg et al., 2020). Issues are that fairness is generally based in effort-sharing (per capita or per unit of economy), but contributions to climate change from the past, including grandfathering[19] (Knight, 2013), can heavily influence the result. Anyway, according to van den Berg et al. (2020, p. 1805), for developed countries, “all

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[18] Note that utilitarian analyses may also be defined for non-economic utilities like the value of being in unspoiled nature or of clean water in lakes and rivers.

[19] “Emissions grandfathering maintains that prior emissions increase future emission entitlements. The view forms a large part of actual emission control frameworks, but is routinely dismissed by political theorists and applied philosophers as evidently unjust.” (Knight, 2013, p. 410)

effort-sharing approaches except grandfathering lead to more stringent budgets than cost-optimal budgets, indicating that cost-optimal approaches do not lead to outcomes that can be regarded as fair according to most effort-sharing approaches.” Turning to the aviation sector, ICAO (2022b) calculated that international aviation would consume between 4.1% (IS1) and 11.3% (IS3) of the global RCB of circa 400 Gton CO_2, which translates to about 6.1% respectively 17% when domestic aviation would be included. Cames et al. (2023) propose the emissions share in 2018 as a ‘fair share’ for the RCB, which was 1.7%. This means that in the LTAG IS1 scenario, aviation takes 3.6 to ten times its ‘fair share’ based on the current share.

Based on the global scenarios given in Figure 2 we drafted Table 10. None of the scenarios reach the fair share of 1.7% in their budget use, while the overshoot is generally around 400%. Only the ‘Envisioning 2030’ scenario comes relatively close to the 1.7% share proposed by Cames et al. (2023).

Table 10: RCB shares of aviation in various scenarios as approximated by the data given in Figure 2.

Scenario	Accumulated emissions (Gton)	Share 1.5 °C budget	Overshoot of 1.7% fair share (Cames et al., 2023)
ATAG	22.1	5.51%	324%
ICAO (LTAG IS1)	69.4	17.36%	1021%
ICAO (LTAG IS2)	44.3	11.07%	651%
ICAO (LTAG IS3)	26.9	6.73%	396%
ICAO (P.29)	26.6	6.66%	392%
SBTi	23.1	5.78%	340%
Envisioning 2030	11.5	2.87%	169%

Grebe et al. (2024) have investigated two IPCC global RCBs for determining remaining carbon budgets for global and for Dutch aviation: the 500 Gt budget (50% likelihood that global warming is limited to below 1.5 °C) and the 700 Gt budget (67% likelihood that global warming is limited to below 1.7 °C). The second budget is not in line with limiting global warming to 1.5 °C, and the extent to which this budget is Paris-aligned is debatable. The authors have allocated the remaining carbon budget for global aviation’s 2019 CO_2 emissions share of minimal 2.4%, and maximum 3.9%.

A decreasing share, justifiable from a luxury product and inequal access perspective, is not pursued. Non-CO_2 effects are excluded. With a 2.4% share, the two RCBs for global aviation would be 12.0 Gt and 16.8 Gt respectively; with a 3.9% share 19.5 Gt and 27.3 Gt respectively (see Table 11). The upper bound for a Dutch aviation budget is a 1.5ºC pathway-aligned 205 Mt which, with current level of emissions, would be exhausted around 2038. Based on a 3.9% hard-to-abate share, this would require at least 30% CO_2 reduction in 2030. With a 2.4% share, CO_2 emissions would need to be 77% lower in 2030.

Table 11: Overview of carbon budgets for global aviation and Dutch aviation. Source: (Grebe et al., 2024)

Global RCB	**50% 1.5° (500 Gt)**		**66% 1.7° (700 Gt)**	
	Global Aviation RCB	Dutch Aviation RCB	Global Aviation RCB	Dutch Aviation RCB
Current share of aviation 2.4%	12.0 Gt	126 Mt	16.8 Gt	176 Mt
IEA NZE share of aviation 3.9%	19.5 Gt	205 Mt	27.3 Gt	287 Mt

Grebe et al. (2024) show that the share of Dutch aviation of global aviation volume (number of flights) is currently 1.16%. When the global carbon budget would be distributed proportionally to countries by shares of the world population in the period of 2019-2050 – ignoring economic development or countries' current aviation, the share of the Netherlands would be only 0.21% or 5.5 times less than the current share of aviation (Grebe et al., 2024). **The conclusion is that aviation assumes to be eligible to take a higher-than-average share of the remaining carbon budget rather than accepting a reduction of its volume to align with other sectors**.

6.2.2 Share land-use/recourses

Fuel supply issues are a key financial risk for airlines and securing fuel supply (any fuel) is a key risk mitigation activity of KLM. KLM spreads risks by having multiple suppliers and multiple supply methods to its hub, Schiphol Airport (KLM, 2024). In its 2023 annual report, KLM lists several SAF-related transition risks: jet fuel price increases due to SAF mandates and new carbon taxes. First, they see a legal and political risk as "insufficient support from governments regarding SAF and synthetic fuel deployment". Second, the exposure to "litigation linked with low credibility of SAF for decarbonisation or use of feedstock causing adverse environmental outcomes" is a reputational risk. Third, the inability to secure sufficient SAF volumes and/or competitive prices for SAF "to meet public targets" is a technological risk (KLM, 2024, p. 101). Securing sufficient supplies of SAF appears to be a key matter for KLM to meet its SBTi targets.

In its Climate Action Plan, KLM explains that it has the ambition to replace 10% of their fuel use by SAF in 2030. In 2023, the actual share of SAF accumulated to 1.2%, 50% up from the 0.8% in 2022 (KLM, 2024). Based on data for KLM (KLM, 2024) and the Boeing Cascade model (Boeing, 2024), we calculated that KLM consumed 1.38% of all globally produced SAF in 2023. By 2030, the 10% SAF KLM share want to use would amount to 1.5% of all SAF expected by the Cascade model to be globally available. However, IATA (2023b) expects a much lower production of SAF. Based on IATA's numbers, KLM used 7.7% of the global production in 2023. IATA (2023b) also provides a projection of the production in terms of the 'need' for SAF based on their Net-zero 2050 scenario. Based on this needed amount of SAF and what KLM plans to use (10% in 2030), the share of KLM reduces to 2.0% of the global needed production. However, this share would increase to 5-6% if KLM would also acquire the 'additional' amount of SAF we calculated as necessary to meet their own 30% carbon intensity target in 2030 (see section 5.2).

In its Climate Action Plan, **KLM displays that the company is aware of the difficulties in securing sufficient SAF up to 2050**. It refers to a recent study by NLR on the supply of feedstocks for more sustainable aviation fuels in the Netherlands (Meerstadt, 2021). KLM concludes from this study that it is not realistic to assume that all available bio-based feedstock (domestic and imported) will be allocated to aviation and that domestic supply can only meet a fraction of anticipated demand. Therefore, it presents e-fuel as solution, as the supply of this type of SAF is not constrained by feedstock supply. KLM is aware that "it depends heavily on the amount of excess renewable electricity allocated to the aviation sector" (KLM, 2023a, p. 37). NLR is a bit less optimistic in their formulation: e-fuel supply relies on a) the potential amount of excess renewable energy produced in the Netherlands (so there should be more supply than demand in other sectors first) and b) the amount of this excess demand available for the aviation sectors (Meerstadt, 2021). Section 6.2.3 further explores renewables constraints to the production of e-fuels.

6.2.3 Share renewables

The chemical industry and aviation are the only sectors where final energy consumption is expected to increase towards 2050 (IEA, 2023b). In the leading aviation roadmaps, including that of the IEA, the energy demand of global aviation is expected to range from 9 to 16 EJ in 2030 and 14 to 25 EJ in 2050 (IATA et al., 2024). To put this in perspective: IEA estimates a total global final energy consumption of 340 EJ in 2050 in its 2023 NZE scenario, from 442 EJ in 2022. Biofuels are suggested to be able to cover a share of 33% of final aviation energy consumption in 2050, and e-fuels 37% (IEA, 2023b). A share of 70% of all fuel is thus to be replaced by SAF, partly SAF-W, enabling some 60-65% emissions reductions. That is far from zero, particularly as this reduction comes with an increase in fuel of some 50% in 2050 compared to 2019.

Energy demand of Dutch aviation is expected to increase from 167 PJ in 2019 to 200 PJ in 2050 (range 140-240 PJ). Extra high SAF blending could lead to slightly lower energy demand due to lower air travel demand, stabilizing at 170 PJ in 2050. In a SAF-focused scenario this would require some 120 PJ from SAF and 50 PJ from e-fuels in 2050. In an e-fuel-focused scenario 50 PJ from SAF, 100 PJ from e-fuels and 20 PJ from hydrogen (Davydenko et al., 2024). Van der Sman et al. (2021) estimate an energy need of 83 – 131 PJ to produce e-fuel for Dutch aviation in 2050**.** However, in the aforementioned e-fuel scenario (Davydenko et al., 2024), only 60% of SAF is e-fuel, while zero-emissions cannot be achieved with other forms of SAF and the assumed 12% of hydrogen seems rather optimistic. Therefore we have increased the e-fuel share to 100%. When we apply that to power capacity calculations of Van der Sman et al. (2021) e-fuel production would require the equivalent capacity of up to five 12 TWh nuclear power plants or that of 1,590 12 MW wind turbines, occupying some 1,700 km^2 of North Sea wind space. Geilenkirchen et al. (2024) also conclude that the renewable energy demand in 2050 will possibly amount to 38% to 92% of the envisaged Dutch wind energy capacity. Davydenko et al. (2024) even arrive at 80% of all envisaged wind turbine capacity for replacing 70% of all fossil kerosene, i.e. more than 100% of Dutch wind energy when all kerosene is replaced. Clearly, an e-fuel powered aviation sector would use very high shares of renewable energy in the Netherlands; likely a much higher one than the current direct added value of Dutch air transport to the Dutch economy of 1.2% (CBS, 2024). For Schiphol Airport, added value to the Dutch economy, including indirect and induced added value, might amount to 2% to 8% (Burghouwt et al., 2017). **A large company with a couple percent added value taking 100% of all wind energy, is at odds with a fair distribution of precious renewables in high demand.**

Renewable energy costs and availability, as well as space capacity, will likely lead to imports of e-fuels and feedstocks from abroad. Meerstadt et al. (2021) expect that Dutch biomass resources can only meet some 15% of demand for aviation fuel. These authors estimate that the electricity demand to produce synthetic fuels for Dutch aviation could in theory be met on the domestic market, if all excess renewable energy were to be allocated to this.

An important question in terms of climate justice, is how renewable energy is distributed between regions, people and sectors. Only Peeters and Papp (2023) performed a serious attempt to determine the consequences of such a fair-share constraint. They assumed that the renewables share for aviation should never rise above some 10%. This is the share for the whole tourism and travel sector, though the majority goes to aviation's e-fuels. The 10% is about the share of the wider tourism & travel industry in the global economy, including indirect and induced economic impacts (WTTC, 2021). The direct economic impact of the T&T sector is about one-third of this, so one may reason 10% is still a relatively high share. The pathway developed by Peeters and Papp (2023) assumed the share of e-fuels to grow along an S-curve from 0% in 2025 through 50% in about 2038 to 100% in 2050. This would require an average renewable share of 6% with a maximum of 9% in 2037. **The main outcome was that global aviation cannot grow between 2019 and 2050 in a scenario depending on a fair share of renewables**.

6.3 Distributional sufficientarian justice

6.3.1 Pax and detours

In section 5.4 we provided a short introduction to the phenomenon that passengers are not always following the shortest route for a journey but take an indirect route with one or more transfers. Of course, such behaviour has consequences for the emissions to make a certain journey from A to B. In this section we try to further analyse the size of these effects on total emissions and the role of KLM's business model and pricing in the development of this behaviour.

One important note on the content of this chapter: much of what we explore here is 'terra incognita'. Therefore, we do not suggest the data given in this section are exact, nor the definitive answer to questions about detours made by passengers because of the supply system of an airline is given. The whole section is explorative and provides indications of issues, opportunities and direction of further research, and changes in thinking about the business models airlines choose.

KLM' business model is the hub & spoke network using Amsterdam Schiphol Airport as its hub. Table 13 shows, based on data from OAG (2024), that 60% of KLM passengers were transfer passengers, not starting from or travelling to Amsterdam Schiphol Airport (AMS), though still making a stop at the airport. Figure 11 shows an example of the connection between New Delhi and Toronto, and the seven indirect alternatives through AMS which KLM sold tickets for.

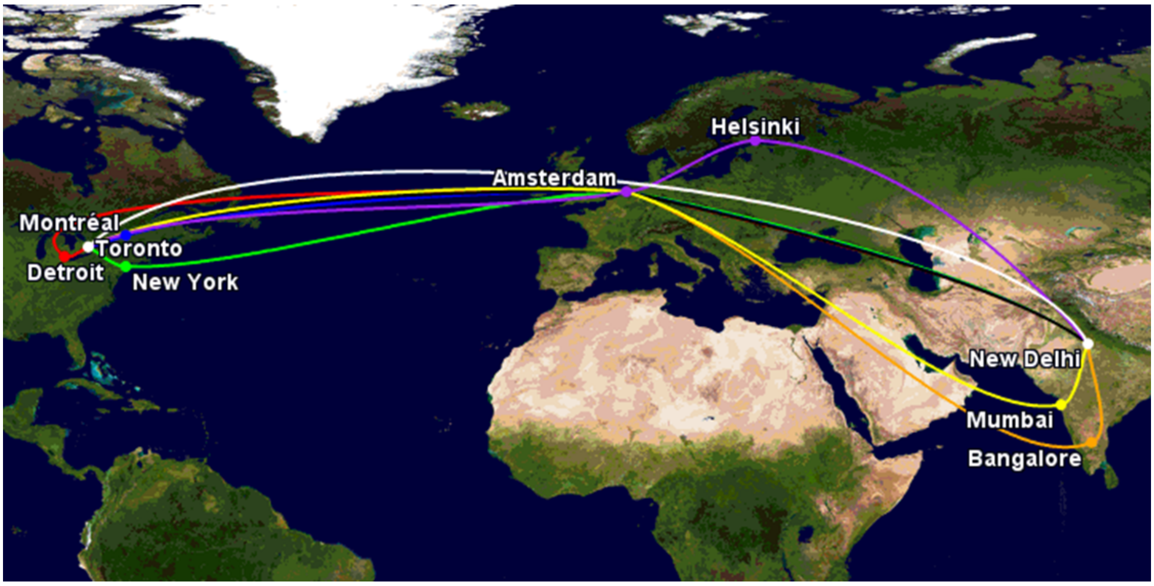

Figure 11: Example of routes sold by KLM between DEL (New Delhi) and YYC (Toronto). A direct connection of at least one flight per day does exist (the white line). Note: data for January 2023. Source of map: (Swartz, 2020).

Table 12 shows the consequences of these indirect flights between New Delhi and Toronto for emissions. If KLM's passengers would have flown directly, rather than using AMS as a hub, they would have saved 11% of CO_2 emissions on average, with a range of 9% to 27% over the various routes sold. As the total number of direct flights between DEL and YYZ is almost ten times the number of indirect tickets sold, the global impact is 1.0%. We included in 'global impact', the emissions of all direct flying passengers plus all KLM transfer passenger, but ignored eventual transfers provided by other airlines. This may seem a low percentage, but it was deliberately generated by KLM's policy to offer the connecting flights at on average 19% lower ticket prices than the direct connection (averaged over all seat classes).

Table 12: overview of the consequences of the connecting flights KLM offers to the New Delhi-Toronto connection (both ways). Note: data for January 2023. Source flight data: OAG (2024).

Journey sold by KLM	Index ticket price (direct=100)	Sum of Estimated Pax	CO_2 (tons)	CO_2 direct alternative (tons)	CO_2 penalty
DEL-YYZ (direct flights)	100	21,950	17,660	17,660	0%
DEL-YYZ (indirect):	81	2,127	1,915	1,711	11%
DEL-AMS-DTW-YYZ	71	31	29	25	15%
DEL-AMS-JFK-YYZ	60	24	23	19	14%
DEL-AMS-YUL-YYZ	51	58	53	47	11%
DEL-AMS-YYZ	85	1,701	1,489	1,368	8%

Journey sold by KLM	Index ticket price (direct=100)	Sum of Estimated Pax	CO_2 (tons)	CO_2 direct alternative (tons)	CO_2 penalty
DEL-BLR-AMS-YYZ	62	69	76	56	27%
DEL-BOM-AMS-YYZ	63	224	227	180	20%
DEL-HEL-AMS-YYZ	129	19	18	16	13%

Airport codes: DEL (New Delhi), AMS (Amsterdam), DTW (Detroit), YYZ (Toronto), JFK (New York), YUL (Montréal), BLR (Bangalore), BOM (Mumbai) and HEL (Helsinki).

An example with a more substantial global emissions impact is the route between Lisbon and São Paulo. KLM raises the global emissions by 4.1% on this route by offering three alternatives (see Figure 12) with on average 34% lower ticket prices as for the direct route.

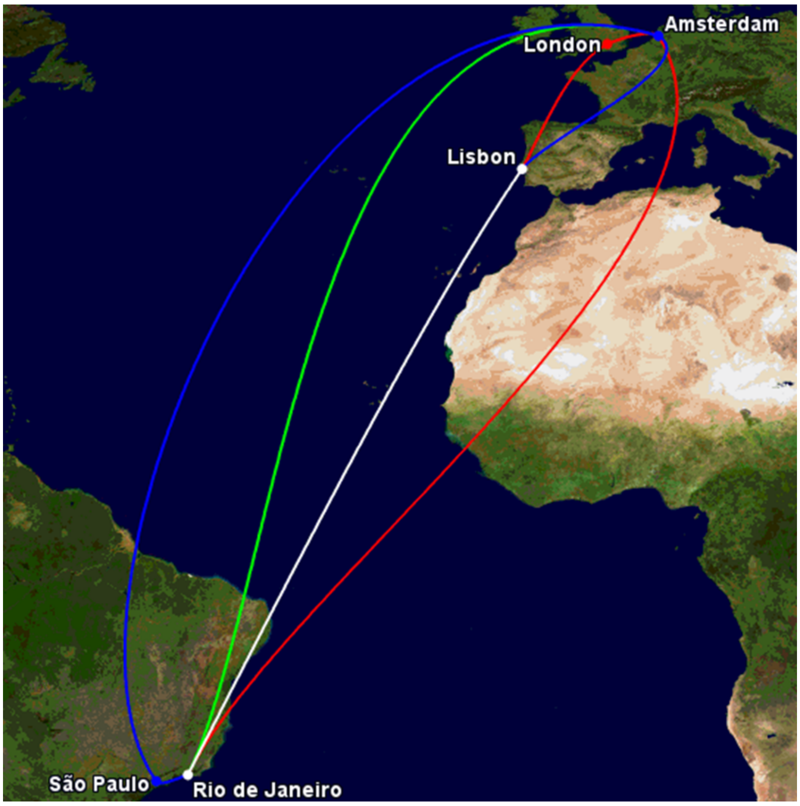

Figure 12: Example of routes sold by KLM between GIG (São Paulo) and LIS (Lisbon). The direct connection is shown by the white line. Note: data for January 2023. Source of map: (Swartz, 2020).

