KLM, science-based targets, and the Paris Agreement

Expert Report

CREATING MEANINGFUL EXPERIENCES

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4 December 2023

Breda University
OF APPLIED SCIENCES

Summary

Aviation is currently a growth-driven industry, where economies of scale allow companies to keep costs low in order to stay ahead of the competition. KLM does this not only through cost savings, competitive prices and fleet expansion, but also through the so-called hub-and-spoke model. It connects passengers via Schiphol to a large number of destinations in Europe and beyond, instead of flying these passengers directly from their origin to their destination. This leads to detours, extra take-offs and landings and therefore extra emissions. At the same time, KLM presents itself as a forerunner in the field of sustainability. But is this appropriate?

The company claims to have been working on sustainability since 1990. KLM also mentions that there are limits to the planet from a climate point of view, and that immediate action from the company is needed to continue to operate within these limits. In 2022, KLM therefore published a climate action plan, in which the company sets itself the goal of reducing CO_2 emissions per passenger-kilometer by 30% by 2030 compared to 2019. This is a short-term CO_2 intensity target. KLM has had this CO_2 intensity target validated by the Science-Based Targets initiative (SBTi).

The SBTi is an international organization that helps companies worldwide to set and validate voluntary, science-based emission reduction targets. These science-based targets link a company's emission reduction targets to the established temperature limits from the Paris Climate Agreement and the resulting necessary emission reductions drawn up by climate scientists. For aviation, the SBTi provides sector-specific guidelines to develop science-based targets, and KLM has followed these guidelines.

In December 2022, the SBTi validated the emissions target set out in KLM's climate action plan. KLM claims that this target is in line with a climate scenario in which global warming is limited to 1.5 °C[1]. Against this background, we examined whether **the science-based target set by KLM and validated by the SBTi – and the measures proposed in the KLM climate plan to achieve this science-based target – fit into a 1.5°C scenario for the earth.**

To be able to say something about this, we first investigated how the SBTi guideline is created, what its scientific value is, whether the set targets are sufficient to fit within 1.5°C, and whether KLM actually sets the proposed target. In doing so, we not only look at CO_2 emissions, but also at aspects such as a fair distribution of the benefits and burdens of aviation and of raw materials and sustainable energy. But a goal is only relevant if it is accompanied by actual and realistic measures to achieve that goal.

Based on our analysis, we conclude the following:
The science-based target set by KLM and validated by the SBTi – the CO_2 *intensity* target – will not be achieved by KLM with the proposed measures. At the same time, KLM expects the company's *total* emissions to fall by only 12%, but the company has not set a target for this. That's because transport volume growth is taken as a given, while research at the global level suggests that a sustainable and equitable zero-emissions future for aviation is only possible with significantly less to no growth.

But first, let's break down how the SBTi system works. The current global system to deal with climate change has its origins in the 1997 Kyoto Protocol and the 2015 Paris Agreement. The SBTi can be seen as a product of Kyoto's climate regime. Within this system, the assumption is that growth in terms of volume increase of economic production is theoretically possible, as long as efficiency improvements are realized – both now and in the future – that are greater than the volume growth of this economic production. The consequence of this for aviation is that volume growth in this sector (in terms of passenger- and tonne-kilometres) is not a problem.

[1] Limiting global warming to 1.5°C compared to the pre-industrial era, as also stated in the Paris Agreement, is the most recent scientifically accepted limit for preventing dangerous climate change.

Developments over the past half century show that efficiency improvements have consistently lagged behind volume growth. This is partly because efficiency measures led to cost reductions and thus additional growth.

The SBTi is limited to assisting companies in setting science-based targets and communicating these objectives to stakeholders such as shareholders and consumers. In this sense, science-based targets are primarily a means of communication with the public and politicians. The SBTi enables companies to demonstrate apparent climate leadership by communicating a validated emissions reduction target. For companies that are under social pressure to take their climate responsibility – such as KLM – this is valuable in communicating with stakeholders. At the same time, the SBTi cannot impose an implementation obligation on companies and does not prescribe measures that companies must take in order to achieve objectives validated by the SBTi. In this sense, science-based targets are also corporate communication and stakeholder management tools.

The SBTi's specific 1.5°C Aviation Sector Directive – 30% emission intensity improvement between 2019 and 2030 – is in line with their sector scenario for 1.5°C. However, this scenario is flawed because it is based on unrealistic expectations of the measures that airlines can take to achieve net-zero emissions by 2050. The SBTi also assumes that a lack of cheap technology to do so makes it difficult for the aviation sector to reduce emissions and that aviation is therefore entitled to a larger share of the remaining global emissions until 2050. This premise ignores arguments of climate justice, equitable distribution of scarce raw materials and renewable energy sources for a sector that is frequently used by a small minority of the world's population. Another issue is that the zero emissions pathway of the SBTi’s 1.5°C aviation sector guidance lacks ambition until 2030. The targeted amount of total emission reductions by 2030 is not very ambitious, causing aviation’s share of the global 1.5°C carbon budget to double compared to a 50% reduction pathway of total emissions by 2030. Finally, it ignores significant non-CO_2 impacts. That is particularly problematic as some of the different measures proposed have varying impacts on these non-CO_2 impacts, and some have no effect at all.

Thus, in the case of the aviation industry, given the limitations of self-regulation and the unrealistic expectations of emission reduction measures in its own dedicated 1.5°C Aviation Sector Directive, the SBTi is to some extent (and unintentionally) complicit in delaying climate action. The SBTi legitimises the existing, growth-based, unsustainable business models of airlines such as KLM, by enabling these companies to communicate science-based targets that are only theoretically achievable and do not provide sufficient guarantee for the required total emission reductions.

In the case of aviation, these targets are based on unrealistic assumptions about the contribution of fleet renewal, efficiency improvements, and the amount of sustainable aviation fuels to emission reductions. We see this reflected in KLM's climate action plan, which, although the target - a 30% intensity reduction by 2030 - is in line with SBTi's specific 1.5°C aviation sector guideline, proposes measures that cannot lead to the company achieving its validated intensity target. Specifically:

- KLM proposes four strategies to improve its 2030 carbon intensity target: operational efficiency (4% of which 2% to be delivered by air traffic control), fleet-renewal (12%), mixing ‘sustainable aviation fuel’ or ‘SAF’ (10% share of fuel mix reducing intensity by 8%) and unidentified ‘additional measures’ which essentially would add more SAF (increasing the share to 15-18%).
- The assumed share of SAF of up to 18% is not realistic as it is at odds with current long-term SAF contracts for only 3% by 2030, economically not feasible (SAF would significantly increase direct operating costs), and at odds with an expected global availability of SAF of 5.7%.
- KLM’s climate plan does not deal with non-CO_2 emissions which is problematic as not all CO_2 intensity improvements have the same effect on non-CO_2 impacts.

Note that the efficiency measures will cause additional transport volume growth and less absolute emission reduction. Part of the fleet renewal involves fleet expansion, thus adding emissions in absolute terms. The company also does not provide realistic options to enable zero emissions by 2050. The technological solutions advanced by KLM, such as flying on hydrogen or electricity and a futuristic aircraft design that KLM is working on with Delft University of Technology, among others, will not be able to replace the world fleet as early as 2050. Only half to two-thirds of KLM's improvement in emission intensity will be covered by concrete plans in the areas of fleet renewal, efficiency improvements and alternative fuels. It is striking that in the recent past, KLM has only ordered enough fuel-efficient, new generation aircraft to renew no more than two-thirds of its aircraft, plus, in recent years, purchased newly built aircraft from Boeing that are still based on last century technology and fuel efficiency.

The overall conclusions are:

- The SBTi target emission pathway assumes 2.9%/annum air transport volume growth, operational and technological efficiency improvements, and a 100% use of SAF. Because of renewable resource limitations, the 100% SAF cannot be aligned in an equitable way with the assumed volume growth. Therefore, this scenario has a low feasibility. Both SBTi and KLM assume that aviation is a ‘hard to abate’ sector and therefore requires a larger share of the remaining global carbon budget than other sectors. Both ignore fundamental ethical and equity issues with this viewpoint. Also, it is unclear which other sectors have to reduce their emissions faster.
- Even though KLM may argue that their target is in line with SBTi’s requirements, KLM's targets are insufficient in multiple ways: 1) they only have an intensity target and an absolute projection which seems to set no actual limit on growth (a projection is not a target), 2) their emissions projection is not in line with a 1.5°C scenario (-12% by 2030), and 3) KLM does not show the even more important 2050 zero-emissions target and how to achieve that.
- Furthermore, the actions that KLM proposes in its climate action plan are insufficient to meet the stated, SBTi-validated intensity target of -30% emissions by 2030 compared to 2019. Overall – for KLM’s SBTi target and its climate action plan – assuming continued aviation growth is a key problem. Science gives several examples of scenarios that show the incompatibility of significant aviation growth and a sustainable and equitable pathway to zero-emissions by 2050 as required by the IPCC 1.5°C pathway.

Samenvatting

De luchtvaart is momenteel een groei-gedreven industrie, waar schaalvoordeel bedrijven in staat stelt kosten laag te houden om zo de concurrentie voor te blijven. KLM doet dit niet alleen door kostenbesparingen, concurrerende prijzen en vlootuitbreiding, maar ook door middel van het zogenaamde hub-en-spoke model. Het verbindt passagiers via Schiphol met een groot aantal bestemmingen in Europa en daarbuiten in plaats van deze passagiers rechtstreeks van hun herkomst naar hun bestemming te vliegen. Dit leidt tot omwegen, extra starts en landingen en daardoor extra emissies. Tegelijk presenteert KLM zich als voorloper op het gebied van duurzaamheid. Maar is dit wel gepast?

Het bedrijf stelt al sinds 1990 aan duurzaamheid te werken. KLM vermeldt ook dat er vanuit klimaatopzicht grenzen zijn aan de planeet en dat onmiddellijke actie nodig is vanuit het bedrijf om binnen deze grenzen te blijven opereren. In 2022 publiceerde KLM daarom een klimaatactieplan, waarin het bedrijf zich als doel stelt om per 2030 30% minder CO_2-emissies te veroorzaken per passagier-kilometer ten opzichte van 2019. Dat is een korte-termijn CO_2-intensiteitsdoelstelling. Deze CO_2-intensiteitsdoelsteling heeft KLM laten valideren door het Science-Based Targets initiative (SBTi).

Het SBTi is een internationale organisatie die bedrijven wereldwijd helpt bij het opstellen en valideren van vrijwillige, op wetenschap gebaseerde, emissiereductiedoelen. Deze science-based targets linken de emissie-reductiedoelen van een bedrijf aan de vastgestelde temperatuurlimieten uit het Klimaatakkoord van Parijs en de daaruit door klimaatwetenschappers opgestelde emissiereducties. Voor de luchtvaart biedt het SBTi sectorspecifieke richtlijnen om science-based targets te ontwikkelen en KLM heeft deze richtlijnen gevolgd.

In December 2022 heeft het SBTi de emissiedoelstelling uit het klimaatactieplan van KLM gevalideerd. KLM beweert dat deze doelstelling in lijn is met een klimaatscenario waarin de opwarming van de aarde tot 1,5°C beperkt wordt[2]. Tegen deze achtergrond bekeken wij **of het door KLM gestelde en door het SBTi gevalideerde science-based target – en de in het KLM-klimaatplan voorgestelde maatregelen om dit science-based target te halen – passen in een 1,5°C scenario voor de aarde**.

Om daar iets over te kunnen zeggen, onderzochten we allereerst hoe de SBTi richtlijn tot stand komt, wat de wetenschappelijke waarde daarvan is, of de gestelde doelen voldoende zijn om binnen 1,5°C te passen, en of de KLM het voorgestelde doel ook daadwerkelijk stelt. Daarbij kijken we niet alleen naar de emissies van CO_2, maar ook naar aspecten als eerlijke verdeling van de lusten en lasten van luchtvaart en van grondstoffen en duurzame energie. Maar een doel is alleen relevant als het gepaard gaat met feitelijke en realistische maatregelen om dat doel te halen.

Op basis van onze analyse concluderen we het volgende:
Het door KLM gestelde en door het SBTi gevalideerde science-based target – de CO_2-*intensiteits*-doelsteling – gaat de KLM met de voorgestelde maatregelen niet halen. Tegelijk verwacht KLM dat de *totale* emissies van het bedrijf met slechts 12% zullen dalen, maar daar heeft het bedrijf geen doelstelling voor geformuleerd. Dat komt doordat de groei van het vervoersvolume als een gegeven wordt beschouwd, terwijl onderzoek op mondiaal niveau erop wijst dat een duurzame en rechtvaardige nul-emissies toekomst voor luchtvaart alleen mogelijk is met aanzienlijk minder tot geen groei.

Maar laten we eerst uiteenzetten hoe het SBTi-systeem werkt. Het huidige mondiale systeem om klimaatverandering het hoofd te bieden vindt zijn oorsprong in het Kyoto Protocol uit 1997 en het Parijse Akkoord van 2015. Het SBTi kan beschouwd worden als een product van Kyoto klimaat-regime. Binnen dit

[2] Het beperken van het opwarmen van de aarde tot 1,5°C ten opzichte van het pre-industriële tijdperk, zoals ook vermeld in het Parijsakkoord, is de meest recente wetenschappelijk geaccepteerde limiet voor het voorkomen van gevaarlijke klimaatverandering.

systeem is de aanname dat groei in termen van volumetoename van economische productie theoretisch mogelijk is zolang efficiencyverbeteringen gerealiseerd worden – zowel nu als in de toekomst – die groter zijn dan de volumegroei van deze economische productie. Het gevolg hiervan voor de luchtvaart is dat volumegroei in deze sector (in termen van passagiers- en tonkilometers) niet geproblematiseerd wordt. Uit de ontwikkelingen van de afgelopen halve eeuw blijkt dat efficiencyverbeteringen voortdurend achterbleven bij de volumegroei. Dat komt deels doordat efficiency maatregelen tot kostenverlagingen en dus extra groei leidden.

Het SBTi beperkt zich tot het assisteren van bedrijven bij het opstellen van science-based targets en de communicatie van bedrijven rondom deze doelstellingen naar stakeholders als aandeelhouders en consumenten. In die zin zijn science-based targets vooral een communicatiemiddel richting publiek en politiek. Het SBTi stelt bedrijven in staat ogenschijnlijk klimaatleiderschap te tonen door een gevalideerd emissie-reductiedoel te communiceren. Dit is voor bedrijven die onder maatschappelijke druk staan om hun klimaat-verantwoordelijkheid te nemen – zoals KLM – waardevol in de communicatie naar stakeholders. Tegelijkertijd kan het SBTi bedrijven geen implementatieplicht opleggen en schrijft het geen maatregelen voor die bedrijven moeten nemen om door het SBTi gevalideerde doelstellingen te halen. Science-based targets zijn in deze zin dus ook corporate communicatie en stakeholder management tools.

De specifieke 1,5°C luchtvaartsector richtlijn – 30% emissie-intensiteitsverbetering tussen 2019 en 2030 – van het SBTi is in lijn luchtvaart scenario voor 1.5°C. Echter, dit scenario is gebrekkig omdat het is gebaseerd op onrealistische verwachtingen van de maatregelen die luchtvaartmaatschappijen kunnen nemen om tot nul-emissies te komen in 2050. Ook gaat het SBTi ervan uit dat het voor de luchtvaartsector door een gebrek aan goedkope techniek om dat te doen lastig is om emissies te reduceren en dat de luchtvaart dus recht heeft op een groter aandeel in de resterende wereldwijde emissies tot 2050. Dat uitgangspunt gaat voorbij aan argumenten van klimaatrechtvaardigheid, rechtvaardige verdeling van schaarse grondstoffen en duurzame energiebronnen voor een sector die door een kleine minderheid van de wereldbevolking frequent wordt gebruikt. Een ander probleem is dat het nul-emissie traject van de 1,5°C-richtlijn voor de luchtvaartsector van het SBTi tot 2030 niet ambitieus genoeg is. De beoogde totale emissiereducties tegen 2030 zijn niet erg ambitieus, waardoor het aandeel van de luchtvaart in het wereldwijde koolstofbudget van 1,5 °C zal verdubbelen in vergelijking met een reductietraject van 50% van de totale emissies tegen 2030. Ten slotte negeert het significante niet-CO_2-effecten. Dat is problematisch, aangezien sommige van de verschillende voorgestelde maatregelen uiteenlopende effecten hebben op deze niet-CO_2 effecten, en in sommige gevallen geen enkel effect zullen hebben.

