Assessing the Credibility of Climate Transition Plans in the Aviation Sector

Discussion Paper

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Abstract

The aviation sector is facing increasing pressure to reduce its climate impacts, prompting coordinated efforts among aircraft operators to achieve net zero emissions by 2050. However, a significant challenge arises when it comes to planning and reporting a credible climate transition plan, as there is currently no established benchmark for companies to follow. This paper aims to fill this gap by introducing the Climate Transition Integrity Score, a novel framework based on climate pathways, technology roadmaps, policy assumptions, and sustainability reporting frameworks. Through an analysis of 60 major airlines, we identify key transition levers that airlines should consider when developing climate transition plans, using our scoring system to evaluate their current reporting practices. Our findings aim to inform the industry, financial sector, standard setters, and regulators about areas for improvement to enhance the integrity of climate transition plans within the aviation sector.

Keywords: climate transition plans, aviation, climate mitigation, net zero, sustainability transition, sustainability reporting.

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Executive summary

The aviation sector faces challenges in transitioning to net zero emissions, including the lack of reporting guidance and immature carbon-neutral technologies, which can be addressed with the proposed Climate Transition Integrity Score (CTIS). Our scoring system evaluates transition plans based on climate pathways, technology roadmaps, policy assumptions, and sustainability reporting frameworks, providing essential guidance for productive engagement between capital providers and aviation counterparts committed to achieving net zero emissions.

The focal point of our paper is the United Nations High-Level Expert Group report on Net Zero Emissions Commitments of Non-State Entities, which underscores the criticality of upholding integrity in corporate transition strategies while recognizing the inherent uncertainty surrounding technology trajectories and policy frameworks. Credibility focuses on technical soundness, while integrity ensures fairness and equity. The report emphasizes stakeholder engagement for sound and equitable transition plans in industries like aviation. Prioritizing integrity enables corporations to navigate uncertainty, engage stakeholders transparently, and build trust in their commitment to a sustainable future.

Assessing the credibility and integrity of climate transition plans requires a regular review of climate pathways to ensure alignment with implementation strategies and targets**.** This exercise helps identify key transition levers overtime and essential elements and desired components that rely on technology roadmaps, policy assumptions, and managed transition risks towards net zero. Distinguishing between climate pathways and scenarios is crucial in understanding the nuances of transition planning. Climate pathways focus on the specific actions and strategies needed to achieve climate goals, while climate scenarios encompass a wider range of possible futures, allowing for the exploration of different trajectories and potential outcomes based on various factors and assumptions.

The International Energy Agency Net Zero Roadmap stands out as the most comprehensive plan for addressing climate change because of its worldwide perspective on transitioning to clean energy**.** However, for a more holistic approach, we suggest combining it with the pathways proposed by the Mission Possible Partnership initiative, One Earth Climate Model, and the United Nations International Civil Aviation Organization (ICAO). They have a common focus on reducing emissions from aircraft operations in the airline industry while considering interdependencies with fuel suppliers, aircraft manufacturers, and other sectors. They outline roadmaps to achieve net zero emissions by 2050, covering all three emission scopes and acknowledging the global challenge of aviation's carbon footprint. Shared assumptions include annual aviation demand growth, technological advancements, and the importance of sustainable aviation fuel (SAF). Credibility is enhanced through stakeholder consultations, alignment with temperature targets, and unique decarbonization approaches. However, to ensure long-term feasibility and stakeholder support, the pathways need to address just transition principles, fair share allocation, and regional differences.

Based on the climate pathways, we identified four key transition levers to foster sustainability and mitigate the carbon footprint of the aviation sector. These levers include: SAF derived from non-fossil sources; operational improvements (e.g. optimized flight paths and demand management); more efficient aircraft designs and propulsion technologies (e.g. electric and hydrogen-powered aircraft); and proactive engagement with government and international regulations.

- **SAF derives from non-fossil sources and is the key transition lever in the short term,** as it directly tackles the main source of carbon emissions from the aviation sector**.** SAF adoption requires compliance with sustainability criteria, and increasing its usage requires expanding production capacity and implementing supportive policies. However, a lack of standardization in reporting frameworks for SAF uptake hinders meaningful comparisons. Financial indicators and operational strategies for integrating SAF vary across frameworks. Therefore, consistent and standardized metrics are needed to track adoption effectively.
- **Operational improvements are vital for enhancing the efficiency and sustainability of airline operations,** leading to reduced fuel consumption and emissions. Strategies such as flight path optimization, weight reduction, engine maintenance, infrastructure enhancements, demand management, and the promotion of virtual meetings can contribute to these improvements. However, while there is a consensus on the significance of operational enhancements and stakeholder engagement, there are discrepancies regarding the specific metrics and targets. Establishing standardized metrics and targets would enable better tracking and reporting of operational improvements, facilitating the transition to a more sustainable aviation industry.
- **Advancements in aircraft design and propulsion technologies, such as electric and hydrogen-powered aircraft,** are crucial for achieving net zero emissions in the aviation industry. Efforts are being made to improve aerodynamics and reduce weight, while guidelines emphasize collaboration and gradual adoption of new technologies. Assessment frameworks provide performance indicators for tracking progress. However, specific metrics and targets for new aircraft technologies are often lacking. To drive the industry towards net zero emissions, corporations should integrate various guidelines and develop comprehensive climate transition plans that align with industry-specific targets and metrics.

- **Proactive engagement by aviation companies in reducing aviation emissions and promoting sustainability requires shaping and complying with government and international regulations.** This involves advocating for feasible policies, supporting SAF, endorsing efficiency improvements, and participating in carbon pricing mechanisms. Engaging with regulators, policymakers, and stakeholders is crucial, as is encouraging modal shifts and partnering with research institutions and technology companies. Challenges include corporate reluctance, but support for SAF obligations and sustainability standards is growing. Measures like taxing jet fuel and CO2, emission trading schemes, and promoting alternative transport options can drive the industry's transition.
- **The CTIS is a scoring system that evaluates the credibility of publicly accessible transition plans in the airline industry.** It assesses six key levers: climate ambition, SAF, operational improvements, low-carbon technology integration, regulatory environment, and additional relevant factors. The scoring system follows a Logical Framework Analysis (LFA) framework with four phases, evaluating elements against specific criteria in three stages. The CTIS aims to identify strengths, opportunities, and risks of greenwashing in transition plans, enabling consistent comparisons and helping financial institutions manage climate-related risks and identify companies committed to a low-carbon transition. The outcomes range from undeveloped to robust plans, with robust plans exceeding standard practices and serving as industry benchmarks.