Table 13 shows the share of passengers, their distances, and emissions for all types of KLM passengers. OD-passengers that flew on a direct flight make up 37.4% of all passengers, against only

1.7% of all who made a transfer elsewhere (not on AMS). The higher share of foreign OD-passengers shows that the number of tourists[20] arriving by air to the Netherlands is higher than the number of Dutch departing from AMS, which resembles the situation that currently inbound tourism is larger than outbound tourism. In total, KLM's hub & spoke business model causes 11.4% more pkm and 11.8% more emissions as compared to a situation in which passengers had only flown direct routes. In the transfer market, i.e. ignoring passengers flying from or to AMS, direct alternatives could theoretically have saved 12.3% of the distance travelled and 14.8% of CO_2 emissions. Of course this depends on the existence of a direct alternative. We explored whether alternatives exist using the data from OAG (2024).

Table 13: Overview of different types of KLM passengers in January 2023. Source: (OAG, 2024).

Row Labels	Passengers (10^3)	Share of passengers (%)	Distance $(10^6$ pkm)	Distance saving if direct (%)	CO_2 journey (kton CO_2)	CO_2 saving if direct (%)
O/D	***643***	***39.2%***	***94***	***4.2%***	***152.7***	***1.2%***
Dutch	*295*	*18.0%*	*26*	*7.0%*	*81.6*	*1.1%*
Direct	280	17.1%	5	0.0%	73.1	0.0%
Indirect	15	0.9%	21	8.6%	8.5	10.8%
non-Dutch	*348*	*21.2%*	*68*	*3.1%*	*71.2*	*1.3%*
Direct	334	20.3%	43	0.0%	63.5	0.0%
Indirect	14	0.8%	25	8.6%	7.6	11.8%
Transfer	***998***	***60.8%***	***756***	***12.3%***	***529.1***	***14.8%***
Dutch	*4*	*0.2%*	*1*	*10.0%*	*1.4*	*14.8%*
Indirect	4	0.2%	1	10.0%	1.4	14.8%
non-Dutch	*994*	*60.6%*	*754*	*12.3%*	*527.8*	*14.8%*
Indirect	994	60.6%	754	12.3%	527.8	14.8%
Grand Total	**1,641**	**100.0%**	**850**	**11.4%**	**681.9**	**11.8%**

For January 2023, Table 14 shows that between 8% and 23% of indirect flying KLM passengers would have had a direct alternative available. The emission savings of letting these passengers fly directly, would have been between 1.1% and 2.7%, depending on the frequency quality required for the alternative. The savings for non-direct flights that have an alternative are around 20% and

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[20] In this report, the definition of a 'tourist' is the one given by UNWTO: everyone who stays at least one nights outside the normal environment regardless of the motive (so including leisure, holidays, business and visiting friends and relatives).

for all indirect flights nearly 15%. In terms of KLM destinations reached indirectly, 79% has a potential direct alternative. Assuming KLM would skip its policy to attract indirect flying passengers, they could potentially reduce the number of passengers between 8% and 23%. Concomitantly, KLM's total indirect flight emissions would then reduce their emissions by 4% to 11% for all its emissions.

Table 14: Overview of passenger, destination and CO2 figures for KLM's indirect flights and potential CO_2 emissions savings through direct alternatives for January 2023. Source data: (OAG, 2024).

Metric	All indirect flights	All indirect flights with any direct alternative	All indirect flights with >1 direct alternative per day	Share with any direct alternative	Share with >1 direct alternative per day
Passengers (10^3)	1,026	233	83	22.7%	8.1%
Number of destinations	894	237	109	26.5%	12.2%
CO_2 all direct and indirect flights on OD-pair (10^6 kg)	545	73	28	13.3%	5.2%
CO_2 direct (10^6 kg)	465	58	23	12.4%	4.9%
Potential CO_2 savings (% of all direct plus indirect flights of OD-pair)	-14.7%	-20.4%	-20.3%		
Potential CO_2 saving of KLM's total		-2.7%	-1.1%		

We also looked in more detail to the OD-market, in which passengers fly direct or indirect to and from AMS, rather than using AMS for a transfer between two other airports. Table 15 shows that 95.6% of all passengers take a direct flight to or from Schiphol. The indirect flights produce 11.3% more CO_2 emissions compared to a scenario in which all these flights would have been direct. If all OD-flights were direct, this will save 1.2% of OD emissions.

Furthermore, the direct OD-market supports 22% of all OD-destinations. This means that simply abandoning indirect OD-flights would significantly erode the network served. But this is not necessarily the case if many transfer passengers would be abandoned, because the number of destinations served with all flights – OD plus transfer - is 894, while all OD-traffic still serves 700 destinations. Whether all destinations really can be served with a reasonable frequency depends on the types of aircraft used and the network served. Particularly the new Airbus A321XLR can fly 8700 km with some 200 passengers, allowing for a doubling of the frequency compared to the current situation where KLM uses wide-body aircraft typically seating 350 to 400 passengers.

Table 15: Overview of passengers flying OD-journeys to and from AMS Schiphol Airport by KLM and potential CO_2 emissions savings for all passengers, for January 2023. Source data: (OAG, 2024).

Metric	OD	Direct OD	Indirect OD	Direct OD share
Passengers (10^3)	642.7	614.2	28.4	95.6%
Number of destinations	700	156	668	22.3%
CO_2 all direct and indirect flights on OD-pair (10^6 kg)	152.7	136.6	16.1	89.5%
CO_2 direct (10^6 kg)	150.9	136.6	14.3	90.5%
Potential CO_2 savings (% of journey)	-1.2%	0.0%	-11.3%	

Because of the above considerations, we dive a bit deeper into the question what would happen if KLM would partly abandon its transfer market. This question is relevant because a recent study found that accumulated direct spending of passengers of 30% of all flights to Schiphol Airport is lower than the environmental cost of CO_2 emissions caused by these flights (Peeters et al., 2024). This was a rough estimate based on rough estimates of the types of passengers (inbound OD, outbound OD or transfer) per flight. The main parameter determining the level of the net contribution to the Dutch economy was the share of transfer passengers. For KLM, in January 2023, the transfer-journeys - 60% of all passengers - by KLM-passengers[21] caused 78% of all KLM's emissions. Transfer-passengers generally fly longer journeys, so the share of emissions is higher than the share of trips.

One can question the hub & spoke policy of KLM. For the Dutch economy, this policy has only a relatively small direct value (Peeters et al., 2024). As 96% of all OD-passengers fly direct, the relevance of the many additional destinations on offer because of the hub & spoke network relates only to 4% of all OD-passengers.

We explored the options for a dedicated de-growth strategy aimed at saving most of the destinations and flights on offer to OD-passengers (direct and indirect). The threshold criterion is for at least one flight per day. Figure 13 shows the results. **The analysis showed (based on data for January 2023) an opportunity to reduce the number of passengers by 26% of the total KLM passengers and save about 30% of the total emissions of KLM. This could be achieved by just removing transfer passengers in such a way that almost all OD-connectivity is retained (<1% of current OD destinations will not be served).**

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[21] Note that we define a 'KLM-passenger' as one that makes uses for at least one segment of the whole journey a flight with KLM as operator.

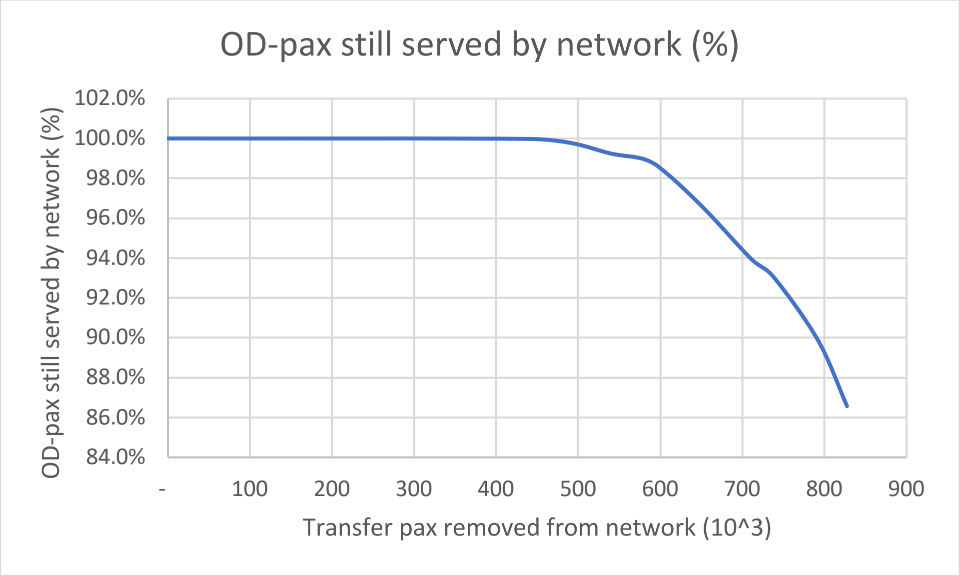

Figure 13: Relationship between the number of transfer passengers that could be removed and the share of OD-passengers that will not be served anymore. Source data: (OAG, 2024).

One of the reasons passengers choose to fly indirectly, is KLM's pricing policy. We compared 104 OD-relations with data about ticket prices and plotted the results Figure 14. The figure shows that about half of the indirect KLM-tickets are cheaper (points below the orange diagonal which shows equal prices) than those for the direct alternative. The trend line shows that for short distances, KLM tends to be more expensive, but that with increasing prices (and presumably distances), the average prices for indirect KLM flights become lower than for direct alternative tickets.

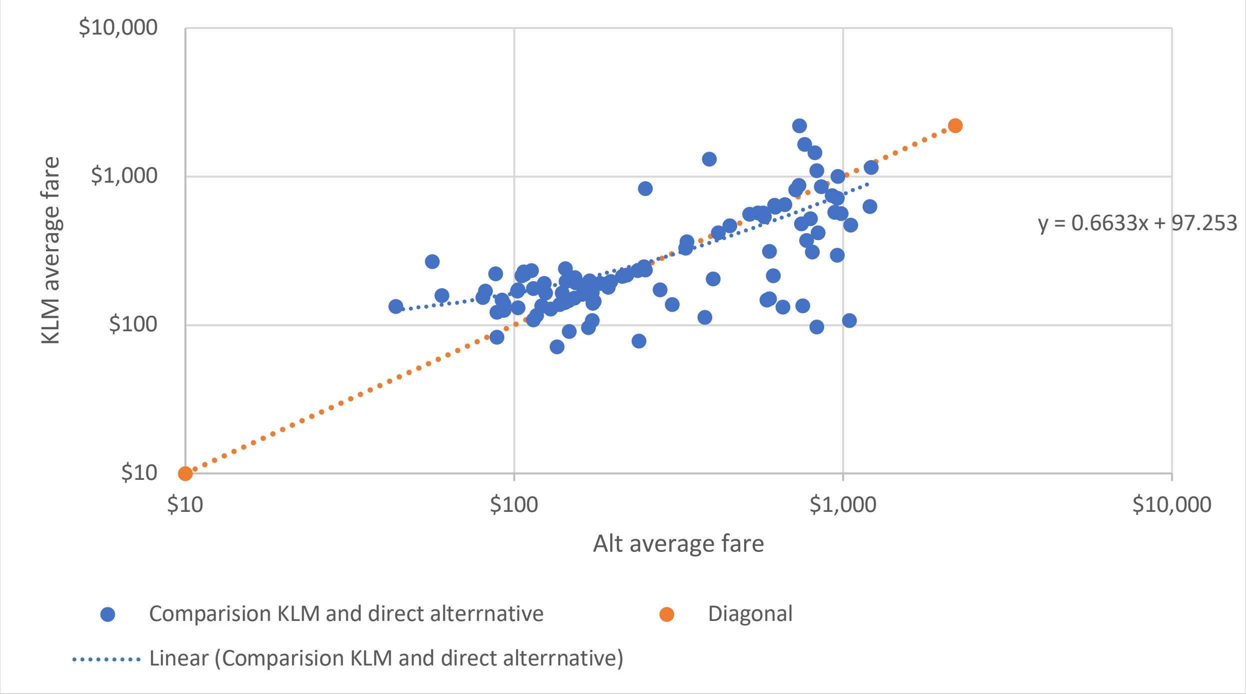

Figure 14: Comparison of a range of OD-relationships (n=104) KLM sells indirect tickets for while an alternative direct flight does exist (for January 2023). Source data: (OAG, 2024). Note: we chose double logarithmic scales to provide better separation of data-points while still showing linearity.

Table 16 compares the average ticket prices for the cases where KLM is cheaper, more expensive and the total. The flights with a direct alternative tend to be substantially cheaper (some 54% of the direct alternative route), while in cases the KLM tickets are more expensive, the deviation is, on average, only a few percent. Note that the average distance of KLM's flights is some 25-30% shorter than for the alternatives, because KLM offers higher shares of relatively short flights with a transfer (not necessarily at AMS).

Table 16: Comparison of KLM's ticket prices and the direct alternative ticket price for 104 journeys in January 2023. Data source: (OAG, 2024).

KLM pricing of route	KLM average fare	Direct alternative average fare	KLM/Alt fare
KLM route cheaper	$349.37	$649.84	53.8%
KLM more expensive	$307.79	$303.91	101.3%
All tickets	$316.42	$473.46	66.8%

Often, the aviation sector suggests that there is demand for aviation products and that airlines simply accommodate this demand. This is the main point of view for the 'hard-to-abate' principle (see section 4.3.3). However, demand and supply are shaping each other (Hepting et al., 2020). For all 41 direct connections shorter than 800 km KLM offered in January 2023, we calculated the fare per passenger-kilometre of a direct flight of these short OD-connections. Then we calculated the average per passenger kilometre fair for all transfer journeys that made use of these 41 short-haul legs. Comparing the fairs as function of distance, we found the short-haul leg-fares if flown as a direct flight, were substantially higher than then fares on the transfer flights making use of the short haul legs. (see Figure 15) This confirms in an even stronger way the results where we compared OD relations with both direct and indirect flights (see Figure 14). As the pricing strategy is largely determined by the management of the KLM, this means that at least part of the transfer market is deliberately targeted by the KLM for business reasons. This is relevant for both the discussions about climate justice and about the 'hard-to-abate' status of aviation.

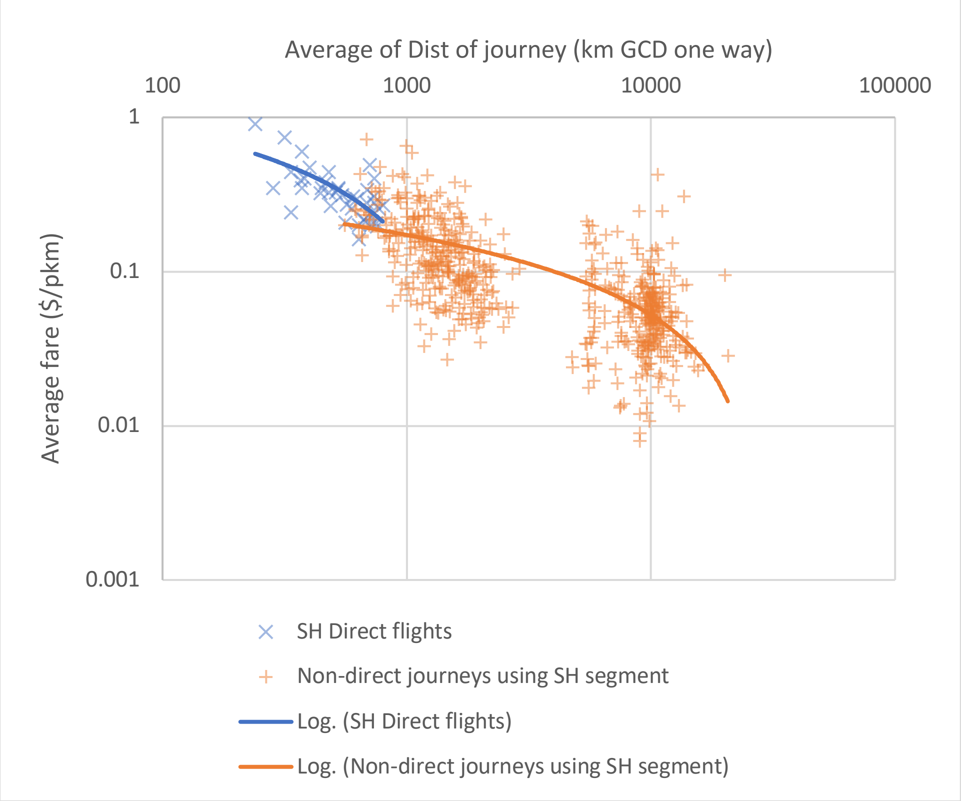

Figure 15: The average cost per km of tickets for short-haul (SH) direct connections of less than 800 km and the cost for non-direct journeys offered by KLM making use of these direct connections, for January 2023. Only flights with fare data given. Source data: (OAG, 2024).

The conclusion of the analyses in this section is that **KLM, by its pricing strategy, increases the transfer market and its economic growth and turnover; a strategy which reduces passenger route efficiency. This never seems to be considered in aviation and climate change communication, but should be part of the discussion about reaching climate goals**. Furthermore, we found that KLM would be able to reduce its transfer transport volume by some 44%, saving up to 30% of the overall emissions, without fundamentally damaging its OD-network. Of course, this move will only succeed if it is gradually implemented over some 5-10 years, as simply removing 26% of all passengers next year would likely cause many financial issues for the airline. But it can be concluded that **a strong degrowth of KLM would bring the achievement of fair climate goals significantly closer**.