In het geval van de luchtvaartindustrie is het SBTi – gelet op de beperkingen van zelfregulering en de onrealistische verwachtingen van emissiereductiemaatregelen in de eigen specifieke 1,5°C luchtvaart-sectorrichtlijn – dus tot op zekere hoogte (en onbedoeld) medeplichtig aan het vertragen van klimaatactie. Het SBTi legitimeert namelijk de bestaande, op groei gebaseerde, niet-duurzame bedrijfsmodellen van luchtvaart-maatschappijen als KLM, doordat het deze bedrijven in staat stelt *science-based targets* te communiceren die alleen theoretisch realiseerbaar zijn en onvoldoende garantie bieden voor de benodigde totale emissie-reducties.

In het geval van de luchtvaart zijn deze doelstellingen gebaseerd op onrealistische veronderstellingen over de bijdrage van vlootvernieuwing, efficiëntieverbeteringen en de hoeveelheid duurzame luchtvaartbrandstoffen aan emissiereducties. Dit zien we terug in het klimaatactieplan van KLM, waarvan weliswaar de doelstelling – een intensiteitsreductie van 30% in 2030 – in lijn is met de specifieke 1,5°C luchtvaartsectorrichtlijn van SBTi, maar dat maatregelen voorstelt die onvoldoende om de gevalideerde intensiteitsdoelstelling te halen. Specifiek:

- KLM stelt vier strategieën voor om haar CO_2-intensiteitsdoelstelling voor 2030 te verbeteren door operationele efficiëntie (4% waarvan 2% door de luchtverkeersleiding), vlootvernieuwing (12%), het mengen van 'duurzame vliegtuigbrandstof' of 'SAF' (10% aandeel in de brandstofmix vermindert de intensiteit met

8%) en niet-geïdentificeerde 'aanvullende maatregelen' die neer komen op het veronderstellen van een nog groter aandeel SAF tot 15-18%).

- Het veronderstelde aandeel van SAF van maximaal 18% is niet realistisch omdat het op gespannen voet staat met de huidige langetermijncontracten voor SAF van slechts 3% in 2030, economisch niet haalbaar is (SAF zou de directe bedrijfskosten aanzienlijk verhogen) en op gespannen voet staat met een verwachte wereldwijde beschikbaarheid van SAF van 5,7%.
- Het klimaatplan van KLM gaat niet in op niet-CO_2 emissies, wat problematisch is omdat niet alle verbeteringen van de CO_2-intensiteit hetzelfde effect hebben op niet-CO_2 effecten.

Merk op dat de efficiëntiemaatregelen zullen leiden tot extra groei van het transportvolume en dus minder absolute emissiereductie. Een deel van de vlootvernieuwing betreft de uitbreiding van de vloot, waardoor ook de uitstoot in absolute termen toeneemt. De door KLM opgevoerde technologische oplossingen als vliegen op waterstof of elektriciteit en een futuristisch vliegtuigontwerp waar KLM met o.a. de Technische Universiteit van Delft aan werkt, zullen onmogelijk al in 2050 de wereldvloot kunnen vervangen. De verbetering van de emissie-intensiteit van KLM wordt slechts voor de helft tot twee derde gedekt met concrete voornemens op het gebied van vlootvernieuwing, efficiencyverbeteringen en alternatieve brandstoffen. Daarbij valt op dat KLM in het recente verleden niet alleen slechts voldoende nieuwe generatie zuinigere vliegtuigen heeft besteld om hoogstens twee derde van de vliegtuigen te vernieuwen, maar ook de afgelopen jaren nog nieuwgebouwde vliegtuigen van Boeing afnam die nog zijn gebaseerd op technologie en dus brandstofefficiency uit de vorige eeuw.

De algemene conclusies zijn:

- Het SBTi-streeftraject gaat uit van een groei van het luchtvervoersvolume met 2,9% per jaar, operationele en technologische efficiëntieverbeteringen, en een 100% gebruik van SAF. Vanwege de beperkingen van hernieuwbare hulpbronnen kan de 100% SAF niet op een rechtvaardige manier worden afgestemd op de veronderstelde volumegroei. Daarom heeft dit scenario een lage haalbaarheid. Zowel SBTi als KLM gaan ervan uit dat de luchtvaart een 'moeilijk te verminderen' sector is en daarom een groter deel van het resterende wereldwijde koolstofbudget opeist dan andere sectoren. Beide negeren fundamentele ethische en rechtvaardigheidskwesties met dit standpunt. Ook is het onduidelijk welke andere sectoren hun uitstoot sneller moeten verminderen.
- Ook al kan KLM aanvoeren dat hun doelstelling in overeenstemming is met de vereisten van SBTi, de doelstellingen van KLM zijn in meerdere opzichten onvoldoende: 1) zij hebben alleen een intensiteits-doelstelling en een absolute projectie die geen daadwerkelijke limiet aan de groei lijkt te stellen (een projectie is geen doelstelling), 2) hun emissieprognose is niet in overeenstemming met een 1,5°C-scenario (-12% in 2030), en 3) KLM laat niet zien wat de nog belangrijkere zero-emissiedoelstelling voor 2050 is en hoe die te bereiken.
- Bovendien zijn de acties die KLM voorstelt in haar klimaatactieplan onvoldoende om de gestelde, SBTi-gevalideerde intensiteitsdoelstelling van -30% uitstoot in 2030 ten opzichte van 2019 te halen. Al met al is het – voor KLM's SBTi-doelstelling en haar klimaatactieplan – een essentieel probleem om uit te gaan van aanhoudende groei van de luchtvaart. De wetenschap geeft verschillende voorbeelden van scenario's die de onverenigbaarheid aantonen van een aanzienlijke groei van de luchtvaart en een duurzaam en rechtvaardig traject naar nul-emissies tegen 2050, zoals vereist door het IPCC-traject van 1,5 °C.

Contents

Author qualifications and acknowledgements

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Paul has been educated as an aircraft engineer at the Haarlem University of Applied Sciences. Before starting the CSTT, he consecutively worked as an aircraft preliminary design engineer at the late Fokker Aircraft Factory in Amsterdam, a researcher on wind turbines at the Dutch Energy Research Agency (ECN), and a researcher-consultant on transport and the environment. He has been working on diverse projects such as airship reintroduction, slow transport modes, cost and benefits of speed reduction, technological development of aircraft fuel efficiency, and tourism and transport CO_2 and decarbonization scenarios; common in almost all projects are the environment and the future.

Paul has twice provided the Dutch House of Representatives with advice concerning the sustainable development of aviation. He has been a member of environmental working group III of the International Civil Aviation Organization (ICAO-CAEP), working on developing and setting a CO_2-standard for new aircraft types. He has published over 130 journal articles, conference papers, chapters and reports on tourism transportation, climate change, ecological footprints, eco-efficiency, and the role of air transportation technology.

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Acknowledgments
We thank Anders Bjørn at the Technical University of Denmark for his comments on a draft of this report. Anders has written multiple scientific articles on corporate climate commitments and science-based targets.

1 Introduction

1.1 Goal and Research questions

We have been asked to provide our views on the following questions:

- What is the view of SBTi validation in scientific literature? (chapter 2)
- Is KLM's (SBTi) target aligned with limiting dangerous climate change in line with the Paris goal? (chapter 3)
- Is KLM's 'Climate Action Plan' (relying on biofuels, synthetic fuels, fleet renewal, operational improvements, and future aircraft with the plan for growth) realistic and sufficient to meet those targets? (chapter 4).

Chapter 5 provides a summary and of the findings and conclusion.

1.2 Definitions

Absolute Contraction approach (ACA)
The ACA sets absolute emissions reduction targets based on the concept of 'contraction': all companies (in a given sector) set emissions reduction targets at the same rate, irrespective of initial emissions performance (SBTi, 2023b). Companies do not have to converge upon a common emissions value (SBTi, 2019).

Paris Temperature Goal
The Paris Agreement article 2(1)a dictates "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015). The Intergovernmental Panel on Climate Change (IPCC) endorsed the 1.5°C target with its Special Report (IPCC, 2018). The 1.5°C target is now scientifically considered as the safe limit for global warming (Cointe & Guillemot, 2023; Rockström et al., 2023). This is confirmed in the European Green Deal, which "underlines the urgent need for ambitious action to tackle climate change and environmental challenges, to limit global warming to 1.5°C" (EC, 2019). The European Climate Law "sets out a binding objective of climate neutrality in the Union by 2050 in pursuit of the long-term temperature goal set out in point (a) of Article 2(1) of the Paris Agreement" (EP & Council of the EU, 2021). The SBTi also confirms that 1.5°C is the safe limit (SBTi, 2023c) and currently only validates targets based on 1.5°C pathways.

Rebound effect
Berkhout et al. (2000, p. 426) define the rebound effect as follows: "Technological progress makes equipment more energy efficient. Less energy is needed to produce the same *amount* of product, using the same *amount* of equipment — *ceteris paribus*. However, not everything stays the same. Because the equipment has become more energy efficient, the cost per unit of services of the equipment falls. [...] A price decrease normally leads to increased consumption. Part of the *ceteris paribus* gains is lost, because one tends to consume more productive services, and the extra demand for productive services from the equipment implies *more* energy consumption. This lost part of the energy conservation is denoted as the rebound effect."

SBTi target setting methods
(SBTi, 2019) defines SBTi target setting methods as frameworks that companies may use "to set emissions reduction targets consistent with the best available climate science". SBTi target setting methods consist of three components: a greenhouse gas budget; a set of emissions scenarios; and an allocation approach. An allocation approach translates "the resulting global or sector-specific emissions pathway into practical requirements that align company emissions with the pathway" (SBTi, 2019, p. 6). The SBTi currently uses two allocation approaches: the Absolute Contraction Approach (ACA) and the Sectoral Decarbonisation Approach (SDA) (SBTi, 2023b).

'Science-based targets'
The term 'science-based' is being used in very different ways, generating considerable confusion (Andersen et al., 2021). Science-based targets are quantitative tools that connect corporate emission reduction goals to climate science to mobilise corporate climate action (Walenta, 2020). It is important to distinguish between overall science-based targets for the world, such as formulated in the Paris Agreement, and specific science-based targets (for individual entities; Andersen et al., 2021). The point is that at the global level, it is feasible to set absolute emission targets like the 1.5°C and 2.0°C budget pathways (IPCC, 2021), but there is no way to unequivocally translate that target to individual (multi-national) companies. A target can be considered as science-based when it (1) has a biophysical possibility of being achieved within its stated timeframe; (2) is quantified so that (a lack of) progress towards the target can be measured and demonstrated: and (3) is supported by a clear analytical rationale that explains why the target is set at its specific level (Andersen et al., 2021).

In its corporate manual The SBTi offers the following (general) definition of science-based targets:

"Greenhouse gas (GHG) emissions reduction targets are considered to be "science-based" if they are in line with what the latest climate science says is necessary to meet the goals of the Paris Agreement to limit global warming to well-below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C" (SBTi, 2023b, p. 5).

At the end of 2021 SBTi made changes for its near-time targets that came into effect in July 2022. SBTi changed its scope 1 and 2 temperature ambition classification from well below 2°C to 1.5°C; its scope 3 temperature ambition classification from 2°C to well below 2°C; and shortened the timeframe from 15 to 10 years (SBTi, 2023f). On its website, the SBTi currently defines 'science-based' as targets that are in line with the 1.5°C temperature limit:

"Targets are considered 'science-based' if they are in line with what the latest climate science deems necessary to meet the goals of the Paris Agreement – limiting global warming to 1.5°C above pre-industrial levels."

Science-Based Targets initiative (SBTi)
The SBTi is a global body enabling businesses to set emissions reduction targets in line with climate science and the temperature limits of the Paris Agreement (SBTi, 2023b). SBTi takes businesses as unit for science-based target (SBT) setting and, when possible, SBTi determines the target for an individual business via sector targets first Andersen et al. (2021).

Sectoral Decarbonization Approach (SDA)
The SDA sets sector-specific emissions intensity reduction targets based on the concept of 'convergence': "all companies in a given sector reduce their emissions intensity to a common value by some future year as dictated by a global emissions pathway" (SBTi, 2019, p. 8).

2 The SBTi and its target setting process

The main findings about SBTi target setting are:

- Science-based targets are quantitative tools that connect corporate emission reduction goals to climate science to mobilise corporate climate action.
- At the global level, there are absolute emission targets like the 1.5°C and 2.0°C budget pathways (IPCC, 2021).
    - SBTi requires companies to define carbon intensity targets, not absolute targets which would lead to absolute emissions reductions. Voluntary science-based targets lead to increased climate action, but there is evidence the targets and scientific mitigation requirements are often not Paris aligned.
- Voluntary science-based targets assume that economic growth is compatible with effective climate action and that market-based approaches and self-regulation are sufficient to align the private sector with the Paris Agreement.
- SBTi presents science-based targets as a low-threshold corporate communications tool to demonstrate climate leadership and, potentially, to delay more ambitious climate policies.
- SBTi uses the apolitical character of science obscuring its science-based targets are based on corporate values like growth and profitability, and reliance on technological solutions.
- A commitment to a near-term target means little in terms of Paris alignment, which requires stable, long-term commitment to secure structural investments, and actions. Having a validated near-term target allows companies with reputation issues to make quasi-credible sustainability. SBTi target setting and validation should therefore be viewed as a corporate stakeholder management tool: a manifestation of the well-known corporate engagement strategy of future-proofing business growth in the face of potentially existential climate risks.

Voluntary science-based targets emerged in the wake of the Paris Agreement, as non-state actors have been enticed to contribute in reaching international climate policy goals (Giesekam et al., 2021; Walenta, 2020). A range of service providers has since emerged that assist a predominantly corporate clientele with developing voluntary science-based targets (hereafter referred to as 'science-based targets'). Over the years, the SBTi has established itself as a major service provider in this domain (Bjørn, Tilsted, et al., 2022; Rekker et al., 2022; Tilsted et al., 2023).

Scientific debate about voluntary science-based targets as approach to align global corporate emissions with the temperature goal of the Paris Agreement has been growing since. The emerging scientific literature addresses various issues that can be grouped under two general themes: *governance aspects of science-based targets* and *methodological aspects of science-based targets*. We address these aspects in 2.2 and 2.3 below. We however begin with briefly addressing the question whether science-based targets lead to Paris-alignment (2.1). And we conclude with presenting a number of implications for understanding the SBTi and its target setting process (2.4).

2.1 Do science-based targets lead to Paris-alignment?

Voluntary science-based targets lead to increased climate action (Bjørn, Tilsted, et al., 2022), but a first quantitative analysis of the Paris alignment of absolute emissions reductions of SBTi target companies shows mixed results (see Ruiz Manuel & Blok, 2023):

- Collectively, SBTi target companies do not align within the 1.5°C temperature goal; they reach only below 2°C;

- SBTi target companies with absolute targets surpassed their targeted reductions (all sectors except transport show this trend), with electricity companies responsible for 78% of the over-achievement and accounting for 98% internal (scope 1) reductions; other sectors only show evidence of emissions reductions outside their operational control (scope 2).