Most assessed airlines lack a climate transition plan or a public net zero pledge. The majority of the assessed airlines have transition plans with moderate credibility and integrity, indicating a passive role and a lack of detailed implementation strategies. Based on the CTIS analysis, there is a positive correlation observed between higher scores, increased carbon footprint, and revenue. This finding suggests that large airlines, equipped with greater resources, are better positioned to disclose a greater number of elements in their climate transition plans. However, concerns about greenwashing were raised, highlighting the need for transparency and credibility in assessing climate strategies. The breakdown of CTIS scores revealed that adequate plans demonstrated quality in establishing specific SAF strategies and regulatory support. Most assessed airlines fell into a tier with moderate credibility, lacking engagement in policy advocacy and detailed implementation strategies.

Credible transition plans hold valuable implications for financial institutions. They can improve monitoring systems, develop sector-specific sustainable finance frameworks, bridge cost differentials in SAF, and support the "Book and Claim" system. These plans facilitate informed decision-making, align financing with sustainability goals, accelerate the transition to sustainable fuels, and attract investment in the green energy sector.

1. Introduction

As the world strives towards achieving net zero emissions, the aviation sector has been categorized as a hard-to-abate sector due to its heavy reliance on fossil fuels, the absence of commercially viable and scalable carbon-neutral technology, and the projected tripling of air travel demand by 2050 (ATAG, 2021). Aviation contributes over 2% of the world's carbon dioxide (CO2) emissions, which account for about two-thirds of its climate effects, and amplifies climate change through additional human-made known as anthropogenic radiative forcing (Brazzola et al., 2022; Dray et al., 2022; Lee et al., 2021). Sector companies can align their business models with the Paris Agreement by implementing climate transition planning and reporting (NGFS, 2023). However, current transition plans lack sufficient guidance for assessing their credibility, feasibility, and overall integrity. To address this knowledge gap, we propose the CTIS, which evaluates transition plan reporting based on climate pathways, technology roadmaps, policy assumptions, and sustainability reporting frameworks. Our objective is to identify essential elements and desirable components that facilitate productive engagement between capital providers and aviation counterparts committed to achieving net zero emissions by 2050.

Transition planning in the aviation sector is an emerging practice that lacks regulatory frameworks and comprehensive corporate-level reporting guidance. This could be attributed to the industry's novelty use of climate pathways and the immaturity of carbon-neutral technologies needed for companies to set targets for achieving their net zero goals (e.g. SAF uptake). Additionally, addressing climate neutrality remains unresolved, as non-CO2 impacts are inadequately considered due to measurement complexities. (SBTi, 2021). This deficiency should encourage corporations and governments to intensify their efforts, surpass current climate pathways, and strive for superior climate outcomes.

To fulfil its climate ambition, the aviation sector needs reduce cumulative CO2 emissions by up to 20 Gt CO2 between 2020 and 2050, according to some climate pathways (e.g., MPP, 2022). Climate scenarios guide risk management and business planning decisions, serving as a compass for substantial emissions reductions in the aviation sector. Amidst evolving climate and technology pathways and reporting standards, evaluating the integrity of corporate climate transition plans within the aviation sector is crucial. Transition plans are crucial for attracting investments from capital providers aligning their investment portfolios with the Paris Agreement goals. This is becoming more important as financial institutions increasingly prioritize supporting climate solutions, limiting global warming to 1.5°C, assisting organizations in transitioning to low-carbon operations, and managing the phase-out of high-emitting assets.(GFANZ, 2022b; RMI, 2022).

We employ a methodology to devise a scoring system for evaluating the credibility and integrity of climate transition plans. This system aligns with the financial sector's disclosure requirements for real economy sectors, encompassing foundations, implementation and engagement strategies, governance, and metrics and targets. These dimensions serve as criteria for assessing key transition levers identified in influential climate pathways, focusing on fuels, technology, operations, and regulation. The scoring system follows a logical framework of inputs, outputs, outcomes, and climate impacts. We test this methodology on 49 airlines with publicly available transition plans, representing less than 30% of the airlines that have endorsed a net zero pledge through the International Aviation Transport Association (IATA, 2022b). We find that major airlines, as the highest emitters, exhibit more advanced transition plans. However, no company achieves the highest score in our system, with most falling into the lower levels denoting undeveloped or minimal transition plans. The lowest scores are attributed to inadequate engagement in supporting climate regulations and policies, as well as the promotion of SAFs, which is crucial in the short term.

Our scoring system comprehensively assesses the integrity of current transition planning and reporting practices, providing valuable insights to capital providers and airlines in their quest for sustainable and resilient operations. The score system evaluates the sufficiency of transition planning practices based on existing standards and expectations from climate pathways. Additionally, our approach emphasizes the necessity of reporting practices, recognizing them as essential and indispensable for achieving sustainable and resilient operations.

Our scoring system aims to bridge the knowledge gap surrounding the integrity of emerging corporate climate transition plans in the aviation sector. Existing initiatives that assess the credibility of climate transition plans often take a sector-neutral perspective (e.g. CA100+, 2022, p. 100; CBI, 2022; CPI, 2022; GFANZ, 2022a; UK TPT, 2022), lacking a comprehensive evaluation of the aviation sector's specific challenges and opportunities. Aviation assessment frameworks tend to prioritize the emission target alignment over technological and operational roadmaps (SBTi, 2021), remaining agnostic in suggesting specific climate pathways (ACT, 2022). Moreover, rating agencies' efforts to assess transition strategies have raised concerns about transparency and consistency (ESMA, 2022; FCA, 2023). Some net zero assessments conflate climate or temperature alignment with transition plans, which are distinct concepts. In essence, climate alignment pertains to the end goal (i.e. of being consistent with climate targets), while a climate transition plan outlines the means to achieve that goal (i.e. the specific steps an organization will take to become more sustainable and climate-resilient).