6.3.2 Essential flights

When discussing climate justice, it is unavoidable to also discuss levels of consumption and over-consumption (Wiedmann et al., 2020). Or as Wiedmann et al. (2020, p. 3) write: "to differentiate between superfluous consumption, which is consumption that does not contribute to needs satisfaction, and necessary consumption which can be related to satisfying human needs". There are not many studies covering this topic. A direct measurement of the 'need' for flights was done by Gössling et al. (2019). They found that relatively high shares of flights taken by frequent flyers were reported to be of 'limited or no importance'. For leisure flights this was 23.6%, for work-related flights even 31.5%, and for VFR (visiting friends and relatives) 18.5%. Furthermore, 'indifferent importance' was reported for another quarter of the flights (Gössling et al., 2019). Likely, for less frequent flyers, the importance might be higher, but the most frequent flyers have a disproportional effect on emissions. For example, it was found that a group of 5% of French frequent fliers caused half of the CO_2 emissions of French fliers (Gössling & Nilsson, 2010). In the light of these findings, the general claims on higher shares of the carbon budget for aviation seem questionable.

An important aspect of the relationship between aviation and climate change is the distribution of distances. For instance, Peeters and Landré (2012) show that some 80% of all kilometres is made by 30% of the trips. The same distributional pattern is revealed by EASA et al. (2023), who established that the flights longer than 4500 km - only 6% of all flights - cause 50% of all aviation emissions for Europe. So, against the context of mitigating climate impacts of aviation, it is also essential to look at the distances travelled. With the same number of journeys, but a reduced average distance, aviation emissions can be substantially mitigated. **For KLM, we found that the average distance of a transfer passenger is 7093 km, with 530 kg of CO_2 emissions, while these numbers are 3140 km and 238 kg CO_2 for OD-passengers**.

The quest for higher transport volumes is not only represented by the incentives airlines give to fly indirect journeys (see section 6.3.1) through their pricing strategies; they also have 'frequent flier' programmes. Gössling and Nilsson (2010, p. 241) argue that frequent flyer programmes "reward high mobility and discursively interlink frequent flying with social status, which is an important element in the development of mobility patterns which shape and create the social structures that `necessitate' air travel".

Such programmes, though understandable from a pure business growth point of view, are likely to generate unnecessary travel and even hypermobility (Adams, 2005). In such a way one could see hypermobility as the result of an imbalance between the distribution of benefits of travel and the damages to the environment and society. Moreover, hypermobility is the result of a self-perpetuating social construct of "glamorization in regard to mobility" causing "an ominous silence" about its negative externalities (Cohen & Gössling, 2015, p. 1661). Schmidt et al. (2023) argues that flying behaviour has become a social norm. The "prevalence of flying has become so high that people who do not fly are subject to normative pressure" to fly (Schmidt et al., 2023, p. 1). On the other hand, excessive flying may even have personal health effects. Cohen and Kantenbacher (2020) found both physiological effects and psycho-social harms of flying, which could potentially be reduced by flying less. They argue that such personal health effects might be more persuasive for frequent flyers to change their behaviour, than more distant threats of climate change. Also at the individual level, Kantenbacher et al. (2019) found some evidence that there is a willingness to sacrifice some flying for the sake of the environment, but the study results were not conclusive. The varying levels of flight-shame and its impacts on behaviour (Mkono et al., 2020), further illustrate that a purely and significant consciousness-driven behavioural change is not likely. The supply complex consisting of the business model (e.g. hub & spoke), pricing, marketing, and the role these play in creating a social construct of pro-flying, is an argument that companies like airlines have a wider responsibility for the consequences of growth of their business. That is because they apparently play an important role in fuelling growth. This is also the main finding by Higham et al. (2021), whose analysis "of the e-mail marketing communications of selected airlines revealed three prominent tropes: adventure and discovery; privilege; and urgency" (Higham et al., 2021, p. 1458). And these "communications bring air travel into the everyday lives of consumers and accelerate the turnover time of tourist consumption" (Higham et al., 2021, p. 1458).

Its supply complex gives scope to hold KLM also responsible for transport volume growth and, despite some mitigation measures KLM has taken, the fact that this growth is one of the roadblocks to achieve IPCC aligned emission reductions by 2030.

6.3.3 Share of LDCs served

The disproportionate physical effect of climate change on developing countries, home to 84% of the world population (UNCTAD, 2022); their low historical responsibility for climate change and limited adaptation capacities; and the concentration of aviation use amongst a small global elite residing in predominantly high income countries have been mentioned in section 6.1. KLM proudly presents itself as oldest airline in the world still operating under its original name, connecting "people, communities and economies since 1919" (KLM, 2023a, p. 5). But who benefits from KLM's current network? Given aviation's asserted hard-to-abate policy status, this is a relevant question of distributive and procedural climate justice and will be covered next.

The aviation industry lobby points at aviation's contribution to the wider economy by means of improved connectivity (IATA, 2023a). Despite having manifold flaws (Peeters et al., 2024), this reasoning offers a powerful political tool. Industry leaders present aviation as a force of good. They see an opportunity for jobs, investments, connections between technical institutes, universities, etc., as they expand their business in the untapped growth markets (Hofmann, 2023). As former flag carrier, historically affiliated with the imperialist history of the Netherlands (Joosten, 2022), KLM too deploys the aviation-as-force-for-good narrative.

In its annual report, KLM presents improving for a better future as strategic ambition. The airline claims to power the knowledge economy and sees aviation as a means to an end. Circulating large numbers of business and leisure passengers through its hub Schiphol Airport serves the creation of "a favourable business climate for international organisations with headquarters in the Netherlands, making the Netherlands a home to global icons such as Philips, Ahold Delhaize, Randstad, and ING, as well as European headquarters of leading brands" (KLM, 2024, p. 17). **KLM thus considers corporations as central beneficiaries of aviation. This is strategic intention.**

KLM's network reflects this strategy. Based on detailed data from the Travel Analyzer (OAG, 2024) for January 2023, we found KLM (excluding Transavia) flew to 155 destination airports, in 60 countries all over the world (but mainly in Europe). Of these destinations, only 14 are in countries that have the CORSIA classification of Least Developed Country (LDC), Land-Locked Developing Country (LLDC) or Small Island Developing State (SIDS). See Table 17 for further details. From the 614,234 OD-passengers that KLM served in this period, an estimated 61,533 passengers (10.0%) travelled to these destinations, of which most to SIDS (8.7%) and only 1.4% to LDC/LLDCs (see Figure 16 and Figure 17). Note that the average income of SIDS is comparable to that of developed countries. The problem of these islands is their economic dependency on tourism and often air travel (Scott et al., 2019). These islands thus are generally not 'least developed', but they do have accessibility challenges.

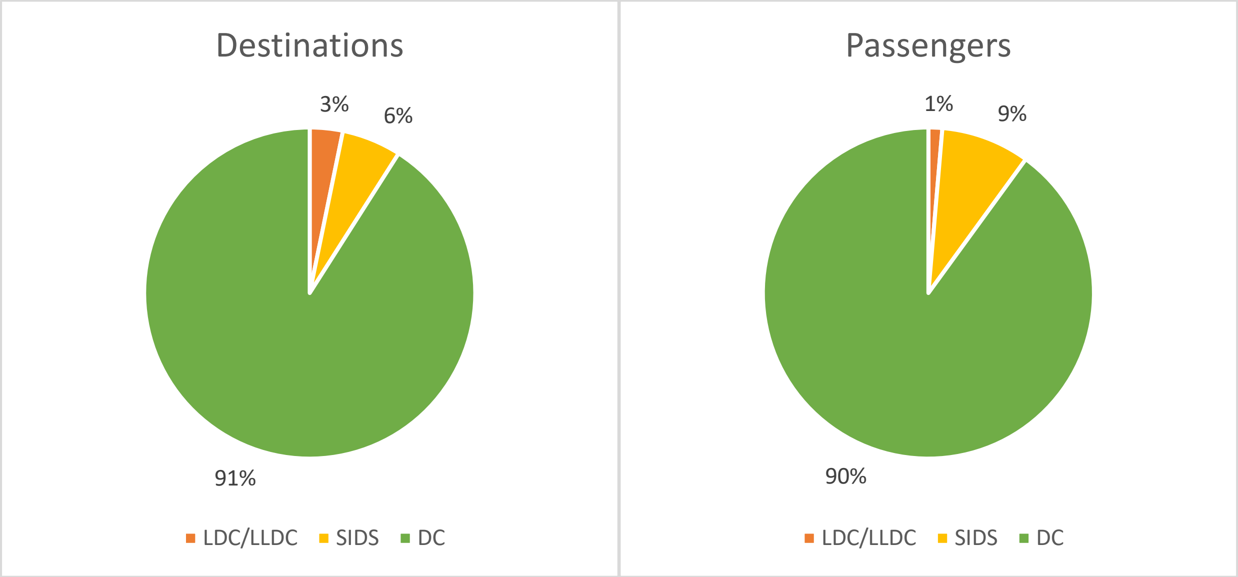

Figure 16: share of destination and passengers as divided over SIDS, LDC and DC countries. January 2023. Source: (OAG, 2024).

Zooming in on the 61,533 passengers that travelled to the 9 countries with LLDC/LDC/SIDS status in CORSIA (see Table 17), more than 78% of these passengers travelled to the Netherlands Antilles and Surinam, 6.2% travelled to global business and emerging fossil fuel energy hubs (Singapore and Bahreinrespectively). And 8,293 passengers, or 13% in total, flew to Rwanda, Tanzania and Uganda, where several large (former) Dutch corporates operate (Netherlands Enterprise Agency, 2022; Netherlands Ministry of Foreign Affairs, 2020). KLM can therefore broadly be considered as a first-world airline. KLM serves its corporate beneficiaries by circulating large numbers of business and leisure travellers mainly within the developed world and the Global North. Traffic to developing countries concentrates on former colonies, global business and emerging fossil fuel energy hubs, and aid-for-trade foreign policy focus countries, with considerable activity of (former) Dutch corporates.

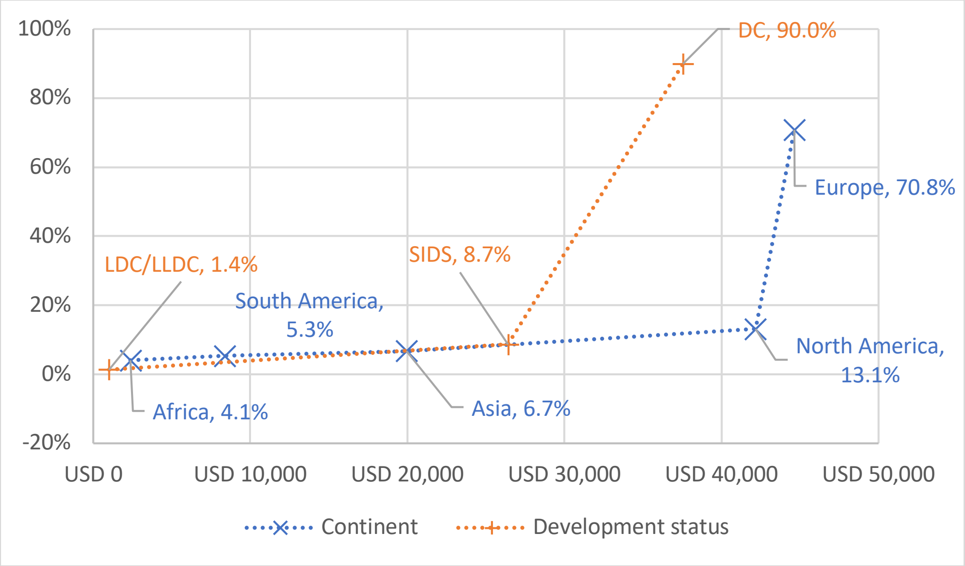

Figure 17: The relationship between shares of passengers served by KLM per continent and per development status. Source: (OAG, 2024).

Aviation uses the force for good argument as one for defending growth and opposing demand-reducing measures. However, increasing traffic to least-developed countries is not at odds with a more general de-growth strategy. The reason is that the share of LDC traffic is extremely low, both globally and for KLM, so a tiny additional degrowth in ‘rich’ markets, would more than compensate for the growth of traffic to poor countries (Tourism Panel on Climate Change, 2023). Therefore, **air travel to poor countries is a weak though commonly used argument against degrowth of aviation**.

Table 17: Overview of KLM destinations to SIDS, LDCs and LLDCs and the estimated number of passengers flying by KLM (at least one leg of each journey).

Airport name	Country	Sum of Estimated Pax KLM 01-23	Ranking	RTK (10^6) (all traffic ICAO)	Share by State (%)	SIDS	LDC	LLDC
Entebbe	Uganda	1056	154	0	0.00%	No	Yes	Yes
International	Tanzania	879	133	12.6	0.00%	No	Yes	No
Kilimanjaro	Tanzania	2027	133	12.6	0.00%	No	Yes	No
Kisauni	Tanzania	3763	133	12.6	0.00%	No	Yes	No
Zanderij Intl	Suriname	13398	93	139.7	0.02%	Yes		
Gregoire Kayibanda	Rwanda	568	89	176.2	0.02%	No	Yes	Yes

Airport name	Country	Sum of Estimated Pax KLM 01-23	Ranking	RTK (10^6) (all traffic ICAO)	Share by State (%)	SIDS	LDC	LLDC
Trinidad	Trinidad and Tobago	768	80	352.6	0.05%	Yes	No	No
Bahrain International	Bahrain	381	57	1362	0.19%	Yes	No	No
Changi	Singapore	3443	13	18706	2.54%	Yes	No	No
Reina Beatrix	Netherlands Antilles	3975	0	0	0.00%	Yes	No	No
Grantley Adams Intl	Barbados	512	0	0	0.00%	Yes	No	No
Flamingo International	Netherlands Antilles	7922	0	0	0.00%	Yes	No	No
Hato International Airport	Netherlands Antilles	21200	0	0	0.00%	Yes	No	No
Princess Juliana	Netherlands Antilles	1641	0	0	0.00%	Yes	No	No

6.3.4 Demand assumptions

As evidenced by all aviation emissions reduction scenarios investigated in this report (see section 3.3), consumption – in this case air travel demand – is not directly challenged or questioned. Some scenarios factor in supressed demand factors, but this is not a policy aim. Instead, it is usually a by-product of passing increased fuel costs to consumers and serves to stimulate the uptake of alternative aviation fuels (see e.g. ATAG, 2021; Graver et al., 2022).

In KLM's 2023 annual report (KLM, 2024), the company is confident that air travel demand will remain and likely outpace supply. KLM presents its global market outlook, stating that all markets performed better in 2023 than in 2022, except for the Middle East. The company also considers "lower demand due to modal shifts and sector stigmatisation" and a "decrease in demand for short-haul flights due to increased remote working" as general transition risks (KLM, 2024, p. 101). Notably, KLM does not consider the impacts of physical climate change effects on aviation or aviation-related climate change mitigation policies on air travel demand. In KLM's Climate Action Plan, the predicted rise in demand for flying is presented as a given.

Although KLM presents the predicted rise in demand for flying as one of the two causes for the sector's hard-to-abate status (the other being a lack of – cheap technological – alternatives), it is not addressed in KLM's climate plan. This is noteworthy because it can be argued that **KLM should also address the rise in demand for flying also as a risk, from the vantage point of a for-profit business, for instance by being clear about possible efforts to decouple volume growth from the company's revenue and profit**. Section 6.3.1 elaborated on the deliberate growth-strategy, for instance on the transfer-market through Schiphol Airport and shows a range of options for de-growth without compromising the essence of aviation to the Dutch economy and citizens.

6.4 Procedural justice: the hard-to-abate issue

The aviation sector is widely considered to be "hard-to-abate" because of its need for high energy-density fuels (Bergero et al., 2023) and its lack of existing technological solutions that can be deployed at scale. Such technologies are far more common in for instance rail systems and the automotive sector (electric cars). In aviation, efficiency improvements have in the past been consistently outpaced by volume growth (D. S. Lee et al., 2021; Peeters & Middel, 2007). Revolutionary zero-emission aircraft cannot be created in a matter of a few years, simply because the resources (labour, factories, materials) do not exist (Bergero et al., 2023; Gnadt et al., 2019; Uppink et al., 2022).

Hence, the IPCC – whilst also finding the emission reduction aspirations in international aviation lower than in many other sectors and falling short of the Paris temperature goal – mentions aviation emissions (next to some emissions from agriculture, shipping, and industrial processes) as hard-to-abate residual GHG emissions that will remain and likely need to be counterbalanced by deployment of Carbon Dioxide Removal (CDR) methods to achieve net zero emissions (IPCC, 2022a). Furthermore, this IPCC-report chooses to accept that aviation will still need some quantities of unabated fossil fuels in 2050, rather than assuming a restriction on growth as the IPCC 1.5 °C special report (IPCC, 2018) concludes to be unavoidable.

The idea of hard-to-abate for aviation has been taken for granted by most scenario developers, scientists, international and sector organisations and policymakers. The question 'why?' – given the limitations of technological mitigation options, current and anticipated volume and demand growth of the aviation sector - has hardly been addressed. A good example is the implicit assumption that a shortfall of the supply of zero-emissions e-fuels to provide 100% of the demand for kerosene, would only have one outcome: emissions will not reduce to zero. The obvious alternative option – taking e-fuel supply as determinant of (limiting) air transport supply – remains unconsidered.

A main reason might be the prevailing abatement costs optimisation method based on Nordhaus (2008) in aviation emission reduction scenarios. However, calculating the costs of both abatement and climate change are extremely difficult and uncertain: Keen (2021, p. 1149) warns that such an approach would obscure that most of the real "economic damages from climate change are at least an order of magnitude worse than forecast by economists, and may be so great as to threaten the survival of human civilization". Based on the abatement costs optimisation method, the suggestion is to first mitigate the emissions of sectors with low abatement cost, and thus to allow a mitigation delay for high-abatement cost sectors. This is also what Figure 2 shows for almost all aviation scenarios. Other economists (e.g.Ekins et al., 2011) have criticised this approach because it ignores synergies between abatement of various sectors, other benefits than the reduction of CO_2, socio-economic issues, uncertainties and the sometimes large time lags in mitigation as for instance exist in the aviation sector (Peeters et al., 2016), which obviously urge for an as soon as possible mitigation policy.