Evaluations into corporate climate reporting often found that science-based targets and scientific mitigation requirements are not aligned. (Dahlmann et al., 2019; Lister, 2018). Lack of publicly available data makes a full independent conduct of such evaluations difficult if not impossible. The general lack of these evaluations *of SBTi reporting so far* (Giesekam et al., 2021) is therefore potentially problematic.

Related, both Ruiz Manuel and Blok (2023) and Bjørn, Tilsted, et al. (2022) express concern – and mention several other studies that have warned and expressed concern – about the *additionality* of corporate climate action. Additionality refers to emissions reductions that would not have occurred otherwise and that can thus be directly attributed to the stated climate action. Additionality is a major issue in carbon offsetting schemes (Cames et al., 2016), a reason for SBTi to not allow such schemes. The possibility of reporting emissions reductions that are non-additional is the result of incomplete and non-transparent corporate emission disclosure and the SBTi's lack of solid emission reporting frameworks and limited jurisdiction to impose these frameworks on target companies (ibid). As a consequence, the emission reductions of corporate climate initiatives are currently assumed to be about one-third additional to NDCs (Ruiz Manuel & Blok, 2023).

Voluntary science-based targets lead to increased climate action, but that does not mean that targets and scientific mitigation requirements are Paris aligned. There is evidence that this is often not the case. It is difficult to independently evaluate the Paris-alignment of voluntary science-based targets and reported progress against these targets because of (1) limited public availability of target data and (2) the possibility that companies report non-additional emissions reductions.

2.2 Governance aspects of science-based targets

The governance aspects of science-based targets have received considerable attention in the scientific literature (Andersen et al., 2021; Bjørn et al., 2017; Bjørn, Tilsted, et al., 2022; Lister, 2018; Tilsted et al., 2023).

Science-based targets can be considered as a product of the post-Paris polycentric climate action regime (Walenta, 2020). In this regime, which emerged in the wake of the 1997 Kyoto Protocol, global climate action is based on the premise that the externality of emissions costs needs to be priced (internalised) into economic transactions and that economic growth is (therefore) compatible with climate action. This allowed space for non-state actors, such as corporations and civil society organisations, to play a role in climate action. A central assumption of the Post-Paris polycentric climate action regime is that the resulting market-based approaches, such as science-based targets as mode of private sector self-regulation, are sufficient to meet the temperature goal and that and that the participation of corporate incumbents in the development of policies and tools aimed at reducing their own climate impact is (therefore) justified (Walenta, 2020). This market environmentalism "conceives markets as the overarching institutional framework defining what is inside and outside the system of societal choice and that conveys the notion that the solution to environmental problems is to be found in the technical domain" (Gómez-Baggethun & Muradian, 2015, p. 222), which meets strong critique (e.g. Hickel et al., 2021). Climate scientists have a high confidence in technology, only being one part in achieving the Paris climate goal (see e.g. IPCC, 2023). Turning to the SBTi, this assumption grants incumbents room for political manoeuvrings. Science-based targets can result in a delay of effective climate action (for instance, in cases when incumbents focus solely on efficiency gains), while independent verification of targets and target progress is difficult if not impossible. We illustrate this below.

Voluntary science-based targets are the product of a post-Paris climate governance regime that assumes that economic growth based in material volume growth with effective climate action and that market-based approaches and self-regulation are sufficient to align the private sector with the Paris Agreement.

2.2.1 The SBTi and science-based targets as corporate communications tool

By nature the SBTi is a voluntary initiative and has no compulsive power. In other words, it needs to persuade companies to join and an expanding membership base to justify its own relevance and importance. The focus of the SBTi is specific: on science-based target *setting and related communications* rather than *the implementation* of science-based targets. In the corporate manual of the Science-Based Targets initiative (SBTi), we read that its overall aim is *"for SBT setting to become standard business practice and for corporations to play a major role in ensuring global warming is kept to a 1.5°C increase"* (SBTi, 2023b, p. 5). On the same page, under the header 'Why join the Science-Based Targets initiative?', we come across a statement that can be read as its purpose or mission: *"The SBTi enables companies to demonstrate leadership on climate action by publicly committing to science-based GHG reduction targets*". The SBTi thus suggests that announcing to set a science-based target and *publicly stating* commitment to that target is sufficient for companies to *demonstrate* climate leadership.

SBTi presents the benefits of joining them as follows: *"Science-based target setting makes business sense (emphasis in original) - it future-proofs growth, saves money, provides resilience against regulation, boosts investor confidence, spurs innovation and competitiveness – while also demonstrating concrete sustainability commitments to increasingly-conscious consumers."* The SBTi presents its target validation process as a (low threshold) service large companies can buy at favourable (package) rates considering the predominantly corporate clientele of the SBTi: fares do not exceed 14,500 USD (SBTi, 2023g). Also, the suggestion is raised that joining the SBTi only brings benefits and that these benefits come quickly: *"Businesses who sign the SBTi commitment letter are immediately recognized as "Committed" on our website, as well as the CDP, UN Global Compact and We Mean Business websites"*. In this way, upon joining the SBTi, companies can brand themselves as climate leaders and instantly communicate their (intended) science-based target commitment to key stakeholders as part of their public affairs strategies.

While a publicly stated emissions reduction commitment may indicate an increase of (future) investments in companies' abilities to reduce emissions (Bjørn, Tilsted, et al., 2022), it says nothing about achieved emissions reductions (see 2.1). In the hands of major corporate polluters that face increasing societal pressure to step up emissions reduction efforts and provide evidence of genuine progress, the SBTi's proposition is therefore a risky one. Companies may use science-based targets to delay more ambitious public climate policies. Tilsted et al. (2023, p. 6), who call for more research into the politics of SBTs, suggest that the SBTi functions as "shielding device to deflect public debate and regulatory pressure on corporate incumbents".

The focus of the SBTi is on science-based target setting and related communications rather than the implementation of science-based targets. The SBTi presents science-based targets as a low-threshold corporate communications tool that companies can rapidly use to demonstrate climate leadership in the face of increasing societal pressure and, potentially, to delay more ambitious climate policies.

2.2.2 The SBTi's science-based targets are not free of values

Socio-political values and choices are central to science-based targets. Science-based targets are in practice scenario-based targets and scenarios are per definition not value-free (Tilsted et al., 2023). For instance, the SBTi often recommends or requires companies to use the Sectoral Decarbonisation Approach (SDA) (see 1.2). The SDA is based on scenarios that by definition accept and do not question substantial industrial production growth. Also, it takes related growth projections and initial emissions intensities into account, and assumes that some sectors will reduce emissions faster than others due to differences in mitigation costs (Tilsted et al., 2023). The growth assumption is a valid assumption for short-term target setting (Hadziosmanovic et al., 2022), but becomes increasingly problematic for the long-term targets SBTi uses it for. The SBTi currently does not disclose the decision-making process and selection criteria deployed to identify the SDA as recommended method; does not explicitly communicate the value judgements embedded in its target-setting methods; and does not require companies to publish information about the target-setting process (although they recommend some level of disclosure) (Bjørn, Tilsted, et al., 2022). In other words, socio-political values and choices inform the manifold choices embedded in the target setting process of SBTi, which remain largely hidden at present as not all methods, company data, and assumptions and choices leading to approved science-based targets are publicly available, obscuring how companies set science-based targets (Tilsted et al., 2023).

SBTi legitimises itself and the process of science-based target setting by mobilising the authority and apparent apolitical character of science as a collection of non-negotiable facts (ibid), obscuring that the process of setting and achieving a science-based target involves the continuous addressing of different cultural, political, social, and economic constraints that can be highly challenging (Andersen et al., 2021). In other words, science-based target setting involves politics, negotiations, and the bringing together of actors with often conflicting interests: *"there is no such thing as a 'scientific target' applied in policy or business – operational targets are socio-political choices* (p. 2). This is particularly relevant here because a core aspect of SBTi's target setting approach is stakeholder consultation.

The SBTi invites corporate and public actors to co-develop sector specific target setting methods that fit their industries. Transparency about the role of these stakeholders and the choices they make is currently insufficient (Tilsted et al., 2023). Considering the above this is problematic. Their involvement may incorporate rather than challenge established growth and profitability conditions; built-in reliance on specific (future) technologies; and ideas about future growth and demand (Bjørn, Tilsted, et al., 2022; Tilsted et al., 2023).

The SBTi mobilises the apparent apolitical character of science, which obscures that its science-based targets are based on incumbent corporate values, notably in relation to current growth and profitability conditions, reliance on (future) technologies, and ideas about future growth and demand.

2.3 Methodological aspects of science-based targets

Methodological aspects of SBTi's target setting process have recently been fiercely debated in the scientific literature (for a discussion on target setting methods see e.g. Bjørn et al., 2021; Bjørn, Lloyd, & Matthews, 2022; Chang et al., 2022). A range of fundamental issues about methodological aspects of the SBTi's target setting procedures persist. In terms of target setting and validation, these issues include, but are not limited to: the freedom of choice companies have in relation to target setting (2.3.1) and regarding target setting method selection (2.3.2); the rigour of the SBTi's target validation process (2.3.3); the common emission allocation principle of the SBTi (2.3.4); and the verifiable Paris-alignment of validated science-based targets (2.3.5). 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 (2.3.6); and untransparent emission accounting and disclosure (2.3.7). We cover these aspects in turn below.

2.3.1 Companies' freedom of choice during target-setting

As voluntary initiative (see 2.2.), the SBTi can only urge companies to aim for the highest level of ambition when committing to a science-based target. At present, the SBTi requires companies to commit to a near-term target; long-term (net-zero) targets remain optional (SBTi, 2023b). Until recently, companies could only set near-term targets. Near-term targets cover a minimum of five years and a maximum of 10 years from the date the target is submitted for assessment and must align with 1.5°C pathways (see also 1.2) (SBTi, 2023b, 2023d). 'Long-term science-based targets' are optional. They reach beyond the near-term interval (with target years 2040 or 2050) in combination with near-term milestones at five-year intervals (SBTi, 2023b). Long-term science-based targets show companies how much emissions reductions they must achieve to reach net zero by 2050 or sooner. A considerable number of companies have set long-term targets (see Net Zero Tracker, 2023).

The SBTi's current focus on near-term science-based targets (companies, after all, have the freedom to set near-term targets only) is considered problematic. Near-term targets are generally based on scenarios that lead to temperature overshoot followed by a return to negative emissions in the second half of the 21st century. Per definition, near-term targets lack a long-term commitment to the implementation of negative emission technologies to address this overshoot (Hadziosmanovic et al., 2022). Also, within their near-term target period, companies can choose to assume that potential breakthrough technologies take effect in the future and follow a path where most emissions reductions are accomplished close to the target year, with higher cumulative emissions as result (Tilsted et al., 2023). Hadziosmanovic et al. (2022) therefore argue that near-term targets must be set within a long-term target, to ensure alignment with a global carbon budget and avoid dangerous overshoot.

Long-term science-based targets also have limitations. Companies may consider committing to long-term emissions reduction target risky because it is at odds with the common business practice of regularly adjusting targets and strategies to unforeseen changes in the business environment, although - scientifically speaking - such changes are not valid reasons for adjusting emission reduction targets and plans (Bjørn et al., 2017). In contrast, as targets are set for the long-term future, companies may also consider long-term science-based target as a risk-free commitment (ibid). This is arguably different in asset-heavy sectors such as aviation. Airlines planning fleet renewal with the latest generation of Boeing or Airbus aircraft will create lock-ins that limit their options for close to zero emissions in 2050, partly owing to the average aircraft economic lifespan (owned or leased) of typically 30 years (see Dray, 2013). In asset-heavy sectors, thus, current investment decisions have consequences for 2050. The SBTi is yet to take this fully onboard. Its current net-zero standard (SBTi, 2023d) and requirements and recommendations for target setting (SBTi, 2023e) do not require companies to address the (longer-term) lock-in effects of investment decisions.

2.3.2 Companies' freedom of choice regarding target setting method selection

The target setting methods that the SBTi offers consist of three components: a greenhouse gas budget; a set of emissions scenarios; and an allocation approach. The SBTi's currently offers two (recommended) allocation approaches: the Absolute Contraction Approach (ACA) and the Sectoral Decarbonisation Approach (SDA) (SBTi, 2019) (see definitions in 1.2). In the scientific literature, we find concerns about the variety in methods. Bjørn, Tilsted, et al. (2022, p. 66) identify at least seven target setting methods, "each using different target equations, global emission scenarios and subjective allocation principles that translate global allowable emissions to individual companies". As companies themselves can choose between available target setting methods, this allows for significant variation in terms of ambition (Tilsted et al., 2023). Within the selected target setting method, the SBTi recommends – but does not require – companies to use the most ambitious decarbonisation scenarios (leading to the earliest reductions and the least cumulative emissions (SBTi, 2023e). Combined with the current lack of transparency on the choices made by companies, this freedom of choice is considered as a key issue (Bjørn, Tilsted, et al., 2022).

2.3.3 Rigour of SBTi's target validation process

The SBTi's Target Validation Team (TVT) – the team responsible for validating targets – consists of a lead reviewer (LR) and appointed approver (AA) (see SBTi, 2023b). The LR conducts a desk review of the submitted target; the AA peer reviews this desk review with a prime purpose of checking for potential conflict of interest. Thus, this process is based on a four-eyes-principle only (only in the event that the TVT is unable to agree on the outcome, the Technical Department of the SBTi steps in). The SBTi also deploys a narrow, financial definition of conflict of interest (see ibid.), disregarding that individuals may be affected in other ways by the outcome of the results of their review. The current conflict of interest policy therefore seems on the light side, given the involvement of, for example, aviation sector actors in the development of SBTi sector guidance documents (see e.g. SBTi, 2021). The overall review process is lighter than common scientific peer review process, which involves part- or full-blind review of manuscripts including one or several rounds of revisions and editorial decisions before it will be published. Peer-review is the basis of the production of science, and avoiding unwarranted claims (Kelly et al., 2014). This raises questions about the legitimacy of the label 'science-based', particularly given the lure of a successful target validation and subsequent expansion of the SBTi membership base.

2.3.4 The principle of emission-allocation favours incumbents

As explained in 1.3, the SBTi currently uses two allocation approaches: the Absolute Contraction Approach (ACA) and the Sectoral Decarbonisation Approach (SDA). Concerns have been raised about whether these approaches will impede "collective alignment with the Paris temperature goal" (Bjørn, Tilsted, et al., 2022, p. 66). The SBTi endorses the SDA (SBTi, 2019). Central to the SDA is the so-called grandfathering emission allocation principle. Grandfathering is based on legacy entitlement, i.e. basing future allowable emissions on past emissions (see Bjørn et al., 2021; Knight, 2014). Grandfathering suggests that incumbents have the right to maintain their incumbent status, both today and in the future. This perpetuates historical inequalities and assumes that the consolidation of current power relations is beyond debate (Tilsted et al., 2023). Considering that, in the case of aviation, 88% of the world's flying population resides in high and upper-middle income countries, and that high income, former colonial powers such as the Netherlands have a significant historical responsibility for global warming (Carbon Brief, 2023; Gössling & Humpe, 2020), grandfathering seems at odds with climate justice.

2.3.5 Verifiable Paris alignment of validated science-based targets

The SBTi makes explicit that it regularly updates its procedures (target types, levels, and intervals; tools and methods; rules for recalculation of targets, etc.) to ensure alignment with the latest climate science (see SBTi, 2023b, 2023c; SBTi, 2023e, 2023f). These procedures are also based on detailed sector inputs (e.g. inputs from the aviation sector, see (SBTi, 2021). At the same time, it is unclear whether the SBTi is capable of ensuring this alignment at present, as it only provides general notions on how science-based targets are set and does not disclose company-specific target validation reports.