The rest of the paper is organized as follows. Section 2 compares climate pathways, focusing on their underlying assumptions, credibility, and feasibility. Section 3 reviews climate reporting frameworks that can assist airlines in their transition planning, based on key levers identified from climate pathways. Section 4 outlines the results of the integrity assessment of existing transition plans for 50 airlines, using a scoring system and climate alignment tiers. Section 5 concludes and discusses the implications for financial institutions.

2. Building the blueprint: transition levers within climate pathways

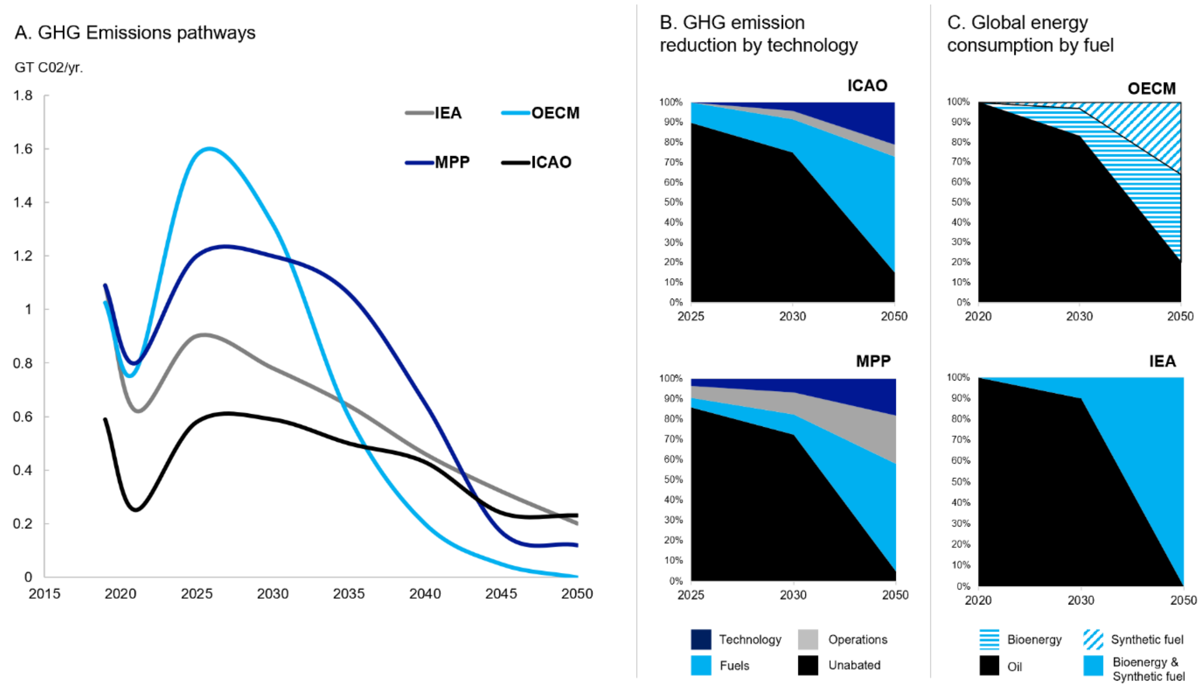
Climate pathways represent goal-oriented scenarios for companies to develop effective plans for transitioning to a more sustainable climate future. While helpful in estimating potential outcomes based on specific assumptions, climate pathways have limitations in fully capturing the complex reality of climate change and the net zero transition. These constructs are purely hypothetical in nature, serving as conceptual frameworks rather than definitive projections or sensitivity analyses (TCFD, 2020). These scenarios, created using enhanced models, may not adequately address certain financial risk scenarios that require a shock-based approach (Baer et al., 2021). They also have limitations in representing factors like frictions, tipping-points, and amplification dynamics, focusing more on gradual changes based on socioeconomic and climatic optimization (Stern et al., 2022). However, as tools for enhancing critical strategic thinking, companies can utilize climate pathways to challenge business-as-usual trajectories, consider socioeconomic interdependencies, and explore alternatives to drive significant emissions reductions in line with global climate goals.

This section provides a comparative analysis of four influential emissions pathways to uncover the key levers driving the aviation sector's climate transition towards net zero by 2050. We adapted the GFANZ (2022c) methodology to assess climate scenarios from the perspective of financial institutions. Our aim was to gain valuable insights into the potential trajectory of aviation emissions, considering socioeconomic factors and identifying actionable intervention areas. Moreover, technology assumptions reveal potential transformative solutions, encompassing propulsion systems, novel aircraft design, and SAFs. By delving into these pathways, this section lays the groundwork for subsequent sections, which examine reporting standards for key levers and assess the integrity of current corporate disclosures of major companies in the airline industry. For detailed information on each selected pathway and the framework used for the comparative analysis, please consult the Supplementary Information.