Furthermore, the abatement cost method ignores the ‘importance’ of a sector. Some, like food and clothing, literally serve every human being, while a sector like space tourism serves only a few people. Air travel is a common consumption pattern for a minority of the global population of around 11%, of which frequent flyers (1%) cause half of the emissions (Gössling & Humpe, 2020).This again touches upon the distributional aspects of climate justice (see section 2.3). Caney (2014) distinguishes two forms of climate justice: ‘burden-sharing justice’ and ‘harm avoidance justice’. Burden-sharing justice assumes the ones who benefit from a certain polluting activity also take the full burden for the damages. Harm avoidance assumes prevention of climate change should be directed at those who suffer most from it (Caney, 2014). Climate justice is an essential element of the Paris Agreement, which dictates Parties to reach emission reduction on the basis of equity (UNFCCC, 2015, p. Art.4.1).

Regarding air travel, the burden is concentrated in developing countries (Dolšak & Prakash, 2022b), while the population of developed countries flies most (IATA, 2020)[22]. Air travel serves mainly more affluent people, with only 2–4% of the global population that fly internationally per year, with 1% of the world population emitting 50% of CO_2 from commercial aviation (Gössling & Humpe, 2020). Even in Europe, the distribution is heavily skewed. The one percent households with the highest budgets have an aviation carbon footprint of 22 tons CO_2e per year, representing 41% of their total annual footprint of over 50 tons. For the top 10 percent households, the aviation footprint is 3 tons on average, while for the vast remaining majority it is 0.1 ton (Ivanova & Wood, 2020). Meanwhile, as discussed in section 6.3.2, the necessity of many flights is particularly questionable as even frequent flyers report that almost half of their flights were unnecessary (Gössling et al., 2019).

Based on both burden-sharing and harm-avoidance justice, the implicit assumption that the demand growth of air travel is unassailable is not a strong argument to declare aviation ‘hard-to-abate’. The failure of the producers of e-fuels and other SAF to supply enough to replace all fossil fuels in aviation by 2050 is a contestable argument to accept significant residual emissions from air travel after 2050 (Meerstadt et al., 2021; Schäppi et al., 2022). In other words: **the fact that aviation is hard-to-abate is an unconvincing argument to provide aviation with a disproportional high share of the global carbon budget, because curbing air transport volume is a viable and equitable option to achieve zero emissions with a just share of renewable energy and resources** (Dolšak & Prakash, 2022a; IEA, 2023a; Katz-Rosene & Ambe-Uva, 2023; Peeters & Papp, 2023). The above discussion resembles a more general discussion about the impact of pure cost-minimizing burden-share approaches and those that follow ethical principles (van den Berg et al., 2020). Table 18 shows the huge differences in air travel intensity per continent. The US plus Canada fly almost five time the world average and forty time more than the average African. It is difficult to argue the necessity of the high air travel consumed in regions (for instance the USA), while other advanced economies do with substantial less (Europe) and still other high growing regions can do with only a fraction (like Asia). Though it is rather common to assume that adding air travel will grow the general economy, a study for four African countries found that

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[22] Only 2.2% of all air transport volume is consumed by the population of Africa while Africa hosts 18.2% of the world population. Compare with the European population that consumes 26.4% of all air transport while comprising only 9.2% of the population. These numbers show that Europeans fly roughly 25 times more than the average African.

that was only the case in one these countries (Tolcha et al., 2020). For the other three, economic growth preceded air travel growth.

Table 18: The uneven distribution of air travel over the continents. Sources: (IATA, 2023a); Wikipedia (2024).

	World population share (2021)	Global RPK share (2019)	Index air travel intensity (1.0=world average)
Africa	17.60%	2.10%	0.12
Asia/Pacific	56.30%	34.60%	0.61
Europe	9.40%	26.80%	2.85
Latin America and Caribbean	8.30%	5.10%	0.61
Middle East	3.70%	9.10%	2.46
North America	4.70%	22.30%	4.74

6.5 Overview KLM position in justice metrics

What do the analyses in the preceding sections say about the distributional or procedural climate justice dimensions of aviation's emissions reduction challenge in terms of emissions and energy use? Figure 10 (section 6.1) shows the airline justice framework identifying some relevant operational metrics. These were in concrete utilitarian just shares of the RCB (6.2.1), resources/land-use (6.2.2), and renewables (6.2.3), and sufficientarian just shares of passenger detour behaviour (6.3.1), just shares of wellbeing/welfare balances like the needs for flights (6.3.2), and just shares of LDCs served (6.3.3). Furthermore, the framework shows 'policy attitudes and assumptions' as a final metric of 'procedural justice' (6.4).

Table 19 summarises some consequences of the climate justice framework arguments. The table does not repeat the references but gives the main sections the statements are based on.

Table 19: Considerations of climate justice and the KLM Climate Plan. Our comments are supported by the sections mentioned in the third column.

Metric of justice	Consequences for KLM's climate plan (KLM, 2023a) including its 2023 annual report 2023 risk assessment (KLM, 2024)
Utilitarian shares of:	
• *Remaining Carbon Budget (2019-2050)*	(6.2.1) KLM does not mention carbon budgets. The SBTi scenario KLM takes its target from, shows a 340% overshoot (3.4 times more RCB than according to an 'equal' share as other sectors). A BAU scenario would come at 1021%. Dutch aviation would arrive at an overshoot of 550% when left unmitigated. For the number of flights from Schiphol Airport, this would mean a reduction of cur-

Metric of justice	**Consequences for KLM's climate plan (KLM, 2023a) including its 2023 annual report 2023 risk assessment (KLM, 2024)**
	rent capacity (500,000 flights) to reduce by 54% in case the current share of intercontinental is maintained at 20%, while a reduction of this share to 11% would allow a volume reduction of 35%. The KLM climate plan assumes to continue the hub & spoke model, with high shares of intercontinental flights, and economically anticipated (desired) growth. This means KLM's climate plan will position the airline at the unjust position of the scale.
• *Renewables*	(6.2.3). KLM does mention the sustainability standards for SAF feedstocks and production methods, as well as the limited resources within the Netherlands. Also, the Annual report lists global SAF-production as a risk to reaching its climate goals. But KLM fails to recognise the issue of renewables and the justice of taking large shares of these. In terms of energy use for e-fuels, all Dutch aviation would require more wind energy than anticipated. As KLM globally uses about the same amount of fuel as is tankered at Schiphol Airport, this means there is no way for KLM to acquire the e-fuel produced within the Netherlands. KLM acknowledges this fact and proposes to have a global system in place to be able to acquire SAF elsewhere, but still being able to claim the carbon credits. At the same time, KLM (2023a, p. 37) states about e-fuels that the "the supply of this type of SAF is potentially unconstrained, although it depends heavily on the amount of excess renewable electricity allocated to the aviation sector".
• *Land-use/resources*	(6.2.2). KLM is highly aware of the limitations of biomass for producing SAF and of the competition with agriculture and nature. It therefore partnered with T&E, an NGO in Brussels, to successfully lobby in Brussels for more strict limitations to the feedstocks allowed, for instance by banning palm oil. Also, KLM is aware of the resource issues with waste as a feedstock.
Sufficientarian:	
• *Detours*	(6.3.1). The KLM business model of hub & spoke and related pricing system, clearly tempts travellers to take (sometimes substantially much) longer routes than necessary for their basic desire to travel from A to B. Furthermore, KLM fails to acknowledge the role of or discuss the necessity of fully advancing this business model, while it is clearly a roadblock to faster emission reduction. The fact that transfer passengers travel roughly double the distance compared to the OD-passenger, and emit substantially more per passenger than OD-passengers, means that a choice for further expanding the hub & spoke model, is at odds to with reducing overall emissions. The Dutch carbon budget policy strongly confirms this by showing that current intercontinental shares would lead to a

Metric of justice	**Consequences for KLM's climate plan (KLM, 2023a) including its 2023 annual report 2023 risk assessment (KLM, 2024)**
	capacity restriction of up to 54% of current capacity, while this reduction would be relaxed to 35% in case the intercontinental share of flights would be reduced to 11%. Still, current pricing policy leads to additional transfer passengers, passenger detours and substantially higher and partly avoidable emissions.
• *Essential flights*	(6.3.2.) Even passengers admit that substantial numbers of their flights are non-essential. The pricing and network policies and supply of KLM undoubtedly add to additional demand. These aspects are not covered by the KLM Climate Plan.
• *LDCs served*	(6.3.3) At the same time, KLM particularly serves the Western markets, while the necessity of flights could more easily be substantiated for Least Developed Countries than for Western countries. These aspects are not covered by the KLM Climate Plan.
Procedural justice	(6.3.4 and 6.4) KLM embraces, as most of the aviation sector, aviation regulators and many aviation scientists, the idea that aviation 'deserves' higher shares of the remaining carbon budget, because of the' hard-to-abate' principle. This principle assumes that fair emission reduction targets should consider the 'technical options' of each sector to abate emissions. Though there is no issue with taking account of these limited options, we have not identified any justice principle that would forbid to also look at demand and eventual restrictions of its development. We roughly explored some opportunities to look at a wider spectrum of business models than KLM's current one. In terms of risk management, as provided by the 2023 Annual Report (KLM, 2024), not discussing a change to business model priorities would be risky commercial behaviour in the light of a range of developments (carbon budget, noise, competition for space and labour) that challenge the continued growth of a hub & spoke network at Schiphol Airport. We hope our considerations are helpful to develop further strategic decisions within the sector.

7 Conclusions and discussion

Our study has three aims: (1) to evaluate KLM's goals for emissions and emissions intensity, which are based in SBTi, against a range of 1.5 °C scenarios; (2) assess the (realism and adequacy) of emission reductions KLM proposes (KLM, 2023a) and if these 'reasonably'[23] enable their goals for 2030 and 2050; and (3) look at the equity and climate justice implications of stated goals and actions vis-à-vis the prolonged volume growth that these goals and actions help legitimise. Aim (3) is important to evaluate whether KLM must reduce substantially more than they plan or is currently required by the Dutch government.

The **main research question** is: ***how does the KLM climate plan realistically relate to the emission reduction targets of a general 1.5°C climate scenario, Dutch policy, principles of climate justice, and legal climate obligations*?**

This question is divided into four sub-questions. To avoid repetition, we only answer the sub-questions. Below we will list these questions and formulate answers to them:

1. What are the emission pathways and emission reduction targets of a 1.5 °C future and how do these relate to the aviation specific targets as proposed by the sector, governments and SBTi?

   There is a large gap between aviation specific targets and scenarios and general science-based scenarios for 1.5 °C. In terms of the emission allowed for 2030, most aviation scenarios assume two-and-a-half times more emissions than an average sector is required to reach. Further reductions are generally proposed, but start 6 to 10 years later than for all sectors together. Most scenarios, whether from governmental institutes, universities or aviation branch organisations, simply assume aviation has the right to take a larger share of the remaining carbon budget, without considering any climate justice, distributional or even economic justice arguments against such a strategy. The consequence is that aviation targets are not aligned with the science-based 1.5 °C targets issued by IPCC and as meant by the Paris Agreement, and allowed to deviate upwards for self-acclaimed reasons.

2. How adequate are KLM's proposed measures? What do they mean for KLM's total emissions and carbon budget up to 2050?

   Of the measures described by KLM in its Climate Plan, we could calculate that contracted measures (fleet renewal, SAF and a few others) deliver half of the 2030 carbon intensity goal, while the planned actions might achieve two-thirds of it. Furthermore, in its 2023 Annual Report KLM presents a reduction of 12% of its absolute emissions in 2030 as a target. However, this will only be reached when the intensity target of -30% is realised, while current plans would cause -0.5% reduction and currently contracted plans a growth of emissions by 5.8%. To achieve an IPCC aligned remaining carbon budget, KLM has either to improve carbon intensity by about 56% in 2030 (baseline 2019), which is not feasible by any known technology or measure, or to reduce its transport volume by at least 21% in 2030 compared to 2019, pending the success of technical mitigation measures.

   Our analyses showed that there is scope for a new business strategy, away from the current focus on the hub & spoke model. Transfer passengers on average cause more than double the emissions of an OD-passenger (a passenger who travels from or to the Netherlands, rather

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[23] Reasonable describes how likely it is or 'in accordance with reason'.

than only using the Netherlands as place for connecting to another flight). This reduction could be substantial without reducing the size of the OD-network. This would guarantee retaining the core societal purpose of KLM, which is providing OD-travel and connect the Netherlands with the rest of the world.

The current plans by KLM will cause a substantial overshoot of its emissions, even if after 2050 strong measures would be taken. KLM is not very explicit about how to achieve their zero-emissions goal in 2050. From the wider literature, we found that such a goal is unlikely to be reached when aviation still substantially grows.

3. How does KLM's goal and climate plan relate to Dutch aviation and climate change policy?

   The reduction target of the Dutch government for 2030 cannot be reached with KLM's contracted or planned emission reductions. The planned reductions may reach the Dutch target of 10% SAF mixing by 2030, but the contracted SAF measures fail this goal by a factor three.

4. What are the climate justice implications of KLM's climate plan?

   Both the Dutch and the SBTi emission targets are not well-balanced against aspects of climate justice, particularly in terms of fair shares of remaining carbon budgets and the required shares of resources and renewables to achieve these inadequate targets. For instance, the recommended carbon budget for the Dutch aviation sector would require a capacity reduction of Schiphol Airport, the main hub of KLM, by between 35% and 54%. Another issue is that KLM would need a share of renewables to cover its need for e-fuels that is many times larger than for instance its direct and indirect contribution to the Dutch economy. In general, climate justice arguments play no role in the discussion about mitigating aviation's emissions. The cause for this is the 'hard-to-abate principle, which provides a self-acclaimed additional carbon budget to the aviation sector, without balancing this to demand for aviation and the necessity of this demand. This hampers a serious discussion about the justice of aviation's climate and mitigation measures, which is arguably essential to get KLM and aviation more Paris-aligned.

The overall conclusion is that, though KLM's Climate Plan is rather unique in the world of airlines, it did not deliver the airline a true and equitable mitigation strategy aligned with the 1.5 °C target recommended by IPCC/science. The climatic effectiveness and credibility of KLM's Climate Plan might increase when a discussion about volume growth, network structure, and hub & spoke strategy would be removed from the taboo sphere.

Literature list

A Dehon, E. (2021). *In the matter of the UN framework convention on climate change and in the matter of the Paris Agreement. Re: Inclusion of emission from internatinal aviation and shipping in Nationally Determined Contributions. Legal Advice*. Cornerstone Barristers.

Adams, J. (2005). Hypermobility: a challenge to governance. In C. Lyall & J. Tait (Eds.), *New modes of governance: developing an integrated policy approach to science, technology, risk and the environment*. Ashgate.

Airbus. (2023). *ZEROe. Towards the world's first zero-emission commercial aircraft*. Airbus. Retrieved 12-11-2021 from https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe

Al Khourdajie, A., Van Diemen, R., Lamb, W. F., Pathak, M., Reisinger, A., Skea, J., Slade, R., Some, S., & Steg, L. (2022). IPCC, 2022: Annex II: Definitions, Units and Conventions.

Alonso, J., Catalano, F., Cumpsty, N., Eyers, C. J., Goutines, M., GröNstedt, T., Hileman, J., Joselzon, A., Khaletskii, I., Mavris, D., Ogilvie, F., Ralph, D., Sabnis, J., Wahls, R., & Zingg, D. (2019). *Independent expert integrated technology goals assessment and review for engines and aircraft. 2017 independent expert integrated review panel.* ICAO.

Andersen, I., Ishii, N., Brooks, T., Cummis, C., Fonseca, G., Hillers, A., Macfarlane, N., Nakicenovic, N., Moss, K., & Rockström, J. (2021). Defining 'science-based targets'. *National Science Review, 8*(7), nwaa186.

Andersson, J. (2020). Ghost in a Shell: The Scenario Tool and the World Making of Royal Dutch Shell. *Business History Review, 94*(4), 729-751. https://doi.org/10.1017/S0007680520000483

Armstrong, J. (2022). *Don't sink Paris: Legal basis for inclusion of aviation and shipping emissions in Paris targets*. Transport and Environment.

Atag. (2021). *Waypoint 2050X. Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a vision of net-zero aviation by mid-century*. ATAG.

Azar, C., Lindgren, K., & Andersson, B. A. (2003). Global energy scenarios meeting stringent CO_2 constraints - cost effective fuel choices in the transportation sector *Energy Policy, 31*, 961-976.

Bağcı, B., & Kartal, M. (2024, 2024/04/01/). A combined multi criteria model for aircraft selection problem in airlines. *Journal of Air Transport Management, 116*, 102566. https://doi.org/https://doi.org/10.1016/j.jairtraman.2024.102566

Barber, J. (2009). Photosynthetic energy conversion: natural and artificial [10.1039/B802262N]. *Chemical Society Reviews, 38*(1), 185-196. https://doi.org/10.1039/B802262N

Beck, U. (2009). *World at Risk*. Polity Press.

Becken, S. (2004). How tourists and tourism experts perceive climate change and carbon-offsetting schemes. *Journal of Sustainable Tourism, 12*(4), 332-345.

Bergero, C., Gosnell, G., Gielen, D., Kang, S., Bazilian, M., & Davis, S. J. (2023, 2023/01/30). Pathways to net-zero emissions from aviation. *Nature Sustainability*. https://doi.org/10.1038/s41893-022-01046-9

Bjerregard, L. (2022). Hydrogen is coming. Aftermarket prepares for hydrogen-electric aircraft conversions. *2022*(July 11-24), MRO20-22.