2.3.6 Allowed use of problematic means for meeting science-based targets

The SBTi does not provide or prescribe sector actions for meeting validated science-based targets (see SBTi, 2023b), but it does exclude carbon offsets and mentions suggested measures in its sector-specific guidelines (like SAF, more efficient aircraft, and operational efficiency for aviation, see (SBTi, 2023h). SBTi target companies are currently allowed to use problematic means to meet science-based targets. This includes, for example, the use of renewable energy certificates (see Bjørn, Lloyd, et al., 2022); and – often unproven – future technologies with unclear scalability. Peeters et al. (2016) and Buijtendijk and Eijgelaar (2022) offer evidence of such technology myths for aviation in general and the Dutch aviation policy context in specific (see chapter 3 and 4). At the same time, companies that fail to meet their targets in the near future will still reap the reputational benefits of their SBTi-affiliation (Tilsted et al., 2023).

2.3.7 Untransparent emission accounting and disclosure

At present, as a voluntary initiative (see 2.2), the SBTi has limited jurisdiction and cannot require companies to provide detailed information on how they intend to meet science-based targets (Tilsted et al., 2023). The SBTi requires companies to publicly report company-wide emissions inventories against validated targets on an annual basis (so far companies face no consequences for not meeting this requirement) and review – and if necessary recalculate – their targets at a minimum of every five years (see SBTi, 2023b). The SBTi currently recommends but does not require that organisational boundaries of target setting companies and targets correspond with the organisational boundaries that companies use in their reporting and accounting. The SBTi offers a range of best-practice disclosure items, including third-party verification, which, according to the SBTi, ensures the quality of the calculation method and underlying disclosed data and processes (see SBTi, 2023b). Thus, companies have significant freedom when it comes to decisions on how to account and disclose their emissions.

While current SBTi reporting rules on validated targets focus mainly on improvements in the emission accounting and disclosure process, it is currently unclear whether science-based target setting companies improve their functional accounting and emission disclosure practices as a result of joining the SBTi (Walenta, 2020). Definitive conclusions are hindered by inconsistent and incomplete corporate disclosures (Bjørn, Tilsted, et al., 2022). Third party verification is a main method for the SBTi and the public to assess company claims (Ruiz Manuel & Blok, 2023). There is evidence that the share of companies seeking external verification is increasing, although most companies only verify at a low level and there is no trend towards stricter verification (Ruiz Manuel & Blok, 2023). As the SBTi currently does not require third-party verification, there is potential for creative emissions accounting and incomplete emissions disclosure, which complicates the assessment of target progress and the effect of science-based targets on global emissions (Bjørn, Tilsted, et al., 2022).

2.3.8 SBTs as communication

The SBTi's current emphasis on corporate communication benefits relating to publicly stating science-based emissions reduction targets, and the listed issues of the current SBTi target setting and validation process means that target companies have considerable space for political manoeuvring. **A commitment to a near-term target means little in terms of Paris alignment, which requires stable, long-term commitment to secure structural investments, and actions.** Having a validated near-term target allows companies with reputation issues to make quasi-credible sustainability claims regardless of their target progress, and allows for backtracking (abandoning targets as the result of a strategy change within the company) and short-termism. SBTi target setting and validation should therefore be viewed as well as a corporate stakeholder management tool: a manifestation of the well-known corporate engagement strategy of future-proofing business growth in the face of potentially existential climate risks (see Tilsted et al., 2023).

2.4 Conclusion for proper understanding of SBTi validation

SBTs are an accepted and improving corporate climate governance practice. But it is not clear at present how SBTs influences total corporate greenhouse gas emissions and under what conditions SBTs accelerate or delay more ambitious climate policy (Bjørn, Tilsted, et al., 2022; Ruiz Manuel & Blok, 2023). The issues we have identified above show that, by themselves, SBTs are insufficient for meaningful and climate-just decarbonisation and, therefore, the application of SBTs cannot substitute public policy (Bjørn, Tilsted, et al., 2022; Lister, 2018; Tilsted et al., 2023; Walenta, 2020). The issues we listed above are also critical issues: many corporations have a history of challenging climate science, blocking climate regulations, and failing to deliver on their own promises (Lister, 2018). For instance, Air France – KLM leads a negative aviation industry climate lobbying effort to strategically oppose all EU and European regulatory measures to achieve mid-term and long-term climate targets (InfluenceMap, 2021). The company also undermines its own sustainability actions by actively lobbying for Dutch airport expansion and against European and Dutch climate regulation for aviation such as taxes on flight tickets and kerosene (InfluenceMap, 2021; Mooldijk et al., 2022). In this light, two policy implications are relevant here.

First, the SBTi legitimizes an incumbent-driven transition shaped by large corporations. It enables these incumbents to further protect themselves from democratic control, for example by allowing them to speculate on the rapid upscaling of unproven technological innovations while ignoring that accomplishing genuine 1.5°C pathways also require demand restrictions, particularly in industries that maintain high-carbon consumer lifestyles (Tilsted et al., 2023). The limited transparency of SBTi target companies and the limited jurisdiction of SBTi to impose solid accounting and disclosure frameworks, means that co-regulation (the coordination of public policy and SBTi-facilitated corporate self-regulation), as first proposed by Lister (2018), is not possible at present.

Second, as Bjørn, Tilsted, et al. (2022) conclude, science-based targets uptake is unevenly distributed across countries and will likely stall without more ambitious public climate policy. Here we observe a fundamental tension with the concept of climate justice. SBTs can result in uneven wealth accumulation and distribution of emission reduction burdens (Walenta, 2020). Companies that are responsible for large, historical emissions and that are based in developed countries can be considered as obliged to commit to the greatest share of global emissions reductions, all other things being equal (Bjørn et al., 2017). As we explained above, this is not reflected in the current 'grandfathering' of emissions central to the SBTi approach.

To conclude, the SBTi is viewed by the private sector as enabling climate policy discourse. SBTs help companies to create business advantages through risk management and carbon efficiency gains. However, currently, SBTs are insufficient to make the private sector Paris-aligned. This requires a broader policy mix that includes state-led prescriptive interventions aimed at transformation of business models, industry structures, and consumption patterns that are at the roots of the current climate crisis: one is not effective without the other (Lister, 2018). Changes in how things are produced, in other words private-sector led efficiency gains, must be supplemented by what is produced and for what reason and the latter entails the socio-political transformation of the economic system in which companies operate (Bjørn et al., 2017).

Given the urgency of climate change and the current insufficiency of public policy, emphasis on corporate self-regulation through voluntary SBTs is highly problematic. Incumbent firms such as KLM Royal Dutch Airlines face the rigidity of their own business model. To deliver on growth promises in saturated markets – often of their own making – these firms have cultivated operations-focused, efficiency-driven cultures and cannot easily change directions (see Buijtendijk et al., 2021; Doz & Kosonen, 2010). They will preserve rather than change the systems of production and consumption that drive the climate crisis (Lister, 2018): the Dutch aviation policy domain is a case in point (see Buijtendijk & Eijgelaar, 2022). Critical for climate policy, in other words, is a combination of private sector initiatives alongside clear, regulatory public sector leadership (Lister, 2018).

In this light, the SBTi's current emphasis on corporate communication benefits relating to publicly stating science-based emissions reduction targets is questionable. It is unclear whether these statements offer a true representation of companies and decision-making processes: at the very least, the corporate practice of committing to SBTs should be viewed also as a stakeholder management strategy in the face of increasing societal pressures to step up corporate climate action (Bjørn, Tilsted, et al., 2022), and be evaluated as such.

Summarised, the SBTi system and process is problematic because:

- The wider critique and contextualisation of SBTi as a limited governance tool with inbuilt incumbent-led approaches.
- SBTi providing a voluntary tool requiring therefore a 'business case' sales point causing SBTi to develop science-based targets as a corporate communications tool.
- The target validation governance shows low transparency and, double counting risk etc.
- SBTi standards are not grounded in a scientific validation or peer-review process and as such cannot be labelled 'scientific'. Some of the resources used to define targets are from science, but with many corporate values involved, particularly regarding technology (techno-optimistic) and volume growth.

3 Is KLM's (SBTi) target in line with the Paris Agreement?

KLM claims that its emission targets are accredited by SBTi and aligned with a 1.5°C climate scenario. This chapter assesses whether the SBTi aviation target scenario is aligned with Paris, and whether KLM's targets, accepted by SBTi, are Paris aligned. The feasibility of reaching the targets is discussed in chapter 4.

Key findings are:

- The SBTi aviation sector target is based on a zero-emissions pathway developed by consultants and NGO's. There is no scientific peer-review process or other method to guarantee its scientific rigor.
- The SBTi target emission pathway assumes 2.9%/annum air transport volume growth, operational and technological efficiency improvements, and a 100% use of SAF. Because of renewable resource limitations, the 100% SAF cannot be aligned in an equitable way with the assumed volume growth. Therefore, this scenario has a low feasibility.
- Both SBTi and KLM assume that aviation is a hard to abate sector and therefore requires a larger share of the remaining global carbon footprint than other sectors. Both ignore fundamental ethical and equity issues with this viewpoint. Also, it is unclear which other sectors have to reduce their emissions faster.
- KLM has set one target: an improvement of its carbon intensity (kg CO_2 per passenger/ton-kilometre) by 30% between 2019 and 2030, which equals the target SBTi requires.

The SBTi explains the need for the aviation sector to take action as follows: "Regulators, investors and consumers are placing increasing pressure on the sector to take action on climate change. Science-based targets to reduce greenhouse gas emissions enable companies to demonstrate concrete sustainability commitments to increasingly conscious consumers" (SBTi, 2023a). For the reasons provided in chapter 2 of this report, SBTi's assertion that SBTI enables companies to demonstrate sustainability commitments for consumers or in general is not well-founded. The SBTi targets for aviation are set by two documents: the Aviation sector guidance for well below 2°C global warming (SBTi, 2021) and an interim 1.5°C pathway for aviation (SBTi, 2023h). The 2023 one supersedes the document of 2021 and sets the goal for efficiency improvement in 2030 over 2019 and some other conditions. An excel file – the Target-setting Tool (version 2) - exists, that helps airlines to calculate their goals. Ultimately submitted targets and accreditation reports are not in the public domain.

SBTi (2023h) has been written by authors from two consultancies (two authors from the International Council on Clean Transportation (ICTT), three from the Boston Consulting Group (BCG), and five authors from an NGO (WWF). Furthermore, "detailed input" was gathered by a dedicated Technical Working Group of 17 organisations (15 aviation sector companies (mostly airlines); the International Energy Agency (IEA); and one university). The role of independent science is weak in this report even though some of the consultants have a scientific background. Also, it lacks an independent scientific review (double-blind or single-blind) as is the basic practice in scientific publishing: "The major advantage of a peer review process is that peer-reviewed articles provide a trusted form of scientific communication" (Kelly et al., 2014, p. 227). SBTi does not prescribe a technology roadmap for meeting emissions reduction targets (SBTi, 2021).

The interim 1.5°C pathway for aviation (SBTi, 2023h) is in partly in line with the SBTi's change in ambition classification from 2°C to 1.5°C warming limit (see SBTi, 2023f), because it assumed "well-below 2°C" (SBTi, 2023h, p. 2) which clearly is higher than 1.5°C. It is presented as an accessible option for aviation companies ready to submit Net Zero targets (SBTi, 2023h). This interim pathway is valid until the SBTi's new 1.5°C aviation sector guidance is released. The SBTi describes the purpose of this forthcoming sector guidance as follows: (it enables aviation sector companies) "to reduce their emissions footprint and prevent the worst effects of climate change" (SBTi, 2023a). The interim 1.5°C pathway for aviation is valid until this new sector specific guidance will be released. The targets for 2030 are almost equal in both reports, one of the reasons that, according to the report's scenario, aviation will take a relatively high share of the carbon budget (see 3.1.2).

The temperature increase in climate change is the result of the accumulated amount of CO_2 in the atmosphere. Annual emissions will add to the total accumulated anthropogenic CO_2 emissions since the industrial revolution in the 19th century. The atmospheric system does absorb part of these emissions, but the total emissions humans can add to the atmosphere to stay below a certain temperature increase is a given number of CO_2-emissions in total. This amount will reduce every year with the combined annual emissions of CO_2, including those from aviation. When emissions stay as they are, the 1.5°C budget will be reached in less than a decade. Based on such consideration the consensus is to reduce global emissions by about 50% in 2030 with respect to 2019 and to net-zero by 2050. The target defined by SBTi (2023h) is based in such a global scenario and shows aviation (SBTi, 2023h) to reach close to zero by 2050. Based on an air transport volume growth of 2.9%/annum, somewhat lower than business-as-usual growth of 3.8% (Boeing, 2023), SBTi (2023h) figured out that 100% sustainable alternative fuels will have to be used in 2050, allowing to follow a defined carbon intensity improvement. The intensity is measured as kg CO_2/pax-km or par revenue ton-km. The total emissions are the product of intensity and volume. As in a liberal economy, the growth of individual companies is difficult to govern in contrast to all companies within a sector. The latter requires a distribution of the share of the carbon budget among all sectors. Nevertheless, companies have the moral obligation to consider whether their claim towards the overall carbon budget is justified on ethical and equity grounds. This all is relevant for the target in 2030, but not in 2050, as then the carbon intensity should be zero regardless of the volume. The feasibility of planned actions to reach a zero-carbon intensity will of course depend on the volume to be served with these actions.

3.1 SBTI's aviation sector guidance and targets

3.1.1 General SBTi approach to set aviation sector targets

SBTi (2021) was originally based on the SDA approach. SBTI (2021) concludes that the aviation sector should improve its emission intensity by "~35-40% between 2019-2035, or ~65% from 2019-2050" (SBTi, 2021, p. 4). In 2023, SBTi published an intermediate 1.5°C guidance (SBTi, 2023h) with a new scenario and new targets, which supersede the original 2021 ones. KLM has used the former guidance, but both refer to a 30% intensity improvement by 2030 over the base year chosen. The global aviation emission targets provided by (SBTi, 2023h) are significantly more ambitious as those given in AR6 of (IPCC, 2022), partly because differences in volume growth assumptions (higher in AR6) and final shares of SAF-E (lower in AR6). Figure 1 shows how the targets compare. SBTi does not give the exact assumptions for the 1.45°C scenario, but does for two underlying scenarios, following the NZE (near-zero emissions) Scenario (IEA, 2022) up to 2031 and the Breakthrough Scenario (Graver et al., 2022) after 2031. This means that until 2031, the global aviation volume growth assumption is 2.5%/year increasing to 2.9% after 2031.

Air transport fuel efficiency improvements are assumed to occur through a combination of more fuel-efficient aircraft and more efficient operations are assumed of 1.5%/year until 2031 and 2%/year after. Finally, in 2050, 100% SAF is assumed. In general, aircraft fuel-efficiency improvements gradually reduce over time (Peeters & Middel, 2007) and Alonso et al. (2019) assume 1.3% per year to be the maximum achievable until 2050, which is much lower than the 2% assumed in the 1.5°C scenario. Opportunities for operational improvements are limited because the operational losses in air traffic control cause losses of at most 10% (Lyle, 2018). One measure that could be taken is to increase the seating density, a strategy that low-cost carriers have applied. That would improve the efficiency per passenger-kilometre by tens of per cents. However, it will have a strong effect on demand, because for every 1% seat density increase, creating almost 1% fuel efficiency improvement, the average ticket prices with also reduce by about 1%, thus causing significant additional growth. Therefore, high seat-density assumptions should translate to the volume growth assumption, or be accompanied by rather high taxes.