This section covers four emissions pathways that outline roadmaps for achieving net zero CO2 emissions in aviation, excluding non-CO2 climate impacts. The first pathway is the Net Zero by 2050 Roadmap of the International Energy Agency (IEA) (2021), supplemented by updates from the latest World Energy Outlook (IEA, 2022b), which provide a plan to accelerate the transition to a clean energy future. The second pathway is the prudent scenario of the Mission Possible Partnership (MPP) initiative (2022), which examines the aviation value chain to reduce emissions and achieve net zero aviation by 2050. We focused on the prudent scenario, as it aligns more closely with the IEA roadmap regarding assumptions about renewable energy deployment. In contrast, the MPP's optimistic scenario assumes a rapid and widespread implementation of power-to-liquid and hydrogen aircraft technologies. However, this optimism overlooks the current reality, where only a small fraction (4%) of projects have progressed beyond the planning stages and are either under construction or have received final investment decisions (IEA, 2022a). Uncertainties about demand, lack of regulatory frameworks, and limited infrastructure for hydrogen delivery to end users contribute to this situation. The third pathway is the updated One Earth Climate Model (OECM) 2.0 (Teske, 2019; Teske et al., 2022; UTS, 2022), commissioned by the UN-convened Net Zero Asset Owner Alliance. It aims to develop science-based decarbonization pathways and targets for different industry sectors, including aviation. The fourth pathway is the Long-Term Global Aspirational Goal (LTAG) for international aviation, adopted by the ICAO (2022b). It sets a target of achieving net zero carbon emissions in international aviation by 2050, supporting the temperature goal of the UNFCCC Paris Agreement. ICAO is a specialized agency of the United Nations responsible for developing standards and recommended practices for international civil aviation.

Figure 1.A presents the emissions projections of the four scenarios from 2019 to 2050, considering the impact of the pandemic in 2020 and 2021. Among them, ICAO demonstrates the lowest emissions level as it focuses solely on international aviation. In contrast, the IEA model depicts a gradual decarbonization transition, while the OECM and MPP scenarios assume significant technological advancements and utilize renewable energy sources. Figure 1.B illustrates the most effective technologies, including sustainable aviation fuels, operational improvements, and aircraft technologies, as outlined in the ICAO and MPP models. Furthermore, the OECM and IEA models provide a breakdown of fuel types that is crucial for decarbonization, particularly emphasizing synthetic and bioenergy-based fuels.

Figure 1. Trajectories of selected climate scenarios and key technology assumptions for the aviation sector



Sources: Authors' analysis using data from ICAO, 2022; IEA, 2021, 2022; MPP, 2022; Teske et al., 2022.

Note: **(A)** The chosen pathways represent the aspiration to achieve net zero carbon emissions, addressing unmitigated emissions through carbon removal and capture technologies. We consider the Prudent Scenario for the MPP pathway and the IS2 scenario for the ICAO, which both rely on moderate assumptions regarding hydrogen and PtL fuels. **(B)** The technology pathways provide a broad overview of how advancements in aircraft technology (Technology), operational enhancements (Operations), and the use of sustainable aviation fuels (Fuel) are expected to contribute to greenhouse gas (GHG) emission reductions by 2050. **(C)** Regarding the global energy consumption in the aviation sector, the OECM and the IEA offer a breakdown of the proportion of bioenergy, synthetic fuel, and oil expected to be utilized by 2050.

To examine the effects of various risk drivers across climate scenarios, multiple plausible hypotheses for the future are set up (BIS, 2021). Before addressing the aviation sector's key transition levers, it is essential to review and update critical aspects of emission pathways. This involves considering two main factors: the scope and ambition of net zero pathways and the underlying assumptions regarding technology and policy. By undertaking this reassessment, policymakers and stakeholders can ensure that the aviation sector's efforts align with broader sustainability goals and global climate commitments. It also enables the incorporation of innovative technologies and policies that significantly impact the transition's feasibility and credibility. Regularly reviewing and adjusting these pathways helps identify potential gaps, risks, and challenges, ensuring a smooth and realistic transition towards a low-carbon aviation industry. Table 1 shows the main aspects examined in our comparative analysis.

Table 1. Comparative analysis of climate pathways for the aviation sector: a summary of selected criteria and findings*

	IEA	MPP	OECM	ICAO
GHG scopes	1, 2, 3	1, 2, 3	1, 2, 3	1, 2
Timeframe	2010–2050	2019–2050	2019–2050	2020–2070
GHG types	CO2	CO2	CO2	CO2
Carbon price	Yes	No	No	No
Carbon budget	18 Gt	18 Gt	20 Gt	16–44 Gt
Fuel mix supply	Yes	Yes	Yes	Yes
Policy assumptions	Yes	Yes	Yes	Yes
2050 GHG emissions	0.21 Gt	0.14 Gt	0 Gt	0.23 Gt
Temperature alignment	1.5˚	1.5˚	1.5˚	1.5˚ **
Technology assumptions	Yes	Yes	Partially	Partially
Demand assumptions	Yes	Yes	Partially	Yes
Investment requirements	Partially	Partially	No	Partially
Asset-level considerations	Partially	Partially	Partially	Partially
Just transition considerations	No	No	No	Partially
Reliance on offsets	Yes	Yes	No	Yes

Sources: Authors' analysis using data from ICAO, 2022; IEA, 2021, 2022; MPP, 2022; Teske et al., 2022. Notes: (*) The selected criteria were derived from the GFANZ (2022c) assessment framework of climate pathways. (**) ICAO states that it aims to be aligned with a 1.5˚C scenario, while the CAT (2022) indicates that ICAO's target is consistent with at least 3˚C of warming, if not 4˚C.

2.1 Scope and ambition of net zero pathway

The four selected pathways primarily focus on emissions resulting from aircraft operations within the airline industry. However, they also consider the material interdependencies with fuel suppliers, aircraft manufacturers, and other industries. When airplanes release gases and particles directly into the upper atmosphere, it impacts the atmospheric composition. These emissions alter the levels of greenhouse gases such as CO2, ozone (O3), and methane (CH4). They also lead to the formation of contrails (long, thin clouds) and potentially increase the presence of cirrus clouds. All these factors contribute to climate change (IPCC, 1999).

All selected scenarios outline roadmaps for achieving net zero emissions by 2050. However, notable differences exist among them. Most pathways cover all three emission scopes, which align with Science-Based Targets initiative (SBTi) requirement to account for emissions derived from transportation and distribution of goods and business travel (SBTi, 2021). However, unlike the ICAO and OECM pathways, the MPP and IEA consider various industries within the aviation sector, such as airports, aircraft manufacturers, and leasing companies. Further, the ICAO pathway uniquely acknowledges the importance of geographical considerations regarding operational improvements and SAF production and distribution. To develop credible transition plans, it is crucial to adopt a cross-sectoral and geographical perspective. This aspect is often overlooked when analysing the climate challenge of aviation, as its carbon footprint extends beyond individual countries boundaries.