Bjørn, A., Lloyd, S., & Matthews, D. (2021, 2021/04/22). From the Paris Agreement to corporate climate commitments: evaluation of seven methods for setting 'science-based' emission targets. *Environmental Research Letters, 16*(5), 054019. https://doi.org/10.1088/1748-9326/abe57b

Bjørn, A., Lloyd, S., & Matthews, D. (2022, 2022/03/08). Reply to Comment on 'From the Paris Agreement to corporate climate commitments: evaluation of seven methods for setting "science-based" emission targets'. *Environmental Research Letters, 17*(3), 038001. https://doi.org/10.1088/1748-9326/ac548e

Bjørn, A., Tilsted, J. P., Addas, A., & Lloyd, S. M. (2022). Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence. *Current Climate Change Reports, 8*(2), 53-69. https://doi.org/10.1007/s40641-022-00182-w

Blankenship, R. E., Tiede, D. M., Barber, J., Brudvig, G. W., Fleming, G., Ghirardi, M., Gunner, M. R., Junge, W., Kramer, D. M., Melis, A., Moore, T. A., Moser, C. C., Nocera, D. G., Nozik, A. J., Ort, D. R., Parson, W. W., Prince, R. C., & Sayre, R. T. (2011). Comparing Photosynthetic and Photovoltaic Efficiencies and Recognizing the Potential for Improvement. *Science, 332*(6031), 805. https://doi.org/10.1126/science.1200165

Boeing. (2024). *Cascade (version 1.6)*. Aerdata. Retrieved 09-05-2024 from https://app.cascade.boeing.com/

Brewer, G. D. (1991). *Hydrogen aircraft technology*. CRC Press.

Brueckner, J. K., & Zhang, Y. (2001). A Model of Scheduling in Airline Networks: How a Hub-and-Spoke System Affects Flight Frequency, Fares and Welfare. *Journal of Transport Economics and Policy (JTEP), 35*(2), 195-222. https://www.ingentaconnect.com/content/lse/jtep/2001/00000035/00000002/art00003

Burghouwt, G., Lieshout, R., & Van Spijker, V. (2017). *Economische effecten Schiphol. Over indirecte effecten en de gevolgen van capaciteitsschaarste* (SEO-rapport nr. 2017-55). S. e. onderzoek.

Cames, M., Graichen, J., Siemons, A., & Cook, V. (2015). *Emission Reduction Targets for International Aviation and Shipping*. DG Internal Policies, Economic and Scientific Policy.

Cames, M., Graichen, J., Wissner, N., Faber, J., Nelissen, D., Van Der Veen, R., Scheelhaase, J., Maertens, S., Grimme, W., Behrends, B., & Jever, M. (2023). *Paris Agreement: development of measures and activities for climate-friendly aviation and maritime transport* (25/2023). German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/25_2023_cc_paris_agreement_0.pdf

Cames, M., Harthan, R. O., Fu̇ssler, J. R., Lazarus, M., Lee, C. M., Erickson, P., & Spalding-Fecher, R. (2016). *How additional is the Clean Development Mechanism? Analysis of the application of current tools and proposed alternatives* (CLlMA.B.3/SERl2013/0026r). Öko-Institut.

Caney, S. (2014). Two Kinds of Climate Justice: Avoiding Harm and Sharing Burdens. *Journal of Political Philosophy, 22*(2), 125-149. https://doi.org/https://doi.org/10.1111/jopp.12030

Cbs. (2024). *Hoe belangrijk is de luchtvaart voor onze economie?* CBS. Retrieved 26-05-2024 from https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/economie/luchtvaart

Cdp. (2024a). *Air France - KLM - Climate Change 2023*. CDP Europe AISBL,. Retrieved 23-04-2024 from https://www.cdp.net/en/formatted_responses/responses?campaign_id=83630982&discloser_id=1028935&locale=en&organization_name=Air+France+-+KLM&organization_number=429&program=Investor&project_year=2023&redirect=https%3A%2F%2Fcdp.credit360.com%2Fsurveys%2F2023%2Fjwbhd7d6%2F250688&survey_id=82591262

Cdp. (2024b). *CDP Disclosure insight action*. CDP Europe AISBL,. Retrieved 14-04-2023 from https://www.cdp.net/en

Cdp. (2024c). *United Airlines Holding - Climate Change 2023*. CDP Europe AISBL,. Retrieved 08–05-2024 from https://www.cdp.net/en/formatted_responses/responses?campaign_id=83630982&discloser_id=1040938&locale=en&organization_name=United+Airlines+Holdings&organization_number=19569&program=Investor&project_year=2023&redirect=https%3A%2F%2Fcdp.credit360.com%2Fsurveys%2F2023%2Fjwbhd7d6%2F293921&survey_id=82591262

Ch-Aviation. (2024). *Aircraft Data*. ch-aviation GmbH,. Retrieved 08-04-2024 from https://www.ch-aviation.com/aircraft

Chang, A., Farsan, A., Carrillo Pineda, A., Cummis, C., & Weber, C. (2022, 2022/03/08). Comment on 'From the Paris Agreement to corporate climate commitments: evaluation of seven methods for setting "science-based" emission targets'. *Environmental Research Letters, 17*(3), 038002. https://doi.org/10.1088/1748-9326/ac548c

Chen, Z., Wang, Y., & Zhou, L. (2021, 2021/02/01/). Predicting weather-induced delays of high-speed rail and aviation in China. *Transport Policy, 101*, 1-13. https://doi.org/https://doi.org/10.1016/j.tranpol.2020.11.008

Cohen, S. A., & Gössling, S. (2015, August 1, 2015). A darker side of hypermobility. *Environment and Planning A, 47*(8), 166-1679. https://doi.org/10.1177/0308518x15597124

Cohen, S. A., & Kantenbacher, J. (2020, 2020/02/01). Flying less: personal health and environmental co-benefits. *Journal of Sustainable Tourism, 28*(2), 361-376. https://doi.org/10.1080/09669582.2019.1585442

Crow, D., Handschuch, I., Saive, G., & Staas, L. (2021). *Do we need to change our behaviour to reach net zero by 2050?* IEA. Retrieved 12-05-2024 from https://www.iea.org/articles/do-we-need-to-change-our-behaviour-to-reach-net-zero-by-2050#

Dahlmann, K., Grewe, V., Matthes, S., & Yamashita, H. (2023, 2023/01/03). Climate assessment of single flights: Deduction of route specific equivalent CO2 emissions. *International Journal of Sustainable Transportation, 17*(1), 29-40. https://doi.org/10.1080/15568318.2021.1979136

Damon Matthews, H., Tokarska, K. B., Rogelj, J., Smith, C. J., Macdougall, A. H., Haustein, K., Mengis, N., Sippel, S., Forster, P. M., & Knutti, R. (2021). An integrated approach to quantifying uncertainties in the remaining carbon budget. *Communications Earth & Environment, 2*(1), 7. https://doi.org/10.1038/s43247-020-00064-9

Davydenko, I., Hilbers, H., & De Wilde, H. (2024). *Klimaatneutrale luchtvaart in 2050. Een verkenning van beelden en paden daar naartoe*. Planbureau voor de Leefomgeving.

Van Den Berg, N. J., Van Soest, H. L., Hof, A. F., Den Elzen, M. G. J., Van Vuuren, D. P., Chen, W., Drouet, L., Emmerling, J., Fujimori, S., Höhne, N., Kõberle, A. C., Mccollum, D., Schaeffer, R., Shekhar, S., Vishwanathan, S. S., Vrontisi, Z., & Blok, K. (2020, 2020/10/01). Implications of various effort-sharing approaches for national carbon budgets and emission pathways. *Climatic Change, 162*(4), 1805-1822. https://doi.org/10.1007/s10584-019-02368-y

Dickau, M., Matthews, H. D., & Tokarska, K. B. (2022). The Role of Remaining Carbon Budgets and Net-Zero CO2 Targets in Climate Mitigation Policy. *Current Climate Change Reports, 8*(4), 91-103. https://doi.org/10.1007/s40641-022-00184-8

Dolšak, N., & Prakash, A. (2022a, 2022/03/07). Different approaches to reducing aviation emissions: reviewing the structure-agency debate in climate policy. *Climate Action, 1*(1), 2. https://doi.org/10.1007/s44168-022-00001-w

Dolšak, N., & Prakash, A. (2022b). Three Faces of Climate Justice. *Annual Review of Political Science, 25*(1), 283-301. https://doi.org/10.1146/annurev-polisci-051120-125514

Dreborg, K. H. (1996). Essence of backcasting. *Futures, 28*(9), 813-828. http://www.sciencedirect.com/science/article/B6V65-3VWC55R-2/2/edc08d03ded8d95155ff147be71ec291

Drünert, S., Neuling, U., Zitscher, T., & Kaltschmitt, M. (2020, 2020/11/01/). Power-to-Liquid fuels for aviation – Processes, resources and supply potential under German conditions. *Applied Energy, 277*, 115578. https://doi.org/https://doi.org/10.1016/j.apenergy.2020.115578

Dubois, G., & Ceron, J. P. (2006). Tourism and Climate Change: Proposals for a Research Agenda. *Journal of Sustainable Tourism, 14*(4), 399-415.

Dubois, T., Massy-Beresford, H., Norris, G., Warwick, G., & Batey, A. (2023). Getting Concrete. *Aviation Week & Space Technology*, (December 26, 2022-January 15, 2023), 94-97. https://aviationweek.com/aerospace/week-technology-june-20-24-2022

Easa. (2022). *European aviation environmental report 2022.* . E. U. A. S. Agency. https://www.easa.europa.eu/en/light/topics/european-aviation-environmental-report-2022#:~:text=EAER%202022%3A%20A%20holistic%20view%20of%20EU%20civil%20aviation&text=The%20EAER%202022%20looks%20at,and%20measures%20to%20reduce%20them.

Easa, Eea, & Eurocontrol. (2023). *European Aviation Environmental Report 2022* (ISBN: 978-92-9210-225-8).

Ekins, P., Kesicki, F., & Smith, A. (2011). *Marginal abatement cost curves: a call for caution* (1469-3062). U. C. London.

Energy Transitions Commission (Etc) (2018). *Mission possible. Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century*.

Epstein, A. H., & O'flarity, S. M. (2019, 2019/05/01). Considerations for Reducing Aviation's CO2 with Aircraft Electric Propulsion. *Journal of Propulsion and Power, 35*(3), 572-582. https://doi.org/10.2514/1.B37015

Eurocontrol. (2020). *Small emitters tool*. Eurocontrol. Retrieved 08-07-2020 from https://www.eurocontrol.int/tool/small-emitters-tool

European Parliament. (2023). *Fit for 55: Parliament and Council reach deal on greener aviation fuels*. Retrieved 25–04-2023 from https://www.europarl.europa.eu/news/en/press-room/20230424IPR82023/fit-for-55-parliament-and-council-reach-deal-on-greener-aviation-fuels

Faber, J., Király, J., Lee, D. S., Owen, B., & O'leary, A. (2022). *Potential for reducing aviation non-CO2 emissions through cleaner jet fuel* (22.210410.022). C. Delft.

Fleming, G. G., & De Lépinay, I. (2019). Environmental Trends in Aviation to 2050. In ICAO (Ed.), *Destination Green. The next chapter. 2019 Environmental Report. Aviation and Environment* (pp. 17-23). ICAO. https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg17-23.pdf

Flightradar24 Ab. (2021). *About Flightradar24*. Flightradar24. Retrieved 20-02-2021 from https://www.flightradar24.com/about

Flottau, J. (2022). *Aerospace Moving Too Slowly On Sustainability, Faury Says*. Aviation Week Network. Retrieved 30-11-2022 from https://aviationweek.com/air-transport/aircraft-propulsion/aerospace-moving-too-slowly-sustainability-faury-says

Fouquet, R., & O'garra, T. (2022, 2022/12/01/). In pursuit of progressive and effective climate policies: Comparing an air travel carbon tax and a frequent flyer levy. *Energy Policy, 171*, 113278. https://doi.org/https://doi.org/10.1016/j.enpol.2022.113278

Fuglestvedt, J., Lund, M. T., Kallbekken, S., Samset, B. H., & Lee, D. S. (2023, 2023/09/01). A "greenhouse gas balance" for aviation in line with the Paris Agreement. *WIREs Climate Change, 14*(5), e839. https://doi.org/https://doi.org/10.1002/wcc.839

Gates, D. (2023). NASA and Boeing chase jet contrails with science of climate impact in doubt. *Seattle Times*. https://www.seattletimes.com/business/boeing-aerospace/nasa-and-boeing-chase-jet-contrails-with-science-of-climate-impact-in-doubt/

Geilenkirchen, G. P., Harmsen, J., & Nusteling, A. W. H. (2024). *Klimaatneutrale mobiliteit in 2050. Een verkenning van beelden en paden daar naartoe*. Planbureau voor de Leefomgeving. https://www.pbl.nl/system/files/document/2024-03/PBL-2024-klimaatneutrale-mobiliteit-in-2050-5235.pdf

Ghosh, A. (2021). *The nutmeg's curse: Parables for a planet in crisis*. University of Chicago Press.

Giesekam, J., Norman, J., Garvey, A., & Betts-Davies, S. (2021). Science-Based Targets: On Target? *Sustainability, 13*(4), 1657. https://www.mdpi.com/2071-1050/13/4/1657

Gnadt, A. R., Speth, R. L., Sabnis, J. S., & Barrett, S. R. H. (2019, 2019/02/01/). Technical and environmental assessment of all-electric 180-passenger commercial aircraft. *Progress in Aerospace Sciences, 105*, 1-30. https://doi.org/https://doi.org/10.1016/j.paerosci.2018.11.002

Godet, M., & Roubelat, F. (1996). Creating the future: The use and misuse of scenarios. *Long Range Planning, 29*(2), 164-171. https://doi.org/10.1016/0024-6301(96)00004-0

Gordon, T. J. (1992). The Methods of Futures Research. *Annals of the American Academy of Political and Social Science, 522*, 25-35. http://www.jstor.org/stable/1047416

Gössling, S., Hanna, P., Higham, J., Cohen, S., & Hopkins, D. (2019, 2019/10/01/). Can we fly less? Evaluating the 'necessity' of air travel. *Journal of Air Transport Management, 81*, 101722. https://doi.org/https://doi.org/10.1016/j.jairtraman.2019.101722

Gössling, S., & Humpe, A. (2020, 2020/11/01/). The global scale, distribution and growth of aviation: Implications for climate change. *Global Environmental Change, 65*, 102194. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2020.102194

Gössling, S., Humpe, A., & Sun, Y.-Y. (2024). Are emissions from global air transport significantly underestimated? *Current Issues in Tourism*, 1-14. https://doi.org/10.1080/13683500.2024.2337281

Gössling, S., & Nilsson, J. H. (2010). Frequent flyer programmes and the reproduction of aeromobility. *Environment and Planning A, 42*(1), 241 – 225.

Graver, B., Mukhopadhaya, J., Zheng, X. S., Rutherford, D., Mukhopadhaya, J., & Pronk, E. (2022). *Vision 2050: Aligning Aviation with the Paris Agreement*. I. C. o. C. Transportation.

Graver, B., Zheng, S., Rutherford, D., Mukhopadhaya, J., Pronk, E. (2022). *Vision 2050: Aligning aviation with the Paris Agreement.* https://theicct.org/publication/global-aviation-vision-2050-align-aviation-paris-jun22/

Grebe, S., Faber, J., Juijn, D., Meijer, C., De Vries, M., Heijink, M., & Rooijers, F. (2024). *Carbon budget aviation* (23.230219.146). C. Delft.

Grebe, S., & Raphaël, S. (2023). *Aviation Non-CO2 estimator (ANCO). A tool for quantifying the non-CO2 climate impact of aviation* (23.220402.096). C. Delft.

Grewe, V., Champougny, T., Matthes, S., Frömming, C., Brinkop, S., Søvde, O. A., Irvine, E. A., & Halscheidt, L. (2014, 2014/09/01/). Reduction of the air traffic's contribution to climate change: A REACT4C case study. *Atmospheric Environment, 94*, 616-625. https://doi.org/https://doi.org/10.1016/j.atmosenv.2014.05.059

Grewe, V., Dahlmann, K., Flink, J., Frömming, C., Ghosh, R., Gierens, K., Heller, R., Hendricks, J., Jöckel, P., & Kaufmann, S. (2017). Mitigating the Climate Impact from Aviation: Achievements and Results of the DLR WeCare Project. *Aerospace, 4*(3), 34.

Grewe, V., Gangoli Rao, A., Grönstedt, T., Xisto, C., Linke, F., Melkert, J., Middel, J., Ohlenforst, B., Blakey, S., Christie, S., Matthes, S., & Dahlmann, K. (2021). Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects. *Nature Communications, 12*(1), 3841. https://doi.org/10.1038/s41467-021-24091-y

Hassan, M., Pfaender, H., & Mavris, D. (2018, 2018/08/01/). Probabilistic assessment of aviation CO2 emission targets. *Transportation Research Part D: Transport and Environment, 63*, 362-376. https://doi.org/https://doi.org/10.1016/j.trd.2018.06.006

Hemmerdinger, J. (2020). *Boeing delivered final commercial 737NG in January, ending 23 years of production*. Flight Global. Retrieved 11-11-2023 from

Hepting, M., Pak, H., Grimme, W., Dahlmann, K., Jung, M., & Wilken, D. (2020, 2020/08/01/). Climate impact of German air traffic: A scenario approach. *Transportation Research Part D: Transport and Environment, 85*, 102467. https://doi.org/https://doi.org/10.1016/j.trd.2020.102467

Higham, J., Hanna, P., Hopkins, D., Cohen, S., Gössling, S., & Cocolas, N. (2021, 2022/07/01). Reconfiguring Aviation for a Climate-Safe Future: Are Airlines Sending the Wrong Message? *Journal of Travel Research, 61*(6), 1458-1473. https://doi.org/10.1177/00472875211033648

Hofmann, K. (2023). *CEO Interview: IndiGo's Pieter Elbers On The Indian LCC's Big Plans*. https://aviationweek.com/air-transport/airlines-lessors/ceo-interview-indigos-pieter-elbers-indian-lccs-big-plans

Houghton, J. T., Jenkins, G. J., & Ephraums, J. J. (1990). *CLIMATE CHANGE. The IPCC Scientific Assessment. Report Prepared for IPCC by Working Group I* (ISBN 0-521-40720-6). Cambridge University Press.

I&W. (2020). *Verantwoord vliegen naar 2050. Luchtvaartnota 2020-2050*. Ministry of Infrastructure and Water Management.

Iaeg. (2023). *Guidance for Calculating Civil Aviation Scope 3 Emissions: Category 11 – Use of Sold Products*. International Aerospace Environmental Group.

Iata. (2020). *World air transport statistics 2020* (ISBN 978-92-9264-122-1).