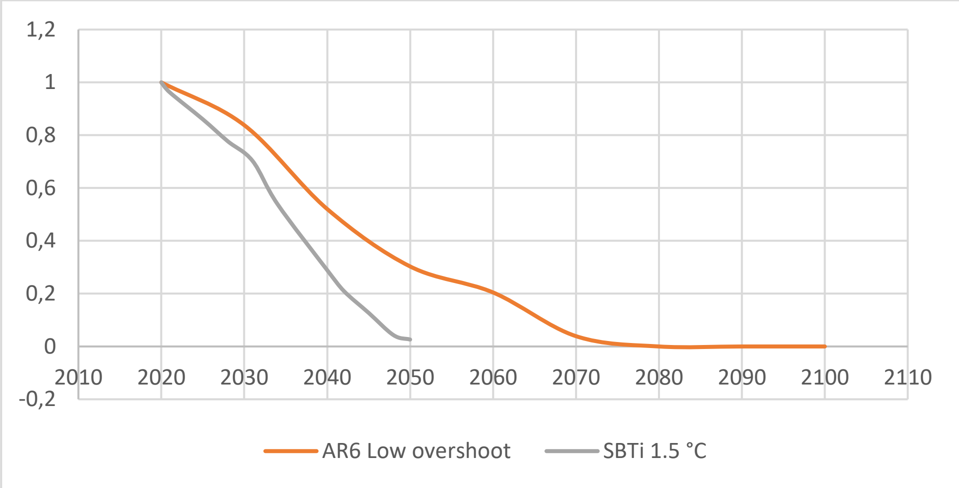

Figure 1: comparing the SBTi target index of total emissions for the aviation sector (SBTi, 2023h) to the lost ambitious one given in AR6 (IPCC, 2022). Total CO_2 emissions in 2020 are indexed at 1.0.

The combination of high growth (2.9%/year) and 100% SAF uptake, with an almost 100% emission reduction means that the majority of SAF should be synthetic e-fuels. Unfortunately, the renewable energy use for producing e-fuels is currently very high (Male et al., 2021), while bio-based SAF suffer from land-use constraints (Becken et al., 2023). Recent scenario work showed that 100% e-fuels would result in extreme shares of global renewables going to aviation (up to 50% according to Peeters & Papp, 2023). This high share raises questions about the equitable distribution of scarce renewable energy across sectors and the global population. Therefore, aviation growth is not easily combined with climate justice, understood here as a socially sustainable (equitable) mitigation of climate change (Peeters & Papp, 2023). Furthermore, it is unlikely that a small sector like aviation can capture between 15% and 50% of all renewable energy.

3.1.2 Hard to abate in SBTi

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, like for instance currently exist in the automotive sector (electric cars). Electric aircraft flying with large numbers of passengers over relevant distances do not exist and will not become available at any significant level by 2030, nor even 2050 due to aircraft development times of over a decade and the subsequent time-lack in replacing a global fleet with more with a value of trillions. That cannot be done in a matter of a few years, simply because the resources (labour, factories, materials) do not exist to do so (Bergero et al., 2023; Gnadt et al., 2019; Uppink et al., 2022). SBTi acknowledges the difficulties to abate aviation’s emissions and states that aviation is “qualifying it for a larger share of future emissions under that framework” (SBTi, 2023h, pp. 3, footnote 1), referring to the Net-Zero Emissions (NZE) scenario that indeed states to accept aviation to take a relatively large share of remaining fossil fuels in 2050 (IEA, 2021). This is translated into a delay of reductions of emissions until 2030, after which reduction rates become faster, while the SSP1-1.9 1.5°C scenario requires the fastest reductions starting immediately to achieve 1.5°C (IPCC, 2021). Furthermore, the accumulated emissions between 2019 and 2050 for the SBTi scenario would amount to some 17 Gtons, which is 5.7% of the global available carbon budget over that period for a 83% likelihood to stay below 1.5°C (Table SPM.2 in IPCC, 2021). One may discuss whether a sector, with a global airlines revenue of $835 billion (IATA, 2020), some 1% of the global GDP[3] in 2019) would indeed take a six times larger share of the remaining carbon budget (refer to the vagueness observed by Lund et al., 2023 to determine what emissions are 'unavoidable'). Also, the targets set by the Glasgow Declaration (One Planet Network, 2021), signed by some 1000 tourism companies and organisations, requires a reduction of emissions of 50% by 2030 and 100% by 2050 over 2019. The accumulated emissions for this target would be some 9.5 Gton between 2019 and 2050, 43% lower than the SBTi target.

[3] Based on the 87.2 trillion given in https://www.statista.com/statistics/268750/global-gross-domestic-product-gdp/.

3.1.3 Translation of targets from the sector to the corporate level

Another issue is how the emission intensities are set based on the sector total emissions scenario. Table 1 shows the result of calculating the volume growth to 2050 (three times of 2019), and the emissions without SAF (45% reduction). SBTi (2023h) assumes 100% 'SAF plus hydrogen' without specifying the shares of each. Because hydrogen is very unlikely to become a major source of energy – and thus CO_2-avoidance – by 2050 (see section 4.7.5), this means that the majority of savings comes from the SAF share and that thus has to be SAF-E, because that is the only type with an almost 100% carbon reduction potential (Schäppi et al., 2022). This is a problematic assumption as we will show at the end of this section.

Table 1: assessing the SBTi 1.5°C scenario assumption. All numbers follow from the SBTi scenario assumptions, but the LCA emissions requirement is calculated from those results as an apparent assumption in the SBTi scenario.

	2019-2031	2031-2050	2019-2050
Volume growth	2.50%	2.90%	
Intensity improvement	-1.70%	-2%	
Volume index 2050			307%
Emissions intensity index 2050 (excluding SAF)			55%
Fuel needed (index 2019)			170%

The SBTi only accredits targets, but not the feasibility of the pathway to reach those targets or specific technology roadmaps delineating how sectors and target setting companies can meet SBTs (see as well chapter 2). The original SBTi's aviation sector guidance documents present companies with a number of options omitting any checks on the decarbonisation levers employed: "airlines may consider improving carbon intensity through fleet renewal, improved operational efficiency, adoption of Sustainable Aviation Fuels or other solutions" (SBTi, 2021, p. 5), SBTi does not allow the use of "out of value chain neutralization or compensation credits".

As observed above, the SBTi 1.5°C scenario assumes 100% alternative sustainable fuels (SAF plus hydrogen) in 2050. That is a problematic assumption when at the same time assuming that the air transport volume will grow substantially for the following reasons:

- For hydrogen, completely new aircraft technology needs to be developed and applied to all types of aircraft in the global fleet for some 10-15 basic classes, different distance classes (commuter, short, medium, long), seat classes (20-50, 50-100, 100-200, 200-300, >300), cabin layout (single aisle narrow-body versus twin-aisle wide-body), engine type (turbo-prop, jet) and that for at least two main airframes. To develop all these aircraft classes requires decades and the new types are unlikely or even impossible to replace kerosene-based aircraft before 2035 for the smallest aircraft and before 2050 for the largest (Noland, 2021). After these type introduction into service, it will take another two to three decades to replace the global fleet, because aircraft have an economic life of 20-40 years (Dray, 2013). See further discussion in section 4.7.5. **So, revolutionary aircraft technology will not reduce emissions much before 2050, if at all.**
- The 100% SAF-use proposed meets several challenges (Capaz et al., 2020). Pure biofuels (SAF-B) need very large areas to grow the crops because plants have a very low solar-energy conversion rate (some 1-3%; Blankenship et al., 2011; Pate, 2013). This means that large stretches of land will be needed to produce the feedstock (Ahmed et al., 2021), threatening food production and nature conservation. Additionally, the feedstock processing and fuel production require large amounts of renewable energy, which also adds to space-use. Particularly algae-based SAF requires more energy inputs than the produced fuel SAF contains. Similarly, waste-based SAF (SAF-W) cannot be produced sustainably in sufficient volumes and at low enough prices; scaling up requires cleaner production methods and – like SAF-B – less reliance on land (Kallbekken & Victor, 2022). Additionally, SAF-W suffers from the risk of creating a market for 'waste' as a resource, while currently much 'waste' is still used for other products. For instance, of total UK cooking oil

most is currently used to "manufacture soap, make-up, clothes, rubber, and detergents" (The Royal Society, 2023, p. 24). But even if 40%-60% of all used cooking oil was now used for UK SAF-W production, it would only cover 0.3% of all annually used Jet A in the UK (The Royal Society, 2023).

- SAF-B and SAF-W, as currently ordered by KLM, do not reduce emissions by 100%, but rather by 50% to 80%, depending on a range of factors concerning feedstock types and the climate zones where they are produced, agricultural systems applied, and the production processes used (ICAO, 2019; The Royal Society, 2023). **So, these types of SAF cannot reduce aviation's emissions to zero.**
- The most environmentally sound solution currently appears to be the SAF-E types of synthetic fuels. Theoretically, these fuels will be able to remove almost 100% of the carbon from the life-cycle and production process, but currently at a low overall systems energy efficiency of between 10 and 20% (Schäppi et al., 2022). The consequence of this low energy efficiency is that relatively high shares of renewables would be needed to provide aviation with high shares of SAF-E. For the case of Germany, it is estimated that mixing 70% SAF-E to Germany's aviation bunkers in 2050 would consume an amount of electricity that equals the total German electricity production in 2018 (Drünert et al., 2020). Peeters and Papp (2023) assume **100% SAF-E for global aviation in 2050 would consume 20-50% of all global renewables expected to be available for humanity in 2050** (IEA, 2021).

SBTi (2023h) does take air traffic volumes development as the basis of their target setting calculations, but it provides only intensity targets for airlines. The reason is not given, but might be related to the fact that for individual airline companies, it is difficult to define a clear growth-related emission reduction goal until 2030. For 2050, the not-required target, the situation is different because both total emissions and emission intensity should be zero. Basically, this zero-emissions can be achieved with e-fuels or by abandoning air travel. Zero-emission aircraft for ultra-short-haul are now being developed but a full portfolio of medium- and long-haul zero-emissions aircraft will certainly not arrive in time to populate the whole global fleet of airliners by 2050. Even though for instance SAF-E has the technical potential to provide zero-emissions for individual flights and even for a whole airline, it is also clear that there will simply not be enough SAF-E in 2050 to accommodate all air travel when global aviation is freely growing as in business-as-usual. Therefore, SCIENCE-BASED TARGETSscenarios need to include the whole sector's volume development *within parameters of structural resource constraints* (feedstocks, rare metals, renewable energy, etc.). Discussions about these constraints emerged since 2020 in the literature (Drünert et al., 2020; Peeters & Papp, 2023).

The current SBTi aviation scenario fails to provide this growth context. It only provides carbon intensity requirements in terms of emissions per revenue seat-km or revenue ton-km. A clear target for zero carbon emissions by 2050 would have helped, but with current knowledge can only be achieved by using 100% SAF-E, which, as explained above, faces critical supply problems in case all airlines would use it. This means that even if an airline sets a goal of 100% SAF-E, it will block the way to zero for other airlines who will not be able to acquire enough SAF-E (let alone other industries), who would then still need to rely on fossil-based fuels. **Therefore, the sustainability of an airline using the SAF-E route would only work under the condition of a mechanism that limits the use of fossil-based kerosene globally.**

3.2 KLM's science-based target.

Below we evaluate KLM's SBTs, looking at the stated goals, below we evaluate KLM's stated goals (3.2.1); the possibility of being allowed a larger share of fossil fuel emissions because aviation's projected 'hard to abate' status (3.2.2); and the non-CO_2 impacts of aviation (3.2.3.

3.2.1 Stated Targets

In 2022, KLM announced that their emission reduction plan was approved by SBTi and that their carbon intensity improvement of 30% with respect to 2019 is "in compliance with the Paris Agreement" and that "the emission reduction target for 2030 adheres to the well-below 2°C trajectory" (KLM, 2022b, p. 1). In a press release, KLM refers to their Climate Action Plan (KLM, 2022a) for how the airline believes to achieve the reduction. The KLM has set the following target (KLM, 2022a): ***Reduce the carbon intensity by 30% between 2019 and 2030***

A consequence of the intensity goal combined with KLM's envisaged transport volume growth plans is that total emissions will reduce by 12% between 2019 and 2030. The failure to set a target for absolute emission reductions faced a critical note from ABN-AMRO, a big investment bank (de Barros Fritz, 2023).

There are two issues remaining in which KLM is aligned with SBTi, but that are debatable. The first one is the claim by both that aviation is 'hard-to-abate' and thus has the right to set less stringent targets than on average. The second is that non-CO_2 need not to be covered in the targets. We'll discuss both issues below.

3.2.2 Hard to abate status as used by KLM

KLM does not hide behind this: "The aviation industry is considered a 'hard to abate' sector, due to a lack of alternatives and a rise in air mobility demand. The general struggle in achieving sustainability is driven by limited zero-emission technology readily available, which will only have meaningful contributions after 2030, and specific regulations affecting the worldwide level playing field. However, this does not dismiss us from taking our responsibility." (KLM, 2022a, p. 6). But at the same time, KLM takes for granted that a higher share is justified because the aviation industry did not come up with a timely technical solution that could combine zero-emissions with free growth of the sector.

Also, the above nuanced position and statements are in contrast with a statement in KLM's Admissibility Defence Sections: "This means that an airline cannot be required to achieve the same reduction rates as some other sectors. This is also the view of SBTi" (Katan & van 't Lam, 2023, pp. 5, par. 20). A question is whether the sheer difficulty to find strong enough technical mitigation options for a certain sector enabling to combine unlimited economic growth with zero-emissions in 2050 is a strong enough reason for allowing that sector a larger share of the carbon budget. SBTi, IEA, the International Air Transport Association (IATA), and others seem to simply accept this way of thinking. They simply weigh the cost of abatement for a growing amount of volume produced by a sector. The SDA method of SBTi uses this logic, as it essentially divides global allowable emissions between sectors in a 'cost optimal' way, hence attempting to minimise global transition costs. In other words, they argue in line with the work of economists like Nordhaus (2008) that abatement costs (cost per ton CO_2 avoided) should guide policies and mitigation. Keen (2021, p. 1149) warns such an approach would obscure 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".

Basically this abatement cost optimalisation approach advocates to first mitigate the emissions of sectors with the lowest abatement cost, and consequently allows sectors with high abatement cost to take a larger share of the remaining carbon budget. But it is also criticised because it ignores synergies between abatement of sectors, additional benefits other than only the reduction of CO_2, socio-economic issues and uncertainties (Ekins et al., 2011). Particularly, 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 are elements to consider for climate justice abatement. There are two forms of climate justice: 'burden-sharing justice' and 'harm avoidance justice' (Caney, 2014). Burden-sharing justice means that the burden of climate change affects particularly those who caused the problem, who can most easily pay for it or who have benefited most from the activities that caused climate change, should take the burden. Harm avoidance, on the other hand, looks at who should do what to prevent climate change, based on the imperative that those who suffer most will be best protected from harm (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, Art.4.1).

When it comes to air travel, this is not the case at all. The burden, devastating extreme weather events, extended droughts, floods, biodiversity loss, soil-degradation are concentrated in developing countries (Dolšak

& Prakash, 2022b) while the population of developing countries flies much less (IATA, 2020)[4]. Because air travel serves mainly rich people, and because the necessity of many flights is particularly questionable as reported by frequent flyers (almost half of the flights was reported to be not necessary; Gössling et al., 2019), one could question whether air travel should grow based on an assumption of unlimited amounts of SAF, the production of which requires high shares of resources, feedstocks and renewables (Meerstadt et al., 2021; Schäppi et al., 2022). In other words: the fact that aviation is hard to abate is not a convincing argument to let aviation take a larger share of the global carbon budget and tries to avoid the discussion about curbing growth of aviation out of the discussion about zero-emissions aviation (Dolšak & Prakash, 2022a; IEA, 2023; Katz-Rosene & Ambe-Uva, 2023). In section 4.2 we will further discuss the role of growth in reaching a Paris-aligned emissions pathway. 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).