Regarding temperature alignment, all pathways exclude non-CO2 emissions impacts, which could result in a minimum 3˚C warming (CAT, 2022; Grewe et al., 2021). However, this exclusion is consistent with the SBTi recommendations, which consider non-CO2 factors as lacking credibility due to scientific uncertainty and limited mitigation levers (SBTi, 2021). Despite this limitation, all pathways claim alignment with the Paris Agreement by outlining a trajectory towards achieving net zero emissions by 2050. Concerning carbon budgets[1], the IEA and OECM pathways do not specify the proportion allocated to the aviation sector, while the MPP estimates a carbon budget of approximately 18 Gt CO2 from 2022 onwards, and

[1] A carbon budget refers to two key concepts. Firstly, it involves assessing the global-scale sources and sinks of carbon dioxide, including emissions from various activities and natural processes that affect atmospheric CO2 levels. Secondly, it represents the maximum allowable amount of human-caused CO2 emissions to limit global warming to a specific level with a certain probability, considering other human-caused climate factors. It can be expressed as the total cumulative emissions since the pre-industrial period or the remaining emissions from a specified recent date (IPCC, 2022). Initially excluded from the Nationally Determined Contributions (NDCs) outlined in the Paris Agreement, aviation is predominantly omitted due to its emissions occurring outside the jurisdictional boundaries of individual states (UNFCCC, 2016).

the ICAO offers a range of 11 to 46 Gt CO_2 as the carbon budget spanning 2020 to 2070. In the IEA scenario, the aviation sector needs to achieve a 30% reduction in overall emissions by 2030. Additionally, the emissions intensity, which measures the amount of CO_2 emissions per Revenue Passenger Kilometre (rpk), should decrease by over 30% by 2030 from the global sector average of 118 GCO_2/rpk in 2019 and by nearly 70% by 2050.

The pathways for carbon capture and removal differ in various ways. The credibility of transition plans is influenced by feasibility concerns, technological uncertainties, environmental considerations, transition risks, and policy alignment. Plans heavily reliant on Carbon Capture and Storage (CCS) may face scepticism if the technologies are not viable or lack support. Careful evaluation of assumptions and evidence is crucial in assessing plan credibility. For instance, the IEA recognizes the potential of technologies like CCS and Direct Air Capture (DAC) with storage in achieving overall net zero emissions. The MPP pathway highlights the significance of DAC and Point Source Capture (PSC) technologies, as well as the importance of establishing CO_2 transport networks and long-term agreements for carbon capture. The OECM does not explicitly quantify the reliance on carbon capture and removal, while the ICAO mentions the use of CCS technologies without specifying expected levels of carbon capture and removal. All scenarios exercise caution regarding Carbon Dioxide Removal (CDR) technologies, as they predict that the majority of CDR deployment will occur in the latter half of the century (Smith et al., 2023). The SBTi prioritizes emissions reductions within companies' operations and value chains as the primary focus, rather than relying on CDR and CCS, as these methods may delay necessary direct emission reduction actions. While some pathways and guidelines include CDR and CCS as transition measures, this paper does not consider them from a short- and medium-term perspective.

2.2 Underlying assumptions

Transitioning to net zero entails risks that are more complex than traditional financial risks. This is because transition risks involve not only economic aspects but also socioeconomic and ecological feedbacks, as well as unprecedented structural changes across geographies. These aspects are challenging to fully grasp and may be underestimated or not yet accurately accounted for by financial institutions (Bolton & Kacperczyk, 2020; Eren et al., 2022). To make well-informed decisions regarding the transition, such as planning for it, we have identified shared assumptions across different approaches. However, even with these shared assumptions, different pathways yield varying levels of emissions in the aviation sector. One common assumption is that aviation demand will grow annually by about 3%, driven by economic growth and increasing prosperity in developing countries (Gössling & Humpe, 2020). All pathways acknowledge the importance of technological advancements and operational improvements in reducing energy use in aviation. They estimate that efficiency will improve by 1% to 2% each year until 2050, consistent with historical trends since 1970 (Bergero et al., 2023). Additionally, all pathways recognize the importance of SAFs as a key element in transitioning to a low-carbon sector. SAFs include biofuels, synthetic fuels, and hydrogen. Both the OECM and IEA provide more specific assumptions regarding the share of different fuel types in the sector by 2050.

The IEA pathway is considered the most credible due to its energy system approach, offering specific projections for carbon prices, the proportion of SAF, and the necessary investments for the sector's transition. In contrast, the MPP, OECM, and ICAO pathways do not explicitly outline assumptions regarding sectoral interdependencies across the energy system. Additionally, the MPP and OECM do not provide precise investment figures, while the ICAO offers a broader range of estimates. Notably, all pathways overlook the sector's constraints in terms of profit margins and new debt obligations, beyond the impact of the pandemic on air transport demand (Dube et al., 2021). Future iterations of climate pathways could integrate debt management, financial restructuring of companies, and strategies for cost reduction and revenue enhancement. However, according to the Energy Transitions Commission (2023), the investment needs for the aviation sector, based on MPP pathways, are estimated to be as high as USD 70 billion per year from 2021 to 2050. This amount constitutes approximately 2% of the total global capital investment required for the energy transition.

Both the MPP and IEA pathways assign a significant role to hydrogen in the aviation fuel mix, envisioning the commercial viability of hydrogen-powered aircraft. This distinguishes them from other pathways that mention hydrogen as a potential option in the distant future without specifying a timeline for its introduction. A useful framework for understanding the technology pathways of aviation fuel is provided by ATAG (Table 2). It acknowledges that emerging technologies like hydrogen and electric propulsion are on the horizon but are not yet mature enough to replace existing aircraft in the short term. Therefore, SAF will remain a crucial component of the aviation fuel mix for the foreseeable future. However, there is ongoing disagreement regarding the minimum requirements, both at a regional and company level. Five methods are currently used to produce SAF that can blend with conventional jet fuel without modifying aircraft engines or structures[2].