Iata. (2021). *Net-Zero Carbon Emissions by 2050. Fly net zero*. IATA. Retrieved 10-06-2023 from https://www.iata.org/en/pressroom/pressroom-archive/2021-releases/2021-10-04-03/

Iata. (2023a). *Global Outlook for Air Transport. Highly Resilient, Less Robust*. IATA.

Iata. (2023b). *Net zero 2050: sustainable aviation fuels. Fact sheet*. IATA.

Iata, Ucl Atsl, Atag, Icct, & Mpp. (2024). *Aviation Net Zero CO_2 Transition Pathways Comparative Review*. International Air Transport Association (IATA), University College London (UCL) Air Transportation Systems Laboratory, Air Transport Action Group (ATAG), International Council on Clean Transportation (ICCT), Mission Possible Partnership (MPP). https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/nz-roadmaps.pdf

Icao. (2017). *Annex 16 - Environmental Protection. Volume III - Aeroplane CO2 Emissions (First Edition)* (ISBN 978-92-9275-139-5). ICAO.

Icao. (2022a). *2022 Environmental Report. Innovation for a green transition*. ICAO.

Icao. (2022b). *Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions*. ICAO.

Icao. (2022c). *Report on the feasibility of a long-term aspirational goal for civil aviation CO2 emission reductions* https://www.icao.int/environmental-protection/LTAG/Documents/REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf

Icao. (2023). *Annex 16 - Environmental Protection. Volume IV - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)* (ISBN 978-92-9285-117-3).

Iea. (2019). *Energy Technology Perspectives 2020*. https://www.iea.org/reports/clean-energy-innovation/innovation-needs-in-the-sustainable-development-scenario

Iea. (2021). *Net Zero by 2050. A Roadmap for the Global Energy Sector*. I. E. Agency.

Iea. (2023a). *Aviation*. International Energy Agency,. Retrieved 12-11-2023 from https://www.iea.org/energy-system/transport/aviation

Iea. (2023b). *Net Zero Roadmap. A Global Pathway to Keep the 1.5 °C Goal in Reach. 2023 update*. International Energy Agency. https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf

Iea. (2024). *Renewables*. IEA. Retrieved 09-05-2024 from https://www.iea.org/energy-system/renewables

Ipcc. (2007a). *Climate Change 2007: Impacts, adaptation and vulnerability. Working Group II contribution to the Intergovernmental Panel on Climate Change. Fourth Assessment Report.*

Ipcc. (2007b). *Climate Change 2007: The physical science basis. Working Group I contribution to to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (978-0-52170596-7).

Ipcc. (2018). *Global Warming of 1.5 °C. Special Report* (ISBN 978-1-5264-6112-). C. U. Press.

Ipcc. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Ipcc. (2022a). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926

Ipcc. (2022b). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (doi: 10.1017/9781009157926). Cambridge University Press.

Ipcc. (2023). Summary for Policymakers. In Core Writing Team, H. Lee, & J. Romero (Eds.), *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-34). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Irvine, E. A., Hoskins, B. J., & Shine, K. P. (2014). A simple framework for assessing the trade-off between the climate impact of aviation carbon dioxide emissions and contrails for a single flight. *Environmental Research Letters, 9*(6), 064021. http://stacks.iop.org/1748-9326/9/i=6/a=064021

Ivanova, D., & Wood, R. (2020). The unequal distribution of household carbon footprints in Europe and its link to sustainability. *Global Sustainability, 3*, e18. https://doi.org/10.1017/sus.2020.12

Joosten, T. (2022). *De blauwe fabel: waarom we de KLM al een eeuw lang tegen elke prijs in de lucht houden*. Follow the Money.

Joppa, L., Luers, A., Willmott, E., Friedmann, S. J., Hamburg, S. P., & Broze, R. (2021). Microsoft's million-tonne CO2-removal purchase—lessons for net zero. *Nature*.

Kallbekken, S., & Victor, D. G. (2022). A cleaner future for flight—aviation needs a radical redesign. *Nature, 609*(22 September 2022), 673-675.

Kantenbacher, J., Hanna, P., Miller, G., Scarles, C., & Yang, J. (2019). Consumer priorities: what would people sacrifice in order to fly on holidays? *Journal of Sustainable Tourism, 27*(2), 207-222. https://doi.org/10.1080/09669582.2017.1409230

Katan, B. M., & Van 'T Lam, V. M. Y. (2023). *Conclusie van antwoord op de voet van artikel 1018C lid Rv, laatste volzin*. S. Advocaten.

Katz-Rosene, R., & Ambe-Uva, T. (2023). Degrowth, Air Travel, and Global Environmental Governance: Scaffolding a Multilateral Agreement for a Smaller and More Sustainable Aviation Sector. *Global Environmental Politics, 23*(4), 119-140. https://doi.org/10.1162/glep_a_00714

Keen, S. (2021, 2021/10/03). The appallingly bad neoclassical economics of climate change. *Globalizations, 18*(7), 1149-1177. https://doi.org/10.1080/14747731.2020.1807856

Klein, A., Hilster, D., Scholten, P., Wijngaarden, L. V., Tol, E., & Otten, M. (2021). *STREAM Freight Transport 2020. Emissions of freight transport modes* (21.190235.012). C. Delft.

Klm. (2022a). *Climate Action Plan version 1*. KLM.

Klm. (2022b). *KLM Group's CO2 emission reduction targets for 2030 approved by SBTi*. KLM. Retrieved 08-11-2023 from

Klm. (2023a). *Climate Action Plan, version 2*. KLM.

Klm. (2023b). *KLM introduces new World Business Class seats aboard B777 fleet*. KLM. Retrieved 15-05-2024 from https://news.klm.com/klm-introduces-new-world-business-class-seats-aboard-b777-fleet/

Klm. (2024). *Annual report 2023*. K. R. D. Airlines. https://www.klmannualreport.com/

Klöwer, M., Allen, M. R., Lee, D. S., Proud, S. R., Gallagher, L., & Skowron, A. (2021a). Quantifying aviation's contribution to global warming. *Environmental Research Letters, 16*(10), 104027. https://doi.org/10.1088/1748-9326/ac286e

Klöwer, M., Allen, M. R., Lee, D. S., Proud, S. R., Gallagher, L., & Skowron, A. (2021b). Quantifying aviation's contribution to global warming. *Environmental Research Letters, 16*(10). https://doi.org/https://doi.org/10.1088/1748-9326/ac286e

Knaw. (2005). *Wetenschap op bestelling: Over de omgang tussen wetenschappelijk onderzoekers en hun opdrachtgevers [Science on command: About the contact between researchers and their clients]* (isbn 90-6984□-□459-□1). Koninklijke Nederlandse Akademie van Wetenschappen.

Knight, C. (2013, 2013/05/01). What is grandfathering? *Environmental Politics, 22*(3), 410-427. https://doi.org/10.1080/09644016.2012.740937

Koetse, M. J., & Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D: Transport and Environment, 14*(3), 205-221. https://doi.org/http://dx.doi.org/10.1016/j.trd.2008.12.004

Larsson, J., Elofsson, A., Sterner, T., & Åkerman, J. (2019, 2019/07/03). International and national climate policies for aviation: a review. *Climate Policy, 19*(6), 787-799. https://doi.org/10.1080/14693062.2018.1562871

Lee, D., Fahey, D., Skowron, A., Allen, M., Burkhardt, U., Chen, Q., Doherty, S., Freeman, S., Forster, P., & Fuglestvedt, J. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment, 244*, 117834/117831-117829.

Lee, D. S., Allen, M. R., Cumpsty, N., Owen, B., Shine, K. P., & Skowron, A. (2023). Uncertainties in mitigating aviation non-CO2 emissions for climate and air quality using hydrocarbon fuels [10.1039/D3EA00091E]. *Environmental Science: Atmospheres*. https://doi.org/10.1039/D3EA00091E

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., Doherty, S. J., Freeman, S., Forster, P. M., Fuglestvedt, J., Gettelman, A., De León, R. R., Lim, L. L., Lund, M. T., Millar, R. J., Owen, B., Penner, J. E., Pitari, G., Prather, M. J., Sausen, R., & Wilcox, L. J. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment, 244*, 117834. https://doi.org/https://doi.org/10.1016/j.atmosenv.2020.117834

Maertens, S., Grimme, W., Scheelhaase, J., & Jung, M. (2019). Options to Continue the EU ETS for Aviation in a CORSIA-World. *Sustainability, 11*(20), 5703. https://www.mdpi.com/2071-1050/11/20/5703

Van Manen, J., & Grewe, V. (2019, 2019/02/01/). Algorithmic climate change functions for the use in eco-efficient flight planning. *Transportation Research Part D: Transport and Environment, 67*, 388-405. https://doi.org/https://doi.org/10.1016/j.trd.2018.12.016

Märkl, R. S., Voigt, C., Sauer, D., Dischl, R. K., Kaufmann, S., Harlaß, T., Hahn, V., Roiger, A., Weiß-Rehm, C., Burkhardt, U., Schumann, U., Marsing, A., Scheibe, M., Dörnbrack, A., Renard, C., Gauthier, M., Swann, P., Madden, P., Luff, D., Sallinen, R., Schripp, T., & Le Clercq, P. (2023). Powering aircraft with 100% sustainable aviation fuel reduces ice crystals in contrails. *EGUsphere, 2023*(preprint), 1-37. https://doi.org/10.5194/egusphere-2023-2638

Meerstadt, C., Peerlings, B., Van Der Sman, E., & Tojal Castro, M. (2021). *Feedstocks for sustainable aviation fuels in the Netherlands: A review of feedstock sustainability and availability and identification of knowledge gaps for policy making* (NLR-TR-2020-210). NLR.

Meerstadt, C. J., Peerlings, B., Van Der Sman, E.S., Tojal Castro, M. (2021). *Feedstocks for sustainable avation fuels in the Netherlands* N. N. A. Centre. https://reports.nlr.nl/server/api/core/bitstreams/92674bb8-ef27-4a9e-9f12-d382c8f3657d/content

Milieudefensie C.S. (2022). *MEMORIE VAN ANTWOORD Zaaknummer: 200.302.332*. Gerechtshof Den Haag. https://milieudefensie.nl/actueel/klimaatzaak-memorie-van-antwoord

Miller, T. R., Chertow, M., & Hertwich, E. (2023, 2023/06/23). Liquid Hydrogen: A Mirage or Potent Solution for Aviation's Climate Woes? *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.2c06286

Millward-Hopkins, J., & Oswald, Y. (2021, 2021/02/15). 'Fair' inequality, consumption and climate mitigation. *Environmental Research Letters, 16*(3), 034007. https://doi.org/10.1088/1748-9326/abe14f

Ministerie Van Infrastructuur En Waterstaat. (2020). *Verantwoord vliegen naar 2050. Luchtvaartnota 2020-2050*.

Ministerie Van Infrastructuur En Waterstaat. (2021). *WDB Action programme*. M. v. I. e. Waterstaat.

Mkono, M., Hughes, K., & Echentille, S. (2020). Hero or villain? Responses to Greta Thunberg's activism and the implications for travel and tourism. *Journal of Sustainable Tourism*, 1-18.

Molloy, J., Teoh, R., Harty, S., Koudis, G., Schumann, U., Poll, I., & Stettler, M. E. J. (2022). Design Principles for a Contrail-Minimizing Trial in the North Atlantic. *Aerospace, 9*(7), 375. https://www.mdpi.com/2226-4310/9/7/375

Morrell, P., & Lu, C. (2007). The environmental cost implications of hub-hub versus hub bypass flight networks. *Transportation Research - D, 12*, 143-157.

Nero, G., & Black, J. A. (1998). Hub-and-spoke networks and the inclusion of environmental costs on airport pricing. *Transportation Research Part D: Transport and Environment, 3*(5), 275-296.

Netherlands Enterprise Agency. (2022). *A guide to doing business in Tanzania* N. M. o. F. Affairs. https://www.rvo.nl/sites/default/files/2022/03/Doing%20Business%20in%20Tanzania%202022.pdf

Netherlands Ministry of Foreign Affairs. (2020). *Uganda*. Netherlands Ministry of Foreign Affairs. https://dutchdevelopmentresults.nl/2019/countries/uganda

Noack, T. (2023). *Airline index*. Plane Spotters. Retrieved 01-11-2023 from https://www.planespotters.net/airlines

Noland, J. K. (2021). Hydrogen Electric Airplanes: A Disruptive Technological Path to Clean Up the Aviation Sector. *IEEE Electrification Magazine, 9*(1). https://doi.org/10.1109/MELE.2020.3047173

Nordhaus, W. (2008). *A question of balance. Weighing the options on global warming policies*. Yale University Press.

Norris, G. (2023). UH2 hydrogen-electric Dash 8 flight test move to phase 2. *Aviation Week & Space Technology, Octobre 16-29, 2023*, 42-43.

Van Notten, P. W. F., Rotmans, J., Van Asselt, M. B. A., & Rothman, D. S. (2003). An updated scenario typology. *Futures, 35*, 423–443.

O'connell, A., Kousoulidou, M., Lonza, L., & Weindorf, W. (2019, 2019/03/01/). Considerations on GHG emissions and energy balances of promising aviation biofuel pathways. *Renewable and Sustainable Energy Reviews, 101*, 504-515. https://doi.org/https://doi.org/10.1016/j.rser.2018.11.033

O'kelly, M. E. (2012). Fuel burn and environmental implications of airline hub networks. *Transportation Research Part D: Transport and Environment, 17*(7), 555-567. https://doi.org/10.1016/j.trd.2012.06.006

Oag. (2024). *Traffic Analizer, version 2.8*. OAG Aviation Worldwide Limited. Retrieved 12-05-2024 from https://analytics.oag.com/analyser-client/traffic-analyser/traffic-home

Oecd, & Itf. (2017). *ITF Transport Outlook 2017*. O. Publishing. http://dx.doi.org/10.1787/9789282108000-en

Peeters, P., Buijtendijk, H., & Eijgelaar, E. (2023). *KLM, science-based targets, and the Paris Agreement. Expert Report*. Breda University of Applied Sciences.

Peeters, P., Buijtendijk, H., Eijgelaar, E. . (2023). *KLM, science-based targets, and the Paris Agreement*. B. U. o. A. Sciences. https://pure.buas.nl/ws/portalfiles/portal/32555525/Peeters_Buijtendijk_Eijgelaar_ExpertReport_v4_Final.pdf

Peeters, P., & Papp, B. (2023). *Envisioning Tourism in 2030 and Beyond. The changing shape of tourism in a decarbonising world*. Travel Foundation.

Peeters, P., Pels, E., & Sunaryo, E. R. (2024). *Network quality and environment framework*. Breda University of Applied Sciences.

Peeters, P., & Reinecke, T. (2021). *Berekening* CO_2*-emissiefactoren voor Nederlandse luchtvaartpassagiers*. Breda University of Applied Sciences.

Peeters, P. M. (2000). *Annex I: Designing aircraft for low emissions. Technical basis for the ESCAPE project.* (00.4404.17). (ESCAPE: Economic screening of aircraft preventing emissions - background report, Issue.

Peeters, P. M. (2010). Tourism Transport, Technology, and Carbon Dioxide Emissions. In C. Schott (Ed.), *Tourism and the Implications of Climate Change: Issues and Actions* (Vol. 3, pp. 67 - 90). Emerald.

Peeters, P. M. (2013). Developing a long-term global tourism transport model using a behavioural approach: implications for sustainable tourism policy making. *Journal of Sustainable Tourism, 21*(7), 1049–1069.

Peeters, P. M. (2017). *Tourism's impact on climate change and its mitigation challenges. How can tourism become 'climatically sustainable'?* Delft University of Technology]. Delft.

Peeters, P. M., Higham, J., Kutzner, D., Cohen, S. A., & Gössling, S. (2016). Are technology myths stalling aviation climate policy? *Transportation Research Part D, 44*, 30-42.

Peeters, P. M., & Landré, M. (2012). The emerging global tourism geography – an environmental sustainability perspective. *Sustainability, 4*(1), 42-71. https://doi.org/10.3390/su4010042

Peeters, P. M., & Melkert, J. A. (2024). *Factsheet toekomst verduurzaming luchtvaart (actualisatie 2024)*. d. K. Tweede Kamer, NWO, VSNU en de Jonge Akademie. https://www.tweedekamer.nl/downloads/document?id=2024D12448

Peeters, P. M., & Middel, J. (2007). Historical and future development of air transport fuel efficiency. In R. Sausen, A. Blum, D. S. Lee, & C. Brüning (Eds.), *Proceedings of an International Conference on Transport, Atmosphere and Climate (TAC); Oxford, United Kingdom, 26th to 29th June 2006* (pp. 42-47). DLR Institut für Physic der Atmosphäre. http://www.pa.op.dlr.de/tac/

Peeters, P. M., Rietveld, P., & Schipper, Y. (2005). Deregulation in European aviation and the evolution of hub-and-spoke networks: impacts on the environment. In O. Atzema, P. Rietveld, & D. Shefer (Eds.), *Regions, land consumption and sustainable growth. Assessing the impacts of the public and private sectors* (Vol. ISBN 1 84542 124 8, pp. 137-153). Edward Elgar Publishing Limited.

Penner, J. E., Lister, D. H., Griggs, D. J., Dokken, D. J., & Mcfarland, M. (Eds.). (1999). *Aviation and the global atmosphere; a special report of IPCC working groups I and III*. Cambridge University Press.

Van Der Ploeg, F. (2018, March 01). The safe carbon budget [journal article]. *Climatic Change, 147*(1), 47-59. https://doi.org/10.1007/s10584-017-2132-8

Pornet, C., & Isikveren, A. T. (2015, 2015/11/01/). Conceptual design of hybrid-electric transport aircraft. *Progress in Aerospace Sciences, 79*, 114-135. https://doi.org/https://doi.org/10.1016/j.paerosci.2015.09.002

Prideaux, B., Laws, E., & Faulkner, B. (2003). Events in Indonesia: exploring the limits to formal tourism trends forecasting methods in complex crisis situations. *Tourism Management, 24*(4), 475-487. http://www.sciencedirect.com/science/article/B6V9R-485PBF4-6/2/5d39acdc1f3677cad55fa3ef148809e1

Riahi, K., Grübler, A., & Nakicenovic, N. (2007). Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting and Social Change, 74*(7), 887-935. https://doi.org/http://dx.doi.org/10.1016/j.techfore.2006.05.026

Ruiz Manuel, I., & Blok, K. (2023). Quantitative evaluation of large corporate climate action initiatives shows mixed progress in their first half-decade. *Nature Communications, 14*(1), 3487. https://doi.org/10.1038/s41467-023-38989-2

Ryley, T., Baumeister, S., & Coulter, L. (2020, 2020/04/17/). Climate change influences on aviation: A literature review. *Transport Policy, 92*, 55–64. https://doi.org/https://doi.org/10.1016/j.tranpol.2020.04.010

Sbti. (2021). *Science-based target setting for the aviation sector* (Version 1.0). SBTi.