3.2.3 Non-CO_2 impacts

KLM excludes non-CO_2 impacts, which is permitted by SBTi guidelines. This does not mean that non-CO_2 effects are unimportant. "For the achievement of the temperature goal in Article 2, both CO_2 and non-CO_2 effects are important. 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). However, Fuglestvedt et al. (2023) also show the difficulties to find a metric that brings both CO_2 and non-CO_2 in one indicator, like for instance CO_2e, which is presumed to translate all non-CO_2 to as if only CO_2 was emitted. The problem here is that the outcome of this calculation depends strongly on the assumption of the timeframe one looks at even though a 100-year period is often used, there is scope to look at a 1000-year period with emissions of CO_2 staying in the atmosphere for such long periods. Discussions about non-CO_2 impacts of aviation really started right after publication of the IPCC Special report on Aviation (Penner et al., 1999). The issue of non-CO_2 impacts was already discussed rudimentarily by (Hidalgo & Crutzen, 1977) and more in detail during a conference in 1996 (Albritton et al., 1997). The 1999 IPCC-report (Penner et al., 1999) introduced the RFA (Radiative Forcing factor). This factor provides the total radiative forcing in year x as caused by all historic aviation emissions and impacts on the atmosphere, divided by the accumulated radiative forcing in year x for CO_2 alone emitted since 1945. Note that this has some similarity with the GWP (Global Warming Potential) introduced by the first IPCC Assessment Report in 1990 (Houghton et al., 1990). They 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). The index highly depends on the assumed time-horizon of the radiative effect. Policy-makers most often use a 100-year timeframe (GWP100), but 50 and 20 years are also used and, as Fuglestvedt et al. (2023) show, that choice makes a large difference. A fraction of every tonne of CO_2 emitted lingers for 1000 years or longer in the atmosphere (Alonso et al., 2019).

This time-dependency becomes a problem when the atmospheric lifetimes of the non-CO_2 emissions are very short (Fuglestvedt et al., 2003; Lee, 2018) and that is exactly the problem with most of aviation's non-CO_2 impacts: contrails and particularly consistent contrails developing contrail-induced cirrus-clouds. That was the reason that several authors warned against using RFI as if it is equal or a good proxy for a GWP of contrails and non-CO_2 impacts of aviation (Forster et al., 2006; Peeters et al., 2007).

One often overlooked difference between CO_2 and non-CO_2 impacts of aviation, related to the lifetime differences, is in terms of the effect on generations. Estimates of how long shares of CO_2 emitted today will stay in the atmosphere vary from about a century up to '1000 years' (Alonso et al., 2019) or partly 'for ever' (Archer et al., 2009; Inman, 2008) which means that current human's emissions will cause climate change for many generations of humans to come. CO_2 is essentially an ***inter-generational*** impact with severe climate-equity

[4] 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.

issues. However, all the non-CO_2 impacts of aviation are very short-lived: from hours to a month, and only a few up to a decade (Penner et al., 1999). This means that non-CO_2 effects are essentially ***intra-generational*** which keeps solving it open for each generation choosing to do so. In that sense, the RFI is estimated far too high, because the socio-economic impacts of CO_2 are fundamentally stronger than those of non-CO_2. Using RFI or CO_{2eq}, as guidance for optimising flight path will increase climate injustice. Therefore, "if aviation is to contribute towards restricting anthropogenic surface warming to 1.5 or 2°C then reduction of emissions of CO2 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 the impacts of CO_2-intensity have varying impacts on non-CO_2 effects. While transport volume reductions and operational measures will generally reduce both CO_2- and non-CO_2 impacts more or less equal, that is not true for the other two mitigation strategies (SAF and aircraft fuel efficiency). The impact of SAF would be negligible if SAF had the exact same non-CO_2 impacts as fossil fuels have. There are some indications, these 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 is not easy to tell what the impact on non-CO_2 will be. Even though the use of a RF-factor, multiplier, etc, suggests that 10% less CO_2 would mean 10% less non-CO_2, but this relationship is not based in current science. For instance, contrail and cloud-cover changes, the main part of non-CO_2, depend on the flight-paths and the individual strength of the effect of each particular aircraft type (Unterstrasser & Görsch, 2014). For a given transport flow, the only potential effect would have to come from a lower production of contrails, which is not only a function of CO_2 (Grewe et al., 2017). A problem with non-CO_2 targets would be to proof compliance. Directly measuring the impact of individual aircraft is experimental, even though progress is made (Märkl et al., 2023). The conclusion is that the omission of non-CO_2 impacts means that about two-thirds of all climatic impacts are ignored, that the CO_2-mitigation strategies have very different impacts on non-CO_2 but that it is difficult to exactly estimate or measure what the final impact is at the individual flights level.

3.3 Conclusions

KLM, for instance, has set near-term relative and absolute CO2-emissions reduction targets for 2019-2030 (KLM, 2022a). A recent evaluation of corporate target setting however scored KLM low on target integrity, stating that the company neglects "the urgent need for immediate and accountable climate action by all actors to limit global warming to 1.5°C." (Mooldijk et al., 2022).

Even though KLM may argue that their target is in line with SBTi's requirements, KLM's targets are insufficient in multiple ways 1) they only have an intensity target and an absolute projection which seems to set no actual limit on growth (a projection is not a target), 2) their emissions projection is not in line with a 1.5°C scenario (-12% by 2030), 3) and the do not show the even more important 2050 zero-emissions target and how to achieve that.

4 KLM's 'Climate Action Plan'

Key findings about the feasibility of KLM's climate plan are:

- KLM proposes four strategies to improve its 2030 carbon intensity target: operational efficiency (4% of which 2% to be delivered by air traffic control), fleet-renewal (12%), mixing SAF (10% share of fuel mix reducing intensity by 8%) and unidentified 'additional measures' which essentially would add more SAF (increasing the share to 15-18%).
- The efficiency measures will cause additional transport volume growth and less absolute emission reduction.
- KLM's 2019 fleet had a technology age of 20 years (the average aircraft used entered operational service 20 years ago).
- KLM has no tradition to be a frontrunner in fleet renewal or new, more fuel efficient, aircraft development. This policy translates to the future as the fleet renewal assumes only two-thirds of the current fleet to be replaced.
- Part of the fleet renewal involves fleet expansion, thus adding emissions in absolute terms.
- KLM's discussion of revolutionary technology – Flying V, hydrogen, electric flight – has no relevance because such technologies will very unlikely replace even a small part of the global aircraft fleet.
- KLM's ticket pricing, serving a hub-and-spoke network, stimulates inefficient passenger behaviour making detours and additional take-offs and landings through the hub.
- The assumed share of SAF of up to 18% is at odds with current long-term SAF contracts for only 3% by 2030, economically not feasible (SAF would significantly increase direct operating costs) and at odds with an expected global availability of SAF of 5.7%.

KLM's Climate Action Plan (KLM, 2022a) follows the general technology-driven approach common within the aviation industry by assuming mitigation options that centre around fuel efficiency and fleet renewal, air traffic and operational efficiency, the shift to the use of SAF, carbon removals, and the development of a range of new zero-emission aircraft that fall in three main categories, namely battery electric, fuel-cell electric and hydrogen-jet (Bergero et al., 2023). In this section we will discuss each of the main options presented by KLM (2022a). We start with looking at the evidence, KLM provides for the 30% improvement of its carbon intensity. This followed is by a more in-depth analysis about the likelihood of the claimed reductions including a general note about the rebound effect and the operational, the SAF, and fleet renewal claims.

4.1 The basis for KLM's 30% carbon intensity improvement

KLM (2023) gives three quantified improvements of its carbon intensity:

1. Fleet renewal will deliver 12%
2. Operational improvements deliver 2-4%, of which 2% represents measures in the power of KLM, and the additional 2% measures to be taken by particularly air traffic control and the European Commission
3. The mixing of 10% SAF, with an assumed life-cycle emission reduction of 80%, delivers another 8%.

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, 2023, p. 7). The consequence of the three above numbers is that the total planned reduction comes at 20.6% (0.88*0.98*0.92=.794), so only one-third of the reduction goal is substantiated by evidence. Currently, an amount of SAF has been contracted up to 2030, that is sufficient to replace 3% of the fuel. When adding another 18% of SAF at an optimistic 80% effectiveness would indeed achieve a little bit more than 30% intensity reduction. However, only an improvement by 15.8%, just over half of the 30% target is covered by concrete and contracted measures (SAF contracts cover up to 3% of fuel by 2030).

4.2 The rebound effect

Much of the sustainability efforts of industries is efficiency-based: industries try to reduce energy use or emissions per unit of product and then claim that emissions will be reduced. Wei and Liu (2017) found a 90% rebound effect for the global energy system, if emissions were reduced by energy efficiency improvement. Berkhout et al. (2000, p. 426) define the rebound effect as follows: "Technological progress makes equipment more energy efficient. Less energy is needed to produce the same *amount* of product, using the same *amount* of equipment — *ceteris paribus*. However, not everything stays the same. Because the equipment has become more energy efficient, the cost per unit of services of the equipment falls. [...] A price decrease normally leads to increased consumption. Part of the *ceteris paribus* gains is lost, because one tends to consume more productive services, and the extra demand for productive services from the equipment implies *more* energy consumption. This lost part of the energy conservation is denoted as the rebound effect."

In air travel, some 30% of an aircraft's direct operating cost is fuel cost. This means that every 1% fuel consumption reduction causes 0.3% reduction of cost and, in a competitive sector as aviation, will translate to 0.3% reduction of ticket prices. And that means, with price elasticities generally in the range of -1.1 to -1.3 (Fouquet & O'Garra, 2022), that the volume will increase by an additional 0.3%. Consequently, this will reduce the impact on overall emissions by 30%, in this case from the presumed 1% (efficiency improvement) to 0.7% because the volume will grow by 30% due to the lower cost of flying enabled by the efficiency improvement. However, when the fuel efficiency improvement is gained by replacing the fleet with newer aircraft types, the effect is potentially larger because the direct operating costs tend to be lower (partly shown by Lee et al., 2019). Such cost reductions may be in the range of some 10%, thus boosting demand by 10%.

The rebound is much larger for several other efficiency measures, particularly those concerning more efficient air traffic control (ATC), as often proposed by aviation organisations (e.g. ICAO, 2022, p. 26) amounting to between 8.6% and 11.2% in Europe (EASA et al., 2023, p. 83), as well as by (KLM, 2023), who expects a 10% reduction is possible. The emission reduction is mainly caused by more direct routing, and avoiding congestion and concomitant holding patterns and detours. Here, the rebound is close to 100%, because the savings in fuel go hand in hand with overall cost savings, as the duration of flights is reduced by about the same percentage as the fuel cost. Flight hours are the main driver of cost and a saving of say 10% of flight time will reduce all costs of an aircraft from wages to maintenance and depreciation cost, which all are mainly determined by flight hours.

4.3 Network efficiency

One topic not often discussed by the airline industry is the inefficiency of networks. Particularly, hub-and-spoke networks (such as KLM's network) may increase the emissions as compared to point-to-point networks. O'Kelly (2012) shows that a hybrid business model– partly hub-and-spoke and partly point-to-point - would safe some 11% compared to a fully hub-and-spoke network. Additional to this, pricing tends to benefit trips involving a transfer (see Figure 2) as shown by Burghouwt et al. (2017). For instance, the lowest prices for indirect flights from Amsterdam to New York were more than for indirect flights.

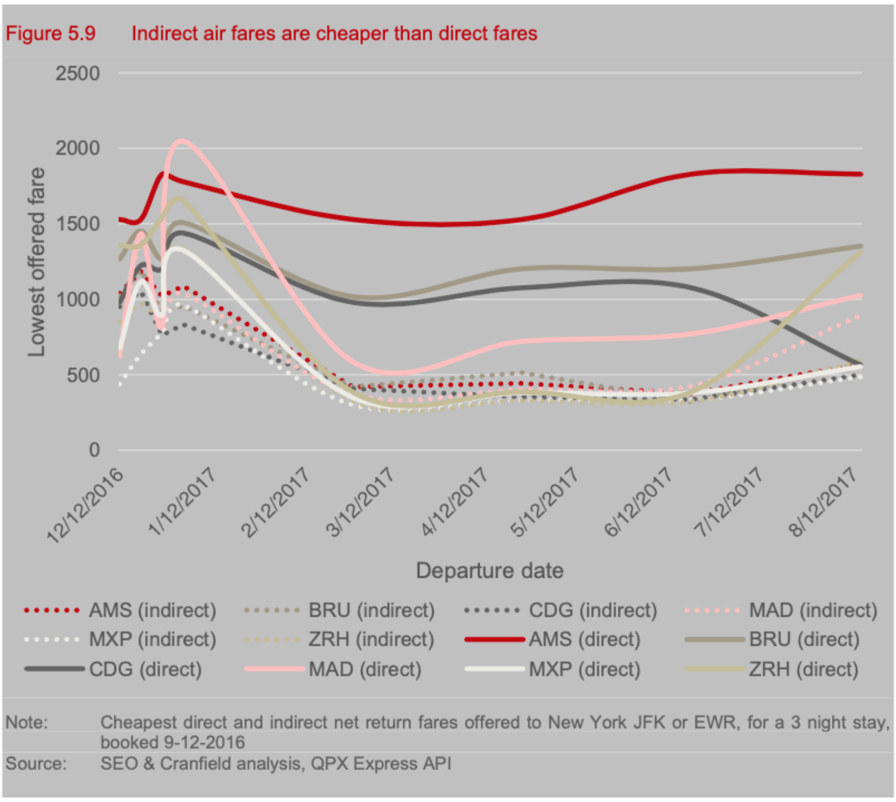

Figure 2: lowest fares offered on direct and indirect connections for a range of connection to New York. Source: (Burghouwt et al., 2017, p. 47).

Avoiding ticket-price induced detours of passengers are not represented by the SBTi emission intensity metric. But the emissions for a non-direct flight can be substantially higher than for a direct flight. For instance, before the pandemic, KLM offered both a direct flight connection to Linkoping (Sweden) and one via Brussels, which not only adds a short inefficient flight but also some 30% additional kilometres, so more than 30% additional emissions. Currently, KLM offers both direct and indirect flights to Gothenburg, the latter through Paris, which often are cheaper. Again, the indirect connection involves a long detour and adding a short inefficient flight the indirect connection emission will be 50% higher than the direct flight emissions. This practice can be explained from network and economic perspectives but is definitely in contrast with doing the best for the environment.

To include passenger detours, one should introduce a metric that shows the ratio between the direct flight distance and connecting flight distances as a proxy, or be recalculated fully by allocating all non-direct flying passengers to direct flights if available on the specific passenger travel itinerary (origin-destination relation). Even for the Dutch holidaymaker, who is well-served with a high number of direct connections all over the world by the third-largest hub – Schiphol Airport - in Europe, in 2010 detours were common. These detours added 2.9% to the distance travelled and 5.2% to CO_2 emissions (Peeters, 2020), showing the significant negative impact on the overall efficiency of adding short flights to a longer trip.

4.4 Operational efficiency

According to the KLM Climate Plan version 2 (KLM, 2023), KLM expects to improve the emission intensity by operational improvements between 2019 and 2030 by 2 to 4 percent points. Of this, 2% is expected to be gained from KLM specific efficiency measures like weight-reduction, aircraft route optimisation, and unspecified measures to increase fuel efficiency. The other 2% is expected to be realised by a more efficient air traffic control system in the EU, but this gain falls beyond the power of the KLM. So, the likely overall improvement of the carbon intensity is 2%. However, this will add to the total volume of KLM because of the rebound-effect. The calculation is that 2% higher operational efficiency (flying more direct) will reduce all costs by 2% and, with a price elasticity of circa -1, increase the transport volume by 2%, thus not reduce the total emission, but only improve the intensity and serve more passengers. **Therefore, though operational measures can improve the intensity, the total emissions will not be reduced or only a little bit, because of the rebound effect.**

4.5 SAF

Sustainable aviation fuels are the only option for the aviation sector to reach zero-emissions, as discussed earlier in 3.1.3. The advantage of SAF is that they can be used by the current fleet. At the moment, there is still a limitation to 50% mixing SAF in the fuel for a flight, but both Airbus and Boeing expect to deliver aircraft that can handle safely up to 100% of SAF by 2030 (Hemmerdinger, 2021). Because several types of SAF are currently certified for use in aviation and because some of these are currently on the market and capacity to produce SAF is quickly increasing, it is a solution that can potentially start today and may follow a S-curved introduction path that reaches 100% eventually. But as shown in section 4.1, there are three types of SAF and all three suffer from some limitations. Biofuels, SAF-B, potentially compete with both agriculture and nature and are generally not anymore considered a sustainable solution. Waste-based SAF, SAF-W, suffer from a range of competing purposes of the 'waste' which, if changed to use waste as a resource for SAF, will can cause that soil in agriculture to degrade, biodiversity in forests being negatively affected. Or it may suffer from extremely low volumes of the specific waste, like wasted cooking oil. Another issue is that there are regular indications of fraud, in a sense that old-fashioned biofuels are sold as advanced, and more expensive, waste-based fuels for the automotive industry (Moskowitz et al., 2023). Risks exists like this type of fraud may further undermine the credibility and sustainability SAF-W.