[2] Currently, there are only five techniques available to produce a fuel that can blend with conventional jet fuel up to a 50% ratio without requiring modifications to the aircraft's engine or structure (ATAG, 2021). These methods include Hydroprocessed Esters and Fatty Acids (HEFA), which use plant or animal-derived oils and fats, and Fischer-Tropsch (FT), a process that converts biomass or waste resources into a gas and then into liquid fuel. The Alcohol-to-Jet (ATJ) method converts alcohols like ethanol into jet fuel, while the Direct Sugars to Hydrocarbons (DSHC) method directly converts sugars into fuel. The US Department of Energy (2020) suggests

Table 2. Aviation technology pathways

		2020	2025	2030	2035	2040	2045	2050
~27% of CO2 emissions	**Commuter** • 9–50 seats • <60 min flights • <1% of industry CO2	SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF
	Regional • 50–100 seats • <60 min flights • <1% of industry CO2	SAF	SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF
	Short haul • 100–150 seats • 45–120 min flights • ~24% of industry CO2	SAF	SAF	SAF	SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF	Electric, Hydrogen fuel cell and/or SAF
~73% of CO2 emissions	**Medium haul** • 100–150 seats • 60–150 min flights • ~43% of industry CO2	SAF	SAF	SAF	SAF	SAF	SAF	Electric, Hydrogen fuel cell and/or SAF
	Long haul • 250+ seats • 150+ min flights • ~30% of industry CO2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

Source: Authors' analysis using data from ATAG, 2021.

that in the near term (0–5 years), research can help further reduce the cost of these techniques. Lastly, the Power-to-Liquid (PtL) method, a relatively new technology, synthesizes jet fuel from carbon dioxide and hydrogen. The suitability of these methods depends on various factors, including feedstock availability, technological advancements, cost considerations, and regulatory approval.

One crucial aspect that is lacking in all the proposed plans is specific details on managing the retirement of high-emitting aircrafts. Stakeholders, including investors, customers, and regulators, increasingly demand transparency and robust strategies for fleet renewal and the phase-out of older, less fuel-efficient aircraft. Without clear retirement plans, concerns may arise regarding an airline's commitment to reducing emissions and transitioning to a more sustainable fleet. By replacing older planes with newer, more fuel-efficient ones, airlines can quickly reduce both fuel costs and CO2 emissions (NLR & SEO, 2021). However, since aircrafts have a long lifespan of about 22 years, it is important to have clear strategies for early retirement, retrofitting with cleaner technologies, or transitioning to low-emission alternatives. The future composition of the aircraft fleet is a vital factor in predicting air traffic and emissions (Schlesinger & Grimme, 2021).

Although all pathways emphasize the significance of policy measures and incentives, they lack explicit guidance on the precise design and implementation of these policies, except for the MPP, which provides a more detailed framework for policies pertaining to stimulating the supply and demand of SAF. These include implementing blending mandates or fuel standards to ensure a minimum SAF usage, providing financial incentives like grants, loans, or tax credits to SAF producers, and introducing carbon pricing to enhance the economic attractiveness of SAFs. The MPP also recommends supporting research and development in SAF technologies, leveraging government purchasing power to stimulate SAF demand, and aiding the development of necessary infrastructure for SAF production and distribution. Furthermore, it suggests providing long-term regulatory certainty to stimulate investment in SAF production and promoting transparency and certification schemes to ensure SAF sustainability and increase consumer confidence.

Finally, the pathways differ in their assumptions regarding the role of carbon pricing. While the IEA provides a specific projection for carbon prices, the MPP, OECM, and ICAO pathways do not offer detailed trajectories. The lack of clarity regarding the future development of carbon prices poses a challenge for the aviation sector's transition to low-carbon practices, as these prices directly impact the economic viability of different technologies and fuels.

2.3 Credibility and feasibility

As represented by the four pathways, the transition to net zero emissions within the aviation sector is an intricate and complex process. However, differences arise in terms of validation processes, stakeholder engagement, and the incorporation of just transition and fair share principles. Credibility can be influenced by stakeholder confidence, particularly if global pathways fail to reflect regional differences or lack robust validation processes and stakeholder engagement. Feasibility perceptions may be affected if existing infrastructure and regulatory frameworks are misaligned with prescribed climate pathways in certain regions. Additionally, pathway feasibility is influenced by adherence to just transition and fair share principles, which help address potential resistance and garner stakeholder support.

The IEA's pathway gains its legitimacy through comprehensive stakeholder consultations encompassing governments, businesses, investors, and civil society organizations. Its alignment with the Paris Agreement's temperature targets further reinforces its credibility (Cozzi & Gül, 2021). It offers a distinctive approach to decarbonization in the aviation sector, focusing on CCS and hydrogen utilization, diverging from IPCC scenarios. However, the pathway falls short in explicitly considering just transition and fair share principles. The absence of specific guidelines for implementing these principles within regional or country-specific aviation pathways could impact the pathway's long-term feasibility.

The MPP pathway, which supports the temperature targets set by the Paris Agreement, lacks detailed comparison exercises within the IPCC, raising concerns about its validation process. Conversely, the pathway places importance on stakeholder involvement and public-private partnerships, indicating a commitment to ensuring a fair distribution of efforts and benefits. The OECM pathway strives for credibility through consultations with academia, industry, and civil society experts, but questions arise about its validation process due to its need for more specific temperature alignment validation and submission for comparison exercises within the IPCC. Similarly, the OECM pathway does not clearly address the integration of just transition and fair share principles in regional or country-specific aviation pathways. Conversely, the ICAO pathway establishes credibility through interactions with the IPCC, industry representatives, NGOs, and academic experts. However, it also falls short in addressing the incorporation of just transition and fair share principles in regional or country-specific pathways. The inclusion of just transition and fair share principles in corporate climate transition plans helps ensure integrity by addressing social equity, minimizing potential resistance, demonstrating social responsibility, fostering trust, and aligning with global climate objectives. Overall, these pathways exhibit strengths and areas for improvement, particularly concerning validation processes and the integration of equitable transition principles.