Sbti. (2023a). *How it Works*. SBTi. Retrieved 27-11-2023 from https://sciencebasedtargets.org/how-it-works

Sbti. (2023b). *Technical Report: The SBTi Interim 1.5° C Sector Pathway for Aviation*. SBTi.

Sbti. (2024a). *Companies taking action*. SBTi. Retrieved 23-04-2024 from https://sciencebasedtargets.org/companies-taking-action

Sbti. (2024b). *SBT Aviation Tool. Sectoral Decarbonization Approach - Aviation Sector. Version 2.0*. https://sciencebasedtargets.org/resources/files/SBTi_Aviation_Tool.xlsx

Sbti. (2024c). *SBTi corporate near-term criteria. Version 5.2*. https://sciencebasedtargets.org/resources/files/SBTi-criteria.pdf

Sbti. (2024d). *Sector guidance*. SBTi. Retrieved 11-05-2024 from https://sciencebasedtargets.org/sectors

Schäppi, R., Rutz, D., Dähler, F., Muroyama, A., Haueter, P., Lilliestam, J., Patt, A., Furler, P., & Steinfeld, A. (2022, 2022/01/01). Drop-in fuels from sunlight and air. *Nature, 601*(7891), 63-68. https://doi.org/10.1038/s41586-021-04174-y

Scheelhaase, J., Maertens, S., Grimme, W., & Jung, M. (2018, 3//). EU ETS versus CORSIA – A critical assessment of two approaches to limit air transport's CO2 emissions by market-based measures. *Journal of Air Transport Management, 67*, 55-62. https://doi.org/https://doi.org/10.1016/j.jairtraman.2017.11.007

Schlossberg, D. (2007). *Defining Environmental Justice. Theories, Movements, and Nature*. Oxford University Press.

Schmidt, F., Sidders, A., Czepkiewicz, M., Árnadóttir, Á., & Heinonen, J. (2023). 'I am not a typical flyer': narratives about the justified or excessive character of international flights in a highly mobile society. *Journal of Sustainable Tourism, online version*, 1-24.

Schmidt, P., Batteiger, V., Roth, A., Weindorf, W., & Raksha, T. (2018, 2018/01/01). Power-to-Liquids as Renewable Fuel Option for Aviation: A Review. *Chemie Ingenieur Technik, 90*(1-2), 127-140. https://doi.org/10.1002/cite.201700129

Scott, D., Hall, C. M., & Gössling, S. (2019, 2019/07/01/). Global tourism vulnerability to climate change. *Annals of Tourism Research, 77*, 49-61. https://doi.org/https://doi.org/10.1016/j.annals.2019.05.007

Scott, D., Hall, C. M., Rushton, B., & Gössling, S. (2023). A review of the IPCC Sixth Assessment and implications for tourism development and sectoral climate action. *Journal of Sustainable Tourism*, 1-18. https://doi.org/10.1080/09669582.2023.2195597

Shue, H. (1993). Subsistence emissions and luxury emissions. *Law & Policy, 15*(1), 39-60.

Simorgh, A., Soler, M., González-Arribas, D., Matthes, S., Grewe, V., Dietmüller, S., Baumann, S., Yamashita, H., Yin, F., Castino, F., Linke, F., Lührs, B., & Meuser, M. M. (2022). A Comprehensive Survey on Climate Optimal Aircraft Trajectory Planning. *Aerospace, 9*(3), 1-32. https://www.mdpi.com/2226-4310/9/3/146

Skelton, A., Larkin, A., Ringsmuth, A., Greiser, C., Fopp, D., Mclaren, D., Stabinsky, D., Huss, E., & Hajdu, F. (2020). *10 myths about net zero targets and carbon offsetting, busted* Climate Home News. Retrieved 10-09-2021 from https://www.climatechangenews.com/2020/12/11/10-myths-net-zero-targets-carbon-offsetting-busted/

Snyder, C. (1998, July 7, 1998). *Zero-emissions aircraft? Scenarios for aviation's growth: opportunities for advanced technology* NASA Environmental Compatibility Research Workshop III, Monterey, CA.

Soler, M., Zou, B., & Hansen, M. (2014, 11//). Flight trajectory design in the presence of contrails: Application of a multiphase mixed-integer optimal control approach. *Transportation Research Part C: Emerging Technologies, 48*(0), 172-194. https://doi.org/http://dx.doi.org/10.1016/j.trc.2014.08.009

Sultana, F. (2022). Critical climate justice. *The Geographical Journal, 188*(1), 118-124.

Sustainable Aviation Table. (2021). *The Netherlands accelerates towards sustainable aviation. Sustainable Aviation Agreement*. Sustainable Aviation Table. https://der78rjp0cfsg.cloudfront.net/uploads/files/akkoord-duurzame-luchtvaart/20210329-Sustainable-aviation-agreement-Public-friendly-version-v1.0.pdf

Suzan, S. (2023). *Biofuels: from unsustainable crops to dubious waste?* T&E.

Swartz, K. L. (2020). *Great Circle Mapper*. Karl L. Swartz. Retrieved 22-03-2020 from http://www.gcmap.com/

The Royal Society. (2023). *Net zero aviation fuels: resource requirements and environmental impacts. POLICY BRIEFING* (ISBN: 978-1-78252-632-2). T. R. Society.

Tolcha, T. D., Bråthen, S., & Holmgren, J. (2020, 2020/06/01/). Air transport demand and economic development in sub-Saharan Africa: Direction of causality. *Journal of Transport Geography, 86*, 102771. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2020.102771

Tourism Panel on Climate Change. (2023). *Tourism and Climate Change Stocktake 2023* (D. Scott, S. Becken, & G. Lipman, Eds.). Tourism Panel on Climate Change,. https://tpcc.info/

Unctad. (2022). *Now 8 billion and counting: Where the world's population has grown most and why that matters*. UNCDAT. Retrieved 16-05-2024 from https://unctad.org/data-visualization/now-8-billion-and-counting-where-worlds-population-has-grown-most-and-why

Unfccc. (2015). *Paris Agreement* (FCCC/CP/2015/L.9/Rev.1). U. nations. https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

Unwto. (2016). *Compendium of tourism statistics. Data 2010-2014. 2016 Edition*. World Tourism Organisation.

Uppink, L., Ganguli, M., & Riedel, R. (2022). *Making net-zero aviation possible. An industry-backed, 1.5°C-aligned transition strategy*. M. P. Partnership.

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

De Vries, R., Wolleswinkel, R. E., Hoogreef, M., & Vos, R. (2024). A New Perspective on Battery-Electric Aviation, Part II: Conceptual Design of a 90-Seater. AIAA SCITECH 2024 Forum, Orlando (FL).

Vvd, Cda, D66, & Cu. (2022). *Looking out for each other, looking ahead to the future. 2021-2025 Coalition agreement*.

Walenta, J. (2020). Climate risk assessments and science-based targets: A review of emerging private sector climate action tools. *WIREs Climate Change, 11*(2), e628. https://doi.org/10.1002/wcc.628

Warnecke, C., Schneider, L., Day, T., La Hoz Theuer, S., & Fearnehough, H. (2019, 2019/03/01). Robust eligibility criteria essential for new global scheme to offset aviation emissions. *Nature Climate Change, 9*(3), 218-221. https://doi.org/10.1038/s41558-019-0415-y

Warwick, G. (2023). Clean Ambitions. *Aviation Week & Space Technology*, *March 13-26, 2023*, 54-58.

Wheatcroft, S. (1991). Airlines, tourism and the environment. *Tourism Management, 12*(2), 119-124.

Wiedmann, T., Lenzen, M., Keyßer, L. T., & Steinberger, J. K. (2020). Scientists' warning on affluence. *Nature Communications, 11*(1), 3107.

Wikipedia. (2024, 3.4.2024). *List of continents and continental subregions by population*. Retrieved 24.4.2024 from https://en.wikipedia.org/w/index.php?title=List_of_continents_and_continental_subregions_by_population&action=history

Williams, V., Noland, R. B., Majundar, A., Toumi, R., & Ochien, W. (2007). Mitigation of climate impacts with innovative air transport management tools. In P. M. Peeters (Ed.), *Tourism and climate change mitigation. Methods, greenhouse gas reductions and policies* (Vol. AC 6, pp. 91-104). NHTV.

Wozny, F., Scheelhaase, J., Grimme, W., & Maertens, S. (2021). *CORSIA-A Feasible Second Best Solution?*

Wttc. (2021). *Travel & Tourism Economic impact 2020 World*. World Tourism&Travel Council.

Zimm, C., Mintz-Woo, K., Brutschin, E., Hanger-Kopp, S., Hoffmann, R., Kikstra, J. S., Kuhn, M., Min, J., Muttarak, R., & Pachauri, S. (2024). Justice considerations in climate research. *Nature Climate Change*, 1-9.

Annexes

Annex I Aspects of the evaluation

I.I Offsets and CORSIA

While offsetting was once considered a viable, feasible and critical tool to reduce CO_2 emissions (Becken, 2004) of the 'hard-to-abate' aviation sector (Energy Transitions Commission (ETC) 2018; ICAO, 2022a, p. 7), its constraints regarding 'additionality', validation and effectiveness have been identified to reduce the effectiveness to almost zero (Cames et al., 2016; Joppa et al., 2021). Therefore, SBTi restrains airline operators to account for offsets. Forty-one scientists (Skelton et al., 2020), provide ten reasons why offsetting and net-zero targets are grossly insufficient to mitigate climate change in a 1.5 °C scenario. These range from the fact that offsetting through trees is as trees at some moment return back as CO_2 in the atmosphere to the problematic assumption that large-scale negative emissions will remove new emissions, while (IPCC, 2018, pp. SPM-23) concludes CO_2 removal “deployment of several hundreds of $GtCO_2$ is subject to multiple feasibility and sustainability constraints (high confidence)”.

Still, the aviation sector heavily relies on offsetting to reduce their impact on the climate. One of the pillars implemented by ICAO (2023) is CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). Warnecke et al. (2019) stresses that it is important to have stringent requirements for offset projects eligible for CORSIA, to avoid credits generated in the past to be used, which of course will not reduce current emissions anymore. Apart from that issue, the impact and scope of offsetting under the CORSIA Scheme in achieving climate goals remains limited, marginal and temporary. Particularly the exclusion of domestic flights, and the rule to only compensate emissions above 2019 levels, allows emissions to continue to grow, though at a slower pace and assuming that all credits are creditable, which we have shown is not the case. In a zero-emissions world, offsets stemming from reducing emissions from energy in other sectors or growing renewable energy will become ineffective and pointless as there will be neither emissions remaining to reduce nor additional renewables to implement Maertens et al. (2019); (OECD & ITF, 2017; Wozny et al., 2021). Finally, the low costs of offsetting contrast the carbon prices required in realizing CO_2 reductions globally (based on Cames et al., 2016; van der Ploeg, 2018).

I.II Efficiency trends

All aviation scenarios assume continued efficiency gains of the global fleet. The efficiency of aircraft shows historically a long line of improvement (Peeters & Middel, 2007) but, as Figure 18 shows, this improvement did not avoid a strong increase of aviation’s emissions between the 1960s and 2015 (Peeters et al., 2016) because the amount of kilometres flown grew much more rapid then the efficiency gains could compensate for.

However, in air transport efficiency gains are driven by the economy of aircraft. Fuel cost form a main driver for efforts of aircraft manufacturers and designers to significantly improve the fuel efficiency of each new aircraft type. Apart from fuel cost savings, Peeters and Middel (2007, p. 46) see also strong improvements for “productivity increases, safety improvements, increased range and take-off and landing performance”. This means that fleet renewal is not a kind of ‘green gift to society’, but an economic necessity for every airline, driving growth and expansion. This growth incentive causes ‘rebound effect’, causing a substantial part of the efficiency gains of fleet renewal going into additional transport volume rather than absolute emission reductions (see further section I.III).

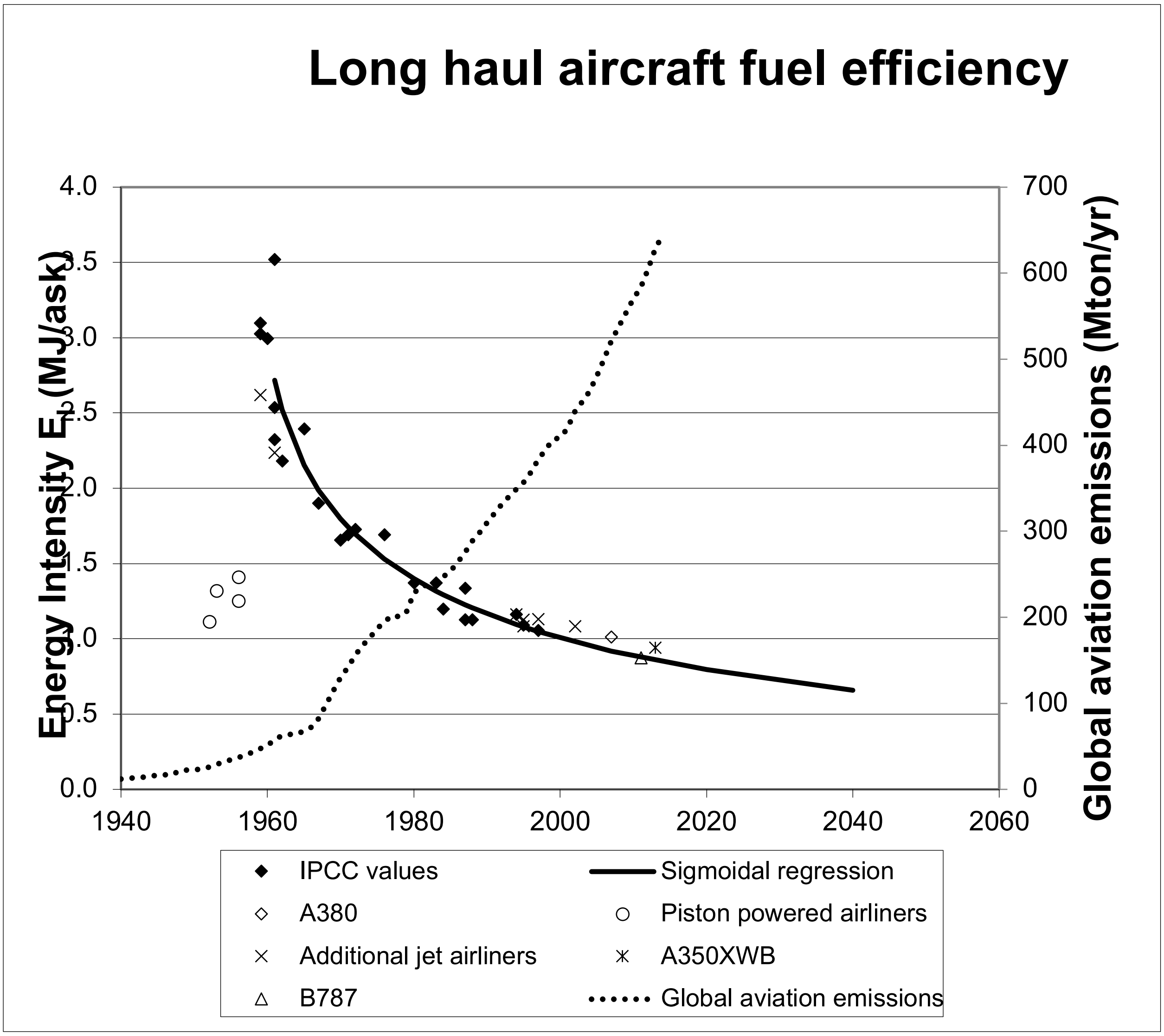

Figure 18: The failure of efficiency development to reverse the trend of increasing aviation emissions. Source (Peeters et al., 2016).

The industry assumes fuel efficiency to improve by 1.5% (IATA, 2021) to 2% per annum (ICAO, 2022a). However, as Figure 18 clearly shows, the improvement per year is far from a constant, but continuously declining. Also, 2% is no longer an option because the development of aircraft takes ever longer and then gains become ever more challenging (Peeters et al., 2016). Independent Experts for ICAO (Alonso et al., 2019) found that the coming decades improvements would go down to about 1.4%.

An important issue is, that fleet renewal comes in waves. When a new type has been introduced into ten market, the fuel efficiency stays almost constant up until the next generation comes to the market. For instance, in the 1990s Boeing introduced the new generation (NG) Boeings, which improved fuel efficiency by some 20-25% mainly because of the new engine type the aircraft were fitted with. Only since 2017 a new generation of Boeings, the Max, started to be delivered to airlines. This aircraft is some 15% more efficient, but it took twenty years before it slowly started replacing the NG types. Because of these waves of new aircraft technology it is not very useful to look at the age of a fleet as measured from the moment each particular aircraft was build. This age does not tell you much about then fuel efficiency as that is solely determined by the type of the aircraft and thus the entry-into-service (EIS) year of that type. This means, that all Airbus A320NEO's in an airline's fleet should be given the same technology age, in this case, based on the EIS of 2016. Therefore, we will use the EIS as the indicator for the 'technology age' of a fleet in a certain operational year.

I.III The rebound effect

It seems straightforward: improve the energy efficiency of an aircraft by x% and you will save also x% of the CO_2 emissions. However, energy efficiency also reduces the cost of air travel, all else equal. One may say that each new aircraft type needs to behave a 10% better direct operating cost over its predecessor. That means, with elasticities in air travel in the range of -1.1 to -1.3 (Fouquet & O'Garra, 2022), that the volume will increase by an additional 11% to 13%. If then fuel efficiency improved by 15-20%, the overall emission reduction no longer equals this 15-20% but only some 4% to 11% of total emissions.