Both SAF-B and SAF-W suffer from the fact that their lifecycle emissions are not zero, so they cannot provide zero-emissions within the SBTi context. Finally, SAF-E is environmentally the most advanced option, but suffers from the fact that is has not been brought to the market in any substantial volumes yet, and its production requires large quantities of renewable energy, which is unlikely to be available by 2050 for an aviation sector that grows as in business as usual.

KLM has contracted SAF from Neste and DG Fuels which would cover 3% of the total amount of fuel burnt by 2030. The ambition is to additionally acquire 7% to reach 10% of SAF in the fuel mix in 2030. This will approximately reduce the emissions by some 7-8% if eventual fraud with feedstocks is effectively avoided. The biomass feedstock used at DG Fuels is not published by the company, making it difficult to assess the LCA-emissions or any other sustainability performance of these fuels. Furthermore, KLM expect to need to increase the share of SAF to 15-18% to be able to reach the 30% reduction of carbon intensity goal. Given that the cost of current SAF on the market is two to four times the cost of fossil-based kerosene (Schäppi et al., 2022), this would mean that KLM' direct operating cost will rise by 9% to 18%, which has to be translated to increased ticket prices. The current business model and growth ambitions are unlikely to be compatible with such a cost rise. Another issue is that according to (IATA, 2021) there total amount of SAF would allow for an average of 5.2% of mixing. When KLM assumes 15-18%, KLM will automatically reduce the amount of SAF available for other airlines, unless the majority of KLM' SAF would be above of the IATA extrapolated global production of SAF.

4.6 Non-CO_2 in KLM's climate plan

Though SBTi does not require to set a goal for non-CO_2 impacts in aviation, the impact of non-CO_2 is large but difficult to weigh against CO_2 impacts (see section 3.2.3). Still, the failure to set any goal for non-CO_2 means that it is impossible to fully evaluate whether the overall impact of measures taken by KLM on the climate. Also, it will be impossible to evaluate whether KLM is on a Paris-compliant pathway. KLM announced that it participates in SATAVIA in an attempt to reduce particularly the impacts of contrails and contrail-induced cirrus clouds. Though some doubt real-time contrail avoidance is possible (van Manen & Grewe, 2019; Molloy et al., 2022; Simorgh et al., 2022), in principle, there is scope for developing such strategies. These strategies are not new as the first high-altitude military spying aircraft suffered from being easily detected due to contrails. This is not documented in public reports (military, secrets?) but it is by former pilots from those planes and involved putting a mirror in the cockpit allowing the pilot to immediately see it when a contrail started to develop and then take action by diving or climbing; also other types of fuels are discussed here[5]. In itself, it is an effective way to mitigate non-CO_2 climate impacts by developing planning techniques to avoid contrails and optimise such procedures using the least additional fuel possible. However, the collaboration with SATAVIA has no credibility. The SATAVIA (https://satavia.com/) business case is to avoid contrails, calculate the equivalent climate benefits in terms of CO_{2eq} and then sell those credits later to industries, including aviation, to compensate for fossil CO_2 emissions. This is a very worrying idea for the following reasons:

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 CO2 credits can be claimed at extremely low cost (Klöwer et al., 2021).
2. The simple exchange of contrails versus CO2 ignores the large impact of intra- respectively the inter-generation effect (see explanation 3.2.3). 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.

For the coming years, it would be better if the aviation sector, would just fund in-depth research to develop an efficient contrail and cirrus avoiding system for flight planning. Such a system becomes highly relevant as soon as large shares of SAF are used and the CO_2-induced inter-generational climate penalty becomes very low. Though KLM is participating in such a scheme, unfortunately, that scheme is flawed in itself by the way it proposes to use the non-CO_2 impact reductions as an offset to compensate CO_2 emissions. Therefore, KLM's climate plan does not deal with non-CO_2 emissions in a way that it fits the 1.5°C climate scenarios of IPCC. The only clear way to simultaneously reduce CO2 and non-CO2 effects for KLM is to reduce their capacity (seat- and ton-kilometres).

4.7 Fleet renewal

4.7.1 Efficiency trends

Jet aircraft gained substantial efficiency since their first introduction with airlines in the 1950s (Peeters & Middel, 2007), with the aircraft generation developed at the end of the 20th century 60-70% more fuel efficient as the first intercontinental jet aircraft (the Comet IV). However, this efficiency gain is entirely driven by economic drivers. As such, aircraft designers always weigh the additional fuel savings of more advanced technology against the cost and risks of developing an aircraft, because a higher fuel efficiency does not only reduce fuel cost but also strongly enhances "productivity increases, safety improvements, increased range and take- off and landing performance" (Peeters & Middel, 2007, p. 46). All in all, fleet renewal is an economic necessity for every airline and also party of an airline's growth and expansion.

Often, the industry communicates 'aspirational' goals of fleet fuel efficiency to improve by 1.5% (IATA, 2021) to 2% per annum (ICAO, 2022). However, this cannot be met by new technology alone as found by independent Experts for ICAO (Alonso et al., 2019). Technology may deliver 1.38% per year for narrow body (single aisle) and 1.43% per year for wide-body (twin-aisle) aircraft types. Though for global modelling, such annual improvements represent roughly the reality of the fleet fuel efficiency development, in reality the improvements come in waves. For instance, original series consisted of the Boeing B737-100, and B737-200 developed in the 1960s. These were the standard until in the 1980s (the 'Classic series came onto the market 300, 400 and 500 series). These aircraft created a steep improvement compared to the original series of some 10% (Airlines Inform, 2023). In the 1990s the new generation (NG) Boeing aircraft (the 600, 700, 800 and 900) were brought to the market, which delivered a steep change of 25% fuel efficiency improvement by reengining with the CFM engine, a high-bypass engine. Basically, the introduction of a new aircraft type has a significant impact on fuel efficiency, but after that the fuel consumption is not changed anymore until the last of that type leaves the production line. Sometimes, minor upgrades are given; e.g. winglets for the NG aircraft Boeing

[5] See https://www.quora.com/How-do-spy-planes-avoid-leaving-contrails-that-would-give-them-away.

introduced in 2000. Winglets reduce fuel consumption by up to 6%, depending on the route flown[6]. Furthermore, in 2011, Boeing introduced a PIP (Performance Improvement Package), which involved some minor changes reducing fuel consumption by another 2% (Boeing, 2012). In general, aircraft type technology age is the parameter that determines the fuel performance of an aircraft, not the age of the individual aircraft (Peeters, 2013, p. slide 17).

4.7.2 KLM's recent fleet renewal

The question is how much of the intensity reduction target can be achieved with fleet renewal and how aggressive KLM is - and has been – in fleet renewal as an emission reduction strategy. Let us first explore whether KLM has been and currently is a frontrunner in fleet renewal. The most proactive airlines will take the risk (and the benefits) of becoming a launch customer for a new aircraft a manufacturer (OEM) is developing. Direct competitors to KLM, like Air France (before the merger), Lufthansa, British Airway and Pan American, all have been launch customers for major jet aircraft from Boeing or Airbus. KLM never took this proactive role, except – as part of the Air France-KLM consortium - recently for the freighter version of the Airbus A350. Longer back in history, KLM was the launch customer for the Fokker III in 1920[7].

Often, airlines share the average age of their fleet. This age is calculated as the average of the number of years of each aircraft in the fleet since its delivery. See Eurostat website https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20191206-1. KLM is not performing particularly good in this respect (see Table 2). But the fuel efficiency is hardly related to the age of the aircraft (when it entered the fleet). Instead, it relates to the age of the technology of that particular aircraft type. This age can be determined by looking at the entry into service (EIS) of the aircraft type that is added to the fleet.

Looking at the fleet renewal behaviour of KLM, we found some peculiar recent moves. In 2019 KLM took delivery of four B737NG (Noack, 2023), including the very last that has been build (Hemmerdinger, 2020), which by then had been in production for 22 years. Hence it was based on 22+ years' old technology (the type delivered almost 5000 aircraft to the global fleet[8]). The new variant of the B737-800, the B737-8MAX, has been on offer since 2011[9], so KLM could have been a front-runner, but chose to also buy the last old-generation 800NG with an EIS of 1998. Also, between 2015 and 2022, KLM took delivery of B777-300ER aircraft, while in the same years also adding the much more fuel efficient B787. The B777-300ER technology level is that of early 1990s, even though this stretched version came into service in 2004. The B787 is based in technology from the early 2000s, so at least 10 years newer. **Concluding, KLM does not have a history of buying newer aircraft that can contribute the highest efficiency gains**.

4.7.3 Overall fleet and network efficiency of KLM

The overall efficiency of KLM is in class C of the A to G classes of the Atmosfair Airline Index (AAI) – ranking global airlines in terms of climate efficiency – of 2018 (Atmosfair, 2018) and comes at the 17th place of this ranking. The AAI is based on the technical performance of the aircraft types in an airline's fleet, the number of seats and the seat occupancy rate. These factors determine the average of the emissions per passenger-km. As the aircraft type is only one of these three factors, we looked at the fleet ages of some interesting entries in the AAI. AAI puts aircraft in five classes (A through E), with A being the best possible, and E being the worst. Furthermore, the 125 airlines described in the report are ranked for the whole fleet and for three distance classes. We compared KLM (rank 17, class C) with Etihad (rank 96, class E), the LATAM (rank 2, class B) and Ryan Air (not ranked as a low-cost carrier, but in AAI class B). Table 2 surprisingly shows that the technical fleet age of the class E airline is the lowest of all four, but that the seat density has a bigger effect than these 5 years newer fleet. It also shows that the aircraft age can be much lower than the technical age of the aircraft types in the

[6] See http://www.b737.org.uk/winglets.htm
[7] See http://www.dutch-aviation.nl/index5/Civil/index5-2%20F3.html.
[8] Source: https://en.wikipedia.org/wiki/Boeing_737_Next_Generation
[9] Source: https://en.wikipedia.org/wiki/List_of_Boeing_737_MAX_orders_and_deliveries

fleet. KLM has a technical fleet age of almost 20 years, but the relatively high seat density brings it in class C. So, fleet renewal will impact efficiency, but the choice of the cabin layout (the number of seats in the aircraft) has at least the same impact and should thus be discussed as well to provide the complete picture. KLM's fleet was in 2019 not particularly new, but its seat-density was above average, so in the AAI 2018 it still scores relatively high.

Table 2: Fleet age data for KLM and some other typical 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).

Airline	Aircraft age	Type technology age	Seat density as % of typical seat density
KLM (excl. Cityhopper, Transavia)	12.1	19.8	107.4%
Etihad	7.4	14.1	99.8%
LATAM	10.4	23.3	116.3%
Ryan Air	10.7	19.8	116.4%

Another way to assess the efficiency of KLM is by comparing its practical network performance for all flights from and to Dutch international Airports (Schiphol, Eindhoven, Rotterdam-The Hague, Maastricht, and Groningen). For the year 2019, emission factors have been determined for a representative sample of flights for each day of the week, but spread over the whole year 2019 (Peeters & Reinecke, 2021). The database for this study contained all exact flights per airline and aircraft type used. For each airline/aircraft type combination, the seating layout was determined, and the emissions of the whole flight were allocated by the m^2 each seat occupied in the aircraft cabin. The aircraft mission fleets were calculated using the 2021 version of the EASA/Eurocontrol Small Emitters Tool (Eurocontrol, 2020). Table 3 shows that the KLM-group (KLM, KLM Cityhopper and Transavia Holland) score 1% better than all other airlines at Dutch airports. However, the core KLM group is 3% less efficient as all other airlines, but 3% points better than the ten largest legacy airlines[10]. Transavia is 21% better than all other airlines (excluding KLM) as one can expect from a low-cost carrier. We may conclude that in 2019, the KLM Group had an average emission intensity comparable to all other airlines, but KLM itself was a bit better than a range of other legacy airlines, which might particularly be caused by the fact that KLM has no first-class seats and for instance United has. First-class seat take-up to ten times the space as a normal economy seat.

Table 3: emission factors and index for a representative sample of 5473 international flights from Dutch airports (source: Eurocontrol, 2020).

Airline	Emissions (kg /skm)	Index (all other airlines = 100%)
KLM-group	0.0796	99%
All other airlines	0.0804	100%
KLM+Cityhopper	0.0826	103%
Transavia Holland	0.0636	79%
Legacies (10 largest at Dutch airports)	0.0854	106%

The database for 2019 allowed us to artificially replace all current aircraft by new types for the same KLM-flights flown in 2019. We replaced as indicated in Table 4. This scheme is based on (KLM, 2023) and some recent (2023) press releases by Air France-KLM.

[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%.

Table 4: assumed KLM Group fleet replacements by 2030. 2030 types between brackets mean no change possible 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
B772	A359
B77W	A359
B789	(B789)
B78X	(B78X)
E190	E295
E295	E295
E75L	(E75L)

The result of the fleet renewal scheme (Table 4) is an improvement of the emission intensity by 18% (see Table 5). This is the result of an overall reduction of the emissions by 16%, and a 5% increase of total seat-kms. The latter is the result of the slightly larger capacity of the aircraft replacing the 2019 fleet.

Table 5: effect of an almost complete fleet renewal of KLM Group' 2019 fleet assuming a representative set of flights for 2019. Note: these results show only passenger flights.

Topic	Total emissions (ton)	Capacity (10^6*skm)	kg/skm
KLM-group 2019	114,850	1,443	0.0796
KLM-Group 2030	98,730	1,520	0.0650
Improvement	-14%	5%	18%

The results in Table 5 only cover passenger flights. As KLM will replace the remaining four B747-400 full freighters with the new A350 freighter, we have looked at the impact of that change in an additional calculation. This revealed that by replacing the four B747-400 freighters by A350 freighters, KLM would reduce the emissions of the four aircraft by 38%, but capacity by 14% (the Airbus has a maximum payload of 111 ton, while the B747-400 had 128.5 tons), so overall emission intensity of full freighters would improve by 28%. We added this improvement to the whole KLM Group fleet by assuming 1 freight ton to be equivalent to 10 passengers (the method supported by SBTi). Because KLM (actually Martinair) owns only four full freighters in a fleet of over 200 aircraft, this did not change the rounded improvement of 18% for passengers alone. However, as explained above, efficiency gains in any event are only part of the emission reduction challenge since they contribute to growth through the rebound effect. Also, part of the acquisition of new aircraft involves fleet expansion and thus growth (see next section).

4.7.4 Growth and targets

The overall growth of transport volume expected by KLM can be calculated from the assumed difference between the reduction of the carbon intensity (30%) and the total emissions reduction (12%). We calculated in this way that the assumed transport volume growth between 2019 and 2030 is 25.7%, translating to an average growth of 2.1%/annum, which is lower than the 2.9%/annum assumed in SBTi 1.5°C scenario. Because of the volume reduction caused by the COVID-19 crisis, we calculated the assumed growth of KLM between 2023 and 2030 at 3.6%/annum, higher than the SBTi scenario assumption. The fleet renewal will induce a relatively strong direct operating cost reduction, likely boosting volume growth even further and causing total emissions to reduce significantly less than the intensity gains.