Failure to prioritize a just transition in the aviation sector can lead to significant financial risks related to operating costs, asset values, corporate reputation, and workforce stability (ETWF, 2022). The absence of clear guidelines for implementing just transition and fair share principles in all pathways is a notable gap. These principles are crucial aspects outlined in the Paris Agreement and encompass financial material factors that influence enterprise value

(Khosla et al., 2023). Additionally, the transition process in aviation is impacted by nature interdependencies, such as feedstock availability and sectoral interdependencies with sectors like agri-food (IRENA, 2020). The reliance on sustainable bioenergy practices needs a sustainable supply of biomass feedstock, closely linking the aviation sector with the fragmented agri-food sector (Emmanouilidou et al., 2023). Disruptions in the agri-food sector can affect feedstock availability and either hinder or accelerate the aviation transition. Therefore, social considerations are crucial in navigating this complex transition.

3. Navigating reporting guidelines and uncharted routes

Based on our analysis of climate pathways, we have identified four key levers that form the foundation of transition planning and reporting for airlines aiming to achieve net zero carbon emissions by 2050. These levers, which are explicitly mentioned in certain climate pathways and reporting frameworks, include scaling up sustainable aviation fuel, advancing aircraft technologies, enhancing operational efficiency and infrastructure, and harmonizing regulations. To evaluate the effectiveness and comprehensiveness of companies' strategies and actions, we employ the concepts of essentiality and sufficiency. Essentiality involves identifying the key actions required, while sufficiency determines if these actions are adequate and comprehensive enough to achieve the desired outcomes. In this section, we compare 17 climate reporting guidelines for the aviation sector to uncover how effectively they support companies in reporting on these key transition levers and whether they guide them sufficiently in transition planning and reporting aligned with well-defined climate goals.

Table 3 provides a comprehensive overview of 17 climate reporting guidelines for companies' transition planning. The table focuses on two main elements: corporate climate ambition, specifically net zero goals, and the reporting requirements for the identified key transition levers. It is important to note that the table emphasizes guidelines supporting preparers in essential aspects of implementation and engagement strategies, as well as metrics and targets. These guidelines differentiate between those aimed at achieving net zero goals and those focused on a low-carbon transition. While governance aspects like board oversight, executive management involvement, and remuneration incentives are not specifically discussed in this section, we acknowledge their importance as fundamental components across all frameworks. We omitted their inclusion as they are beyond the scope of the aviation sector's transition planning. However, a thorough analysis of these governance aspects, including assurance and accountability, will be addressed in the subsequent section.

We categorized the reviewed guidelines by trade association pledges, disclosure guidelines, assessment methodologies, target-setting and verification frameworks, and jurisdictional expectations. Trade association pledges entail voluntary commitments made by industry-specific trade associations to address sector-specific environmental and social issues. Disclosure guidelines serve as guidance for organizations to disclose relevant environmental, social, and governance (ESG) information, promoting transparency and comparability. Assessment methodologies provide frameworks for assessing and evaluating sustainability performance using indicators and metrics. Target-setting and verification frameworks focus on establishing and monitoring specific sustainability targets to effectively track progress. Lastly, jurisdictional expectations refer to sustainability reporting requirements proposed by regulatory bodies or regional agencies, which organizations are expected to comply with to ensure consistency and accountability.

Table 3. Climate reporting guidance for airlines’ net zero goals and transition levers

	Trade Assoc		Disclosure frameworks					Assessment frameworks				Target-setting and verification			Jurisdictional expectations		
	IATA	**ATAG**	**IFRS**	**GFANZ**	**ISO**	**TCFD**	**UK TPT**	**CBI**	**TPI-MQ**	**CA100+**	**ACT**	**Moody’ s**	**SBTi**	**TPI-CP**	**US ACAP**	**EU D2050**	**UK**
Foundations																	
Net zero goals	● (blue)	● (blue)	● (dark)	● (blue)	● (blue)	● (dark)	● (dark)	● (dark)	● (dark)	● (blue)	● (dark)	● (blue)	● (blue)	● (dark)	● (blue)	● (blue)	● (blue)
Sectoral pathways	● (blue)	● (blue)		● (blue)		● (dark)		● (dark)			● (dark)	● (blue)	● (blue)	● (dark)	● (blue)	● (blue)	● (blue)
Transition levers																	
Fuels	● (blue)	● (blue)	● (dark)	● (blue)							● (dark)				● (blue)	● (blue)	● (blue)
Operations	● (blue)	● (blue)	● (dark)								● (dark)					● (blue)	● (blue)
Technology	● (blue)	● (blue)	● (dark)	● (blue)							● (dark)					● (blue)	● (blue)
Regulation	● (blue)	● (blue)	● (dark)	● (blue)	● (blue)	● (dark)	● (dark)		● (dark)	● (blue)	● (dark)			● (dark)	● (blue)	● (blue)	● (blue)

● Guidance for net zero transition planning reporting
● Guidance for low-GHG transition planning reporting

Sources: Authors’ analysis using data from ATAG, 2021; FAA, 2021; GFANZ, 2023; IATA, 2022a, 2022b, 2023, 2023; IFRS, 2018; ISO, 2022; Moody’s, 2021, 2022; NLR & SEO, 2021, 2021; SBTi, 2021; TCFD, 2021; TPI, 2021a, 2021b; UK DfT, 2022; UK TPT, 2022.

3.1 Corporate net zero goals and use of sectoral pathways

Corporate net zero goals and climate pathway assumptions are part of the GFANZ framework's Foundations element, representing airlines' overarching objective and action plan to combat climate change. Our research compares reporting guidelines regarding GHG emissions measurements, carbon performance tracking systems, and the utilization of sector-specific climate pathways for goal setting. This analysis evaluates the sufficiency of climate reporting guidelines in guiding metric selection and target calibration, while identifying similarities, differences, and areas requiring further knowledge.

GHG emissions measurement stands as the cornerstone of any corporate climate ambition, and all frameworks recognize its significance. Most frameworks recommend reporting absolute GHG emissions (e.g. CA100+, 2022; IFRS, 2018; ISO, 2022). Regarding intensity metrics, airlines commonly report Tank-to-Wake (TTW) or combustion emissions in their emission calculations (TPI, 2021a). However, the SBTi aviation sector guidance advocates for the development of inventories on a Well-to-Wake (WTW) or life-cycle basis (SBTi, 2021), which may include Scope 3 emissions as well. This comprehensive approach accounts for both direct emissions from fuel combustion and indirect emissions associated with the entire life cycle of the fuel, providing a more holistic assessment of the environmental impact of aviation fuel (SBTi, 2021). However, WTW does not encompass emissions related to aircraft manufacturing.

According to ACT (2022), when WTW emissions data is inaccessible, it is advised to adopt a TTW approach, considering regional conversion factors related to WTW analysis. IATA recommends a simpler method for calculating CO2 emissions per passenger (IATA RP 1678), which uses standard weights per passenger and available seats, assuming fuel usage is proportional to weight. Total weight divided by aircraft weight multiplied by total fuel used determines passenger fuel usage. Some reporting standards advise airlines to apply these guidelines for computing CO2 emissions (ATAG, 2021).

Additional emissions to consider in Scope 1 and 2 (ATAG, 2021; IATA, 2022a) relate to ground operations and purchased electricity, but they generally constitute a minimal portion, usually less than 1% of total Scope 1+2 emissions (TPI, 2021a). Certain frameworks emphasize the importance of disclosing climate-related risks, opportunities, and tracking progress towards low-carbon goals (TCFD, 2021).

Regarding using climate pathways, some frameworks provide guidance on utilizing them to establish climate targets. For instance, TPI and ACT recommend leveraging sectoral pathways to determine corporate climate targets, acknowledging the unique context of the aviation industry. SBTi advocates for aligning emissions reduction targets with sectoral decarbonization pathways to contribute to global efforts in limiting global warming to well below 2°C. While the International Financial Reporting Standards (IFRS) and ISO do not explicitly mention sectoral pathways, they emphasize the need for industry-relevant metrics and targets.

The lack of clear guidelines for consistent emissions comparison in the aviation industry poses a significant gap, resulting in inconsistent reporting practices. To fix this, countries can work towards including both domestic and international flights in their net zero emissions strategies (e.g. CCC, 2020; UK DfT, 2022). Globally, collaboration among countries can establish a common baseline for emissions measurement within the CORSIA scheme. This will enhance clarity and consistency in emission reporting and benchmarking within the aviation sector. Further, this kind of effort can also clear how global or regional climate pathways directly translate to corporate-level targets. Another gap is the insufficient guidance on non-CO2 climate impacts. While most frameworks acknowledge their existence, detailed guidelines for effective measurement and mitigation are lacking. This information gap restricts airlines' ability to comprehensively assess and address their overall climate impact.

In summary, various guidelines agree that the primary indicators for assessing performance in the aviation sector are absolute emissions, which refer to the total GHG emissions produced by all flights conducted by an entity, and emissions intensity, which represents the amount of GHG emissions per unit of output, such as passenger kilometres or freight ton kilometres. However, it is worth noting that certain Scope 3 emissions, specifically those associated with aircraft manufacturing, are currently not accounted for, alongside non-CO2 climate impacts, due to existing scientific uncertainties. Anticipated advancements in benchmarking practices for both domestic and international flights can be expected through their inclusion in national-level net zero objectives and carbon budgets, as well as the forthcoming mandatory implementation of the CORSIA scheme from 2027, which will apply to major airlines.

3.2 Climate transition levers

The Foundations element of the GFANZ framework considers an outline of corporate climate transition levers. However, it is crucial to provide detailed information on implementation and engagement strategies, as well as the selection of metrics and target calibration to track progress. This subsection offers insights into the vital aspects of transition planning, including guidance on implementation and engagement strategies. It assesses the adequacy of these frameworks in guiding the metric selection and target setting. The analysis also identifies similarities, differences, and areas that require further knowledge.

Fuels: SAFs are derived from sustainable, non-fossil sources that can be used in aircraft. They have the potential to significantly reduce aviation's carbon footprint. SAFs can be made from various feedstocks, including waste oils, agricultural residues, and even carbon captured from the air.

SAF plays a crucial role in the transition planning process for airlines aiming to achieve carbon neutrality and mitigate their environmental impact. Due to its potential to reduce carbon emissions by up to 80% and its advanced technological maturity (IEA, 2021), SAF is considered a key lever in the short term, surpassing other alternatives like new aircraft technology (IATA, 2022c; WEF, 2020). Various types of SAF are available, including synthetic aviation fuels, advanced biofuels, and biofuels derived from sustainable feedstocks. However, adopting SAF requires compliance with specific sustainability and GHG emissions criteria. A notable advancement in synthetic jet fuel development is the concept of “drop-in” fuels, which enable approved synthetic fuels to blend seamlessly with regular jet fuel without necessitating expensive recertification or modifications (Airbus, 2023). These blends effectively decrease soot and non-CO2 impacts (EC, 2020).

Several actions are necessary to achieve net zero and significantly increase the use of SAF from less than 0.1% of all aviation fuels in 2021 to approximately 10% by 2030 (IEA, 2021). SAF usage rate throughout the global fleet is expected to be between 45% and 90% in 2050 (Dray et al., 2022). This includes investing in the expansion of SAF production capacity and implementing new policies like fuel taxes, low-carbon fuel standards, and mandatory blending requirements. These measures are crucial to encourage the adoption of SAF and drive the transition towards a more sustainable aviation industry.

The comparative analysis of climate reporting frameworks in Table 3 indicates that the uptake of SAF by airlines in their transition planning process is not comprehensive yet. The existing practices lack standardization in terms of indicators for SAF uptake, making it difficult for users to compare them. One fundamental similarity among them is the recognition of SAF as