Other efficiency measures suffer from even larger rebound effects. For instance, the sector often mentions improved air traffic control, ATC, which might reduce emissions by about 10% (EASA et al., 2023; ICAO, 2022a; KLM, 2023a). The idea is that ATC implements more direct routes, saving kilometres between origin and destination airports avoiding holding patterns and detours. However, this will proportionally reduce all costs of the flight – the fuel cost, the flight-hours, maintenance cost, , cost per aircraft-kilometre and thus the rebound will be close to 100%. Also, other operational efficiency measures may generate large rebounds. In general, the rebound effect induces additional volume growth, which is hardly compensated by the higher fuel efficient so efficiency will not easily reduce absolute emissions, but generally will increase volume for almost the same emissions.

I.IV Implications of non-CO_2 climate impacts

SBTi does not require to include non-CO_2 climate impacts (see basic explanation in section 3.1). even though the "non-CO_2 impacts contribute 66% of the aviation sectoral total climate effect (in terms of Effective Radiative Forcing; ERF) at present, with significant uncertainties" (Fuglestvedt et al., 2023, p. 1). This statement contains two elements in the discussion. The first is that non-CO_2 can be substantial, but the second is that uncertainties are large, and the CO_2 and non-CO_2 impacts are difficult to put under one denominator. The current discussion follows two strains:

1. One strain argues that the uncertainty about clouds/contrails is such to large that it is even uncertain whether it is heating or cooling (Fuglestvedt et al., 2023; Lee et al., 2023), even though the most authoritative climate change increasing impact figures come from D. Lee et al. (2021).
2. The second strain accepts the large impact of clouds and contrails as a given and tries to find methods to calculate the effects at the individual flight or origin-destination level (Dahlmann et al., 2023; Molloy et al., 2022). The idea is to provide ways in which ATC (air traffic control) can help to avoid contrail vulnerable areas in the atmosphere and so reduce the impact significantly.

The IPCC Special Report on Aviation (Penner et al., 1999) was the first to propose the 'radiative forcing index' a metric for non-CO_2 impacts of aviation inspired by the global warming potential (GWP). The first IPCC Assessment Report introduced the GWP in 1990 (Houghton et al., 1990), and defined GWP as "the time-integrated warming effect due to an instantaneous release of unit mass (1 kg) of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide" (Houghton et al., 1990, p. XIX). This means that the GWP give the ratio between the climatic impact over a certain time of emitting 1 kg of the greenhouse gas over 1 kg of CO_2. The time is typically 100 years, but 20, 50, and 500 are also often presented. After its release, CO_2 slowly disappears from the atmosphere as it is taken up by the oceans, rock-decay, and turned into biomass. "Since 1750, it is estimated that about 2/3rds of anthropogenic CO_2 emissions have come from fossil fuel burning and about 1/3rd from land use change. About 45% of this CO_2 has remained in the atmosphere, while about 30% has been taken up by the oceans and the remainder has been taken up by the terrestrial biosphere. About half of a CO_2 pulse to the atmosphere is removed over a time scale of 30 years; a further 30% is removed within a few centuries; and the remaining 20% will typically stay in the atmosphere for many thousands of years" (IPCC, 2007b, p. 25). Important other greenhouse gases are methane, Nitrous oxides (N2O), a range of Fluorinated gases, and hydrocarbons. The GWPs cover an enormous range from 1.0 (by definition the value for CO_2), to 32,600 for sulphur hexafluoride (SF_6) for the GWP500 (500 year).

An important issue is the GWP's high dependence on the assumed time-horizon. This dependency is a function of the lifetime of the gas in the atmosphere. To illustrate this, we assessed the indexed differences between a twenty-year time horizon (GWP20, index=1.0) and GWP100 and GWP500. For all GHGs with a lifetime of less than 100, the decreases from GWP20 through GWP100 to GWP500. Lifetimes between 10 and 300 show an inverted U-shape (the GWP100 has the highest value), while above 300 years, the relationship becomes continuously increasing. The lifetime of most aviation's non-CO_2 climate effects, those caused by contrails and contrail-induced cirrus clouds, is extremely short (0.01-0.02 years). For GHGs with a lifetime of less the 1 year, the GWP20 is some 3.5 times higher the GWP100. At the same time GWP500 is only one-third of GWP100. This time-horizon-dependency becomes problematic for very short lifetimes because it varies much for different arbitrarily chosen time horizons (Fuglestvedt et al., 2003; Lee, 2018)

So, while GWPs are inappropriate to apply to climatic impacts that are not directly related to a slowly decaying gaseous emission to the atmosphere, another problem is in the definition of the aviation factors. This goes back to the definition given by Penner et al. (1999) which is: the RFI is the ratio between all current radiative forcing caused by any climate impacts of aviation, divided by the total climate impact of the since 1945 accumulated CO_2. This definition is fundamentally different from a comparison of the climate impact of a pulse-emission of 1 kg of a GHG versus that of 1 kg of CO_2. It is therefore not correct to use the RFI, or any other factor based in long-term historical accumulated emissions, as if it represents a GWP and can be used to calculate CO_{2e} for the total effect (Forster et al., 2006; Peeters et al., 2007).

One other generally overlooked difference between CO_2 and non-CO_2 impacts of aviation is related to the varying impacts on generation. In a climate justice context, generating climate impacts of a beneficial behaviour by in generation N which only emerges in generation N+X (for 100 years some four generations later), means that generation N+X can only take the burden, while the benefits are long forgone. CO_2 is therefore essentially an ***inter-generational*** impact. In contrast, all the non-CO_2 impacts of aviation are short-lived between hours to up to a decade (Penner et al., 1999). Such impacts can be mitigated within one generation: they are essentially ***intra-generational***. Because the RFI ignores this generational effect, its value is too high, when a climate justified balance between CO_2 and non-CO_2 effects is desired. "If aviation is to contribute towards restricting anthropogenic surface warming to 1.5 or 2°C the reduction of emissions of CO_2 from fossil fuels remains the top priority" (Lee et al., 2023, p. 1).

Still, it is important to also set goals with respect to non-CO_2, because it is a significant impact and because CO_2 mitigating measures have varying impacts on non-CO_2. Transport volume reductions and operational measures will generally reduce both CO_2- and non-CO_2 impacts equally, but (sustainable aviation fuels (SAF) and aircraft fuel efficiency may not do so. For SAF, the non-CO_2 impacts might be a bit lower due to small differences in the composition of the fuels (EASA et al., 2023, p. 74). For efficiency improvements it depends much on how these were generated and what the impact was on the exact composition of the engines exhaust, particularly with respect to N_2O. The calculation of CO_{2e} using RFI or equivalent methods, basically applying a constant factor over the CO_2 for each flight, is unable to adequately describe the precise effects and to evaluate the impacts, not only of various mitigation options (Grewe et al., 2017), but also of the exact flight path in positions and altitudes (Märkl et al., 2023).

Because of the strong impact of the route choice on contrail and contrail-induced cirrus clouds or aircraft-induced clouds (AIC) forming, several authors suggested to fly around those contrail vulnerable areas (Grewe et al., 2014; Irvine et al., 2014; Soler et al., 2014; Williams et al., 2007). In 2023, Google and an organisation with the name Breakthrough, reported 54% reduction of AIC in a trial on 35 American Airlines routes (Gates, 2023). Plans are to scale up this project in 2024. At the same time, David Lee warns against this kind of actions because of the additional CO_2 emissions involved, which climate effects are highly certain, while the avoided impact is highly uncertain (Lee et al., 2023). Another idea developed by Grebe and Raphaël (2023) is that contrails and AIC prone areas are extremely uneven distributed around the world. They show that the non-CO_2 impact of all flights from Amsterdam is about four times the impact of CO_2 alone (calculated using the Average Temperature Response (ATR100), an equivalence factor based on a 100-year period), while the global average is about 3.0. At individual route-level, the factors vary much from only 1.2 for the route to Lille (France) up to 12.8 for Svalbard (Norway) for European routes and from 2.6 for Bali (Indonesia) up to 8.6 for Vancouver (Canada). We need to be careful simply applying these equivalence factors because they are based on a common but rather arbitrary choice of a climate impact over 100 years, highly uncertain (Lee et al., 2023) up to even uncertainty of the sign (heating or cooling) of the effects and, when communicated to individual travellers a source for even more confusion about the impact of aviation. One might even conclude that flying to Bali is from a climate impact perspective two times better than flying to Svalbard, while in terms of CO_2, the much longer distance to Bali causes almost three times the CO_2 emissions (see Table 20). It seems highly certain that this will generate inadvertent behaviour with environmentally conscious travellers.

Table 20: Some examples of the variation of non-CO_2 factors per route from Amsterdam and the consequences for CO_{2e} calculations. Source: (Grebe & Raphaël, 2023).

	ATR100 factor	CO_2 (typical value from Goole Flights	CO_{2e}	CO_2-index Svalbard	CO_{2e}-index Svalbard
Svalbard	12.8	327	4,186	100%	100%
Vancouver	8.6	626	5,384	191%	129%
Bali	2.6	919	2,389	281%	57%
New York	3.6	461	1,660	141%	40%
Barcelona	2.6	108	281	33%	7%

The best strategy would be to develop a separate trajectory for mitigating non-CO_2 impacts, particularly contrails, at the same time demanding some reduction of the demand of air travel, to avoid additional CO_2 emissions caused by the less-optimal flightpaths needed for avoiding contrails. As overall, contrail avoidance might cost between 1.5% to 2.8% for a 50% reduction respectively 100% reduction of contrails (Simorgh et al., 2022). Our suggestion would thus be to accompany any contrail and AIC avoidance policies with policies that effectively reduce demand of aviation by at least some 5% of the business-as-usual situation (without contrail/AIC avoidance). In that way, even if the contrails appear to be not heating as much as currently assumed, the penalty for CO_2 is avoided. A tax on flights would be one way to achieve this.

Annex II Policy assumptions of six scenarios

Table 21 provides an overview of the policy assumption of the six main aviation scenarios assessed in our study. This table assesses eight policy assumptions or dogma's:

1. Overall emissions reduction (timing, true or net zero)
2. Technology attitude (hesitant to optimistic)
3. Unequal resource seizure for aviation (from critical concern to optimistic)
4. Unequal renewable energy use for producing e-fuels (from none to fully equity constraint)
5. Hard-to-abate principle (form aviation-centred to integrated)
6. Lean-to-lose principle (demand development from free to constrained by resources)
7. CO_2 vs non-CO_2 (CO_2 only to non-CO_2 included)
8. Modal shift (from damaging, negatively affecting alternative modes, to promising).

Table 21: Overview of policy attitudes and assumptions of six aviation scenarios.

	EASA	ICAO (LTAG IS3)	ATAG	SBTi	Destination 2050	Envisioning 2030
Reference	EASA et al. (2023)	ICAO (2022b)	ATAG (2021)	SBTi (2023b)	Van der Sman et al. (2021)	Peeters and Papp (2023)
Overall reduction (true, not net)[24]	**Delayed; not true zero.** 10% CO$_2$ reduction in 2030 and 60% in 2050 compared to 2019.	**Delayed; not true zero.** 8% CO$_2$ reduction in 2030 and 66% in 2050 compared to 2019.	**Delayed; not true zero.** 0% CO$_2$ reduction in 2030 and 85% in 2050 compared to 2019.	**Delayed; true zero.** 4% CO$_2$ reduction in 2030 and 94% in 2050 compared to 2019.	**Delayed; not true zero.** 19% CO$_2$ reduction in 2030 and 84% in 2050 compared to 2019.	**Fast reduction; true zero.** 27-69% CO$_2$ reduction over 2030-2033 and 99% in 2050 compared to 2019.
Technology attitude	19% of CO$_2$ emission reductions from tech by 2050 + 5% hydrogen/electric aircraft. **Hesitant.** Emphasizes importance and contribution of SAF not technology.	24% of CO$_2$ emission reductions from tech by 2050. **Hesitant.** Emphasizes importance and contribution of SAF not technology.	34% of CO$_2$ emission reductions from tech by 2050. **Optimistic.** Acknowledges significant investment needed by the commercial aerospace sector, research, and government.	18% of CO$_2$ emission reductions from tech by 2050. **Medium optimistic.** No-step change in technical efficiency until 2035. Emphasizes the growing and out-weighing importance of SAF towards 2050.	38% of CO$_2$ emission reduction from tech by 2050. **Optimistic.** Technology (by hydrogen-powered aircraft) seen as largest contributor in reaching net-zero and acknowledges effect on demand. Acknowledges importance of tech-readiness by 2027-2030.	BAU improvement of 24%, an 6% additional energy efficiency resulting in overall 29% improvement 2050 over 2019. **Medium optimistic.** Between 2035 and 2048 new aircraft types fitted with a fuel cell-hydrogen-electric powertrain enter the market reducing emissions by 19% in 2050.
Unequal resource seizure for	**Concern.** Highlights enormous challenges ahead in terms of energy production scale-up and	**Careful concern.** Mentions some challenges	**Optimistic.** Assumes most economic use of feedstock and energy sectors modification to meet	**Optimistic.** Assumes enormous scale-up of production and related policy support.	**Critical concern.** Insufficient feedstock available in 2030 given current air traffic demand.	**Critical Concern.**

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[24] True zero means only in-sector reductions, excluding offsets or negative emissions.

	EASA	ICAO (LTAG IS3)	ATAG	SBTi	Destination 2050	Envisioning 2030
	securing renewable electricity also required by other sectors. Enormous scale-up in SAF production required to meet net-zero.	ahead due to regional variations of supply caused by combination of factors.	aviation demand and acknowledges the sufficiency of feedstock for SAF production towards 2050 and beyond. Asia-Pacific shows the highest potential for feedstock. Competition between sectors for feedstock remains unaddressed.	Acknowledgement that it has been slow to date. Assumes acceleration due to proposed fuel mandates.	Production of ‘advanced feedstock’ (non-food crops, residues) mainly allocated to EU on regional supply-chains.	No SAF-B or SAF=W assumed, but only constrained SAF-E (e-fuels; see below)
Unequal renewable energy use (e-fuels)	**No equity constraints.** EASA shows that mixing 28% e-fuel in 2050 would take 5.5% of all renewable electricity in the EU. 100% e-fuel mixing would mean 20% of renewables going to aviation e-fuel production. Equality issues not mentioned.	**No equity constraints.** ICAO does consider global constraints for carbon resources (from waste or DAC[25]), and renewable electricity. But the constraints are physical/economic, not from an equity perspective (ICAO, 2022b; Figure 4.3 of Appendix M5).	**Reversed equality constraint.** Optimistic about resources and renewables for SAF. Regarding equality, ATAG suggests “The fairness constraint reflects the balance of feedstocks that can be used for SAF production, compared to use by other sectors. (…) The final constraint is the volume of feedstock that can be economically used to produce fuels and enable flights at economically sustainable socially acceptable prices” (ATAG, 2021, p. 80). This feels like an incomplete and reversed equality constraint.	**No equity constraints.** Stresses the increase in/pre-dominance of in e-fuels/e-kerosene due to falling costs. But no constraints in resources, feedstocks or renewables seem to be considered.	**No equity constraints for renewables; some for biomass.** Regarding the cost of SAF, (Van der Sman et al., 2021, p. 126) says: “Uniform pricing may give rise to equity concerns, especially with respect to emerging and developing economies”. But (Van der Sman et al., 2021, p. 82) also ask to ensure that SAF-production “does not compete with these primary resources” like food. E-fuels are considered not to be constraint by renewable energy resources, contrasting the EASA and	**Equity constraint applied.** Mandate gradually increasing to 100% e-fuel (SAF-E) in 2050. Maximum share of renewables for aviation limited to 10% (on average some 5%), which limits aviation growth to zero until 2050.

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[25] DAC is direct air capture of CO_2 from the atmosphere.

	EASA	ICAO (LTAG IS3)	ATAG	SBTi	Destination 2050	Envisioning 2030
					Envisioning 2030 scenarios.	
Hard-to-abate principle	**Integrated approach.** Concerted measures across sectors, including aviation.	**Aviation priority.** Aviation industry interests should be served first and foremost.	**Aviation priority.** Considers importance and priority over other sectors.	**Aviation priority.** Aviation is qualifying for larger share of future emissions due to the need of fuels with high energy intensity.	**Integrated attempt.** Concerted measures across sectors, including aviation, but renewables for e-fuels availability too optimistic.	**Aviation a ;normal’ sector.** The scenario looks at the full travel system and does not treat aviation in a special way.
Lean-to-lose principle	**Demand following.** Assumes demand responds to transition costs and (perceived) effects of climate change.	**Demand following.** Assumes demand responds to transition costs. Traffic forecasts have factored in fuel costs and/or economic measures.	**Demand following.** Assumes demand is autonomous. Impacts of transition and climate change are not modelled.	**Demand following.** Assumes demand responds to transition costs. Current air traffic growth considered a problem, but not directly addressed.	**Demand following.** Assumes demand responds to transition costs and (perceived) effects of climate change.	**Demand constraint by equity.** Proposes a global airport slot regulation, limiting the growth of ten number of flights to allow for a ‘fair share’ of maximum of 10% of renewables.
CO_2 vs non-CO2	**Mentioned stand-alone.** Noise, nitrogen oxides are all separately considered.	**Mentioned stand-alone.** Appendix S1 is dedicated to all climatic impacts, but no specific role in main scenarios.	**CO_2 only.** Non-CO_2 included in terms of a (beneficial) side-effect of CO_2- mitigating measures.	**CO_2 only.**	**CO_2 only.**	**CO_2 only.**
Modal shift	**Limited.** BAU development of high-speed rail is taken into account.	**None.** No mention of other transport modes and modal shift.	**Damaging.** Rail as feeder for long-haul air travel is mentioned. Note that air-rail optimisation is often disadvantageous for rail-travellers. Real shifts to other modes of transport (such as rail) downplayed.	**Promising.** 20% traffic shift from air to rail, starting in 2030 on domestic and intra-European routes of less than 750km. Number of passengers greater than 100,000 annually. Policy-driven shift not modelled.	**Damaging.** Modal shifts are not part of the study. Rail as feeder for long-haul air travel is mentioned. Note that air-rail optimisation is often disadvantageous for rail-travellers.	**Promising.** Share of transport volume of other than air and private car rises from 15% in 2019 to 25% in 2050.

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