Science gives several examples of scenarios that show the incompatibility of significant aviation growth and zero-emissions by 2050 as is the general Paris 1.5°C pathway. Examples can be found that limit growth between 2019 and 2050 to some 19% in total (Peeters & Papp, 2023), and advocate moderate growth (Bergero et al., 2023).

Concluding, the potential fleet renewal replacing almost every current aircraft with the newest generation of aircraft, would improve the network efficiency (based in the 2019 network) by 18%. This contrasts the much lower claim by KLM (2023) of 12%, which suggests that KLM will have renewed only two-thirds of their fleet by 2030. Because most aircraft stay in operation for 20-40 years, it is unlikely that KLM will fully renew its fleet a second time before 2050, but it may partly do so; this means for the period 2019-2050, a minimum of 18% carbon intensity will be achieved and a maximum of some 20-25%.

4.7.5 Revolutionary technology

For zero-emissions (CO_2 and non-CO_2) one would need an aircraft that no longer uses kerosene, but is either fully electric with batteries as energy source, or uses hydrogen as energy source either with fuel cells to drive electric engines or by burning the hydrogen in jets (Bergero et al., 2023). It is important to never use the term 'electric aircraft;' without specifying what the electricity source is (battery or fuel cell), because the two solutions are very different as we will explain below. The first two options potentially provide true zero-climate impacts as they would remove both CO_2 and non-CO_2. Burning hydrogen in jets will most likely still cause all non-CO_2 impacts related to NO_x emissions and contrails and cirrus, though potentially at a lower level.

Though there are many projects around battery-powered aircraft, so far only one has been certified and can be sold and used. This the Pipistrel Velis Electro[11], which can fly 50 minutes at 98 km/hr which, in still air, would provide 82 km of range for two people weighing together and including luggage a maximum of 172 kg. The problem with batteries is that both the volume- and weight-based energy density are more than 40 times lower than current fuels deliver. This is highly problematic in an aircraft because every aircraft needs to be as small and as light as possible (Epstein & O'Flarity, 2019). Some authors still propose performance for battery aircraft that would cover a large number of the shortest haul flights, but these suggestions generally assume battery energy densities that are three to ten times higher than current batteries (Schäfer et al., 2019). Such batteries are unlikely to come to the market before 2050. **Therefore, battery electric aircraft will not play a role in big aviation and thus not for KLM – not in 2030 nor in 2050** (Nakano et al., 2022). The solution with hydrogen and fuel cells has far better potential for the short to medium haul markets. But again, as even conventional aircraft types require more than a decade to develop from the drawing board to entry into service, such aircraft will only start to play a significant role in the second half of the 21st century and thus way too late for climate mitigation. Even Airbus, which is ahead of Boeing in the development of zero-emission aircraft, does not expect to have a short-range and low payload hydrogen-fuel cell aircraft on the market by 2035 (Airbus, 2023). Batteries were dismissed by Airbus as not viable for big aviation.

The KLM supports the Flying V project initiated by the Technical University of Delft (KLM, 2023). This aircraft is based in the so-called blended wing body (BWB) type of aircraft design (Liebeck, 2004), an idea that dates back to the 1920s, but only became feasible when automatic control of aircraft]became available in the 1990s[12]. One of the four ideas within the Airbus ZEROe project is also a BWB type of aircraft and there is some collaboration between TU Delft, Airbus and KLM. However, this kind of aircraft will not enter the market before 2050 and thus is not relevant for the 2030 goals and 2050 outlook of KLM. **Concluding, revolutionary aircraft and engine technology will not have an impact on KLM's climate pathway before 2050.**

[11] See https://www.pipistrel-aircraft.com/products/velis-electro/
[12] See https://en.wikipedia.org/wiki/Blended_wing_body.

"Electric, hydrogen, aerodynamic breakthroughs will take place for the regional and medium haul fleet between 2030 and 2040 at the earliest. For the long-haul fleet (...) this is expected to become a reality after 2040". This statement by KLM is not supported by the wider scientific literature. KLM did not repeat it in version 2 of the Climate plan.

4.8 Some conflicting statements by KLM

KLM recently announced their commitment to net-zero CO_2 emissions by 2050 but essential details that are required to determine the feasibility of that commitment are not available, "leaving the door open for contentious neutralisation measures to achieve this target" (Mooldijk et al., 2022, p. 84):

- "Electric, hydrogen, aerodynamic breakthroughs will take place for the regional and medium haul fleet between 2030 and 2040 at the earliest. For the long-haul fleet (...) this is expected to become a reality after 2040" (Katan & van 't Lam, 2023, p. para 165). This statement by KLM is not supported by the wider scientific literature and no longer mentioned in the Climate plan version 2. Battery electric aircraft will not play a role in big aviation and thus not for KLM – not in 2030 nor in 2050 (Nakano et al., 2022). The solution with hydrogen and fuel cells has much more potential for the short to medium haul markets.
- "Electric, hydrogen, aerodynamic breakthroughs will take place for the regional and medium haul fleet between 2030 and 2040 at the earliest. For the long-haul fleet (...) this is expected to become a reality after 2040" (Katan & van 't Lam, 2023, p. para 165). This statement by KLM is not supported by the wider scientific literature and no longer mentioned in the Climate plan version 2.

5 Summary and conclusions

The Science-Based Targets initiative (SBTi) is a global organisation that helps companies set voluntary science-based emissions reduction targets. These science-based targets connect corporate emission reduction goals to climate science and the temperature limits of the Paris Agreement. For some sectors, including aviation, the SBTi offers target setting companies sector-specific guidelines for setting science-based targets. Companies increasingly turn to the SBTi as part of their climate action plans. KLM Royal Dutch Airlines is one of these companies. The SBTi validated KLM's emissions reduction target in December 2022.

We have been asked to evaluate the practice of science-based target setting and the SBTi, the SBTi's sector specific aviation guideline, and KLM's climate action plan. In this report we provide our views on the following questions:

- What is the view of the SBTi and its target setting process in the scientific literature? (chapter 2)
- Is KLM's (SBTi) target aligned with limiting dangerous climate change in line with the Paris goal? (chapter 3)
- Is KLM's 'Climate Action Plan' (relying on biofuels, synthetic fuels, fleet renewal, operational improvements, and future aircraft with the plan for growth) realistic and sufficient to meet those targets? (chapter 4).

Below we summarise the key findings of each chapter, before presenting a general conclusion based on our central observations.

5.1 The SBTi and its target setting process

Voluntary science-based targets must be understood within the broader context of the current Post-Paris climate governance regime and as a product of this climate governance regime. The Post-Paris climate governance regime assumes that economic growth – even when including product and service volume growth – is compatible with effective climate action and that market-based approaches and self-regulation approaches such as voluntary science-based targets are sufficient to align the private sector with the Paris Agreement.

There is scientific evidence that voluntary science-based targets lead to increased corporate climate action, but that does not mean that targets and scientific mitigation requirements are Paris aligned. There is evidence that this is often not the case. Also, it is difficult to independently evaluate the Paris-alignment of science-based targets and the progress companies report against these targets, because of the limited public availability of target data and the possibility that companies report non-additional emission reductions. Non-additional emission reductions are emission reductions that would have occurred as well without the stated climate action and can therefore not be directly attributed to that action.

The SBTi presents science-based targets as a low-threshold corporate communications tool that incumbent companies can instantly use to demonstrate climate leadership in the face of increasing societal pressure. As voluntary initiative without compulsive power, the SBTi needs this business-case sales point to persuade companies to join and an expanding membership base to justify its own relevance and importance. The focus of the SBTi is on science-based target setting and related communications rather than the implementation of science-based targets.

The current SBTi target setting process offers target setting companies a significant amount of freedom when it comes to target setting, implementation and communication and has several methodological issues:

- The SBTi's only requires companies to set a near-term target. Near-term targets can result in temporary overshoot of the temperature goal. The SBTi does not require a long-term commitment to the implementation of negative emission technologies to address this overshoot;
- The SBTi allows companies considerable freedom in the selection of target setting methods, but is currently not transparent about the choices companies make in the selection of target setting methods;
- The SBTi's current 'grandfathering' emission allocation principle favours incumbents;
- The SBTi's target validation process is lighter than the common scientific peer review process;
- As the SBTi does not share data on how science-based targets are set, it is difficult to independently verify whether validated targets are Paris-aligned;
- The SBTi allows companies to use problematic means to meet validated science-based targets, such as renewable energy certificates and future technologies with unclear scalability;
- The current emission accounting and disclosure by target setting companies lacks transparency.

Science-based targets can potentially be used to delay more ambitious public climate policies. The SBTi enables incumbent companies to mobilise the apparent apolitical character of science, which obscures that the science-based targets of the SBTi are based on incumbent corporate values. Current growth and profitability conditions, reliance on (future) technologies, and ideas about future growth and demand inform the target setting process.

5.2 The SBTi's aviation sector guidance and KLM's SBTi target

No full-fledged, independent, scientific third-party evaluation of the SBTi's 1.5°C aviation sector guidance has been performed. The SBTi's 1.5°C aviation sector guidance is based on a zero-emissions pathway developed by consultants and NGOs. There is no scientific peer-review process or other method to guarantee its scientific rigor.

The zero emissions pathway of the SBTi's 1.5°C aviation sector guidance lacks ambition until 2030. The targeted amount of total emission reductions by 2030 is not very ambitious, causing aviation's share of the global 1.5°C carbon budget to double compared to a 50% reduction pathway of total emissions by 2030.

The SBTi's zero emissions pathway has a low feasibility. It assumes an annual air transport volume growth of 2.9%, operational and technological efficiency improvements, and a 100% use of sustainable aviation fuels (usually referred to as SAF, particularly e-fuels, but still significant bio- and waste-based SAF). This growth cannot be aligned in an equitable way with the assumed air transport volume growth because of feedstock with SAF-B and SAF-W and renewable energy limitations, the 100% SAF.

The SBTi should develop net-zero emissions pathways within the parameters of the structural resource constraints for SAF. The possible decarbonisation solutions for aviation that the SBTi's list as part of its zero-emissions aviation pathway are by themselves not sufficient to accomplish net-zero emissions by 2050. Revolutionary aircraft technology will not reduce emissions much before 2050, if at all. SAF-E has the technical ability to provide zero emissions. The SBTi's zero emissions pathway assumes a 100% use of SAF-E, which is unrealistic. This assumption violates limitations for other resources (particularly renewable energy shares to be used by aviation) in a fair – equitable – way. SAF-E only works as scalable decarbonisation solution under the condition of a concerted public policy mechanism that limits the use of fossil-based kerosine globally.

Both the SBTi and KLM assume that aviation is 'hard-to-abate' and therefore has the right to claim a larger part of the remaining carbon budget than other economic sectors. This assumption is problematic. Both the SBTi and KLM ignore the fundamental ethical and equity issues of this assumption, particularly for an activity that is not a basic need and regularly used by only a few per cent of the world population.

5.3 KLM's climate action plan

KLM's climate action plan proposes four strategies to improve its 2030 carbon intensity target: operational efficiency (4% of which 2% to be delivered by air traffic control); fleet-renewal (12%); mixing SAF (10% share of fuel mix reducing intensity by 8%); and 'additional measures' which essentially would add more SAF (increasing the share to 15-18%).

KLM's target has low integrity as it does not demonstrate emissions alignment with the Paris temperature goal. KLM has set one target: an improvement of its carbon intensity (kg CO_2 per passenger/ton-kilometre) by 30% between 2019 and 2030, which equals the target SBTi requires. Alongside this intensity target they state an absolute projection (-12% by 2030), which seems to set no actual limit on growth (this makes it a projection; not a target). KLM also does not have longer-term 2035 or 2040 targets to tie the post-2030 reductions to concrete measures. Its net-zero by 2050 ambition is unclear as KLM does not state how much offsetting will be used.

The efficiency measures will cause additional transport volume growth. This will limit absolute emission reduction (rebound effect).

Fleet renewal has decarbonisation potential, but KLM is not a frontrunner in both fleet renewal and new aircraft type development (becoming a launch customer). This contrasts many public statements in which KLM presents itself as a greener airline. KLM's 2019 fleet had a technology age of 20 years (the average aircraft used entered operational service 20 years ago). KLM's strategy to economically optimise its fleet comes at the cost of unnecessary additional environmental impacts: in recent years KLM for instance bought the last aircraft of a series built from 20-year-old technology, while more modern and efficient aircraft types are available in the same class. Its stated fleet renewal target of 12% suggests that KLM will have renewed only two-thirds of their current fleet by 2030. As most aircraft stay in operation for 20-40 years, it is unlikely that KLM will (fully) renew its fleet for a second time before 2050, but it may partly do so. This means that for the period 2019-2050, a minimum number of 18% will be achieved and a maximum of 20-25%. In practice, the term 'fleet renewal' may in practical terms come down to fleet expansion, in which case the corresponding volume growth will be at odds with projected emissions reduction gains (rebound effect).

KLM's current business model incentivises passengers to take inefficient routes. KLM's ticket pricing, serving a hub-and-spoke network, stimulates inefficient passenger behaviour making detours and additional take-offs and landings through the hub.

The assumed share of 18% SAF is not realistic. This assumed share is at odds with current long-term SAF contracts for only 3% by 2030; economically not feasible (SAF would significantly increase direct operating costs); and at odds with an expected global availability of SAF of 5.7%. Related, current SAF varieties ordered by KLM (SAF-B & SAF-W) cannot reduce aviation emissions to zero because of various resource and value chain constraints.

The actions that KLM proposes in its climate action plan are insufficient to meet the stated, SBTi-validated intensity target of -30% emissions by 2030 compared to 2019. While this target is in line with the SBTi's 1.5°C aviation sector guidance, the measures KLM proposes to meet this target would add up to just 20.6% emission reductions. Thus, KLM cannot achieve this goal based on its currently published climate plan.

5.4 Conclusion

Science-based targets help companies to create business advantages through risk management and carbon efficiency gains. As voluntary tool, science-based targets are by themselves insufficient for meaningful and climate-just decarbonisation that makes the private sector Paris-aligned. The application of science-based targets can therefore not substitute public policy. State-led prescriptive interventions aimed at transforming the business models, industry structures, and consumption patterns that are at the roots of the current climate crisis are also required.

In this light, the SBTi's current emphasis on corporate communication benefits relating to publicly stating science-based emissions reduction targets is questionable. It is unclear whether these statements offer a true representation of companies and decision-making processes. Therefore, at least for a large part, the corporate practice of committing to SBTs should be viewed as a stakeholder management strategy in the face of increasing societal pressures to step up corporate climate action, and be evaluated as such.
The methodological issues of the SBTi's target setting process obscure the politics of science-based target setting. 'Science-based' targets, although based on science, are not free of values. This is critical because incumbent companies in polluting industries, such as KLM Royal Dutch Airlines, often have a history of challenging climate science, blocking more ambitious climate regulation and failing to deliver on their own promises. Two observations are particularly relevant here.

First, the SBTi legitimizes an incumbent-driven transition shaped by large companies. It enables these companies to further protect themselves from democratic control, for example by allowing them to speculate on a rapid future upscaling of unproven technological innovations while ignoring that accomplishing genuine 1.5°C pathways also require demand restrictions, particularly in industries that maintain high-carbon consumer lifestyles.

Second, and related, there are tensions between this incumbent driven transition and the concept of climate justice. As the grandfathering emissions allocation principle and the SBTi's zero emissions pathway for aviation illustrate, science-based targets can (further) enforce uneven wealth accumulation and distribution of emission reduction burdens. Companies, sectors, and countries that are responsible for disproportionately large, historical emissions can be considered as obliged to commit to the greatest share of global emissions reductions, all other things being equal.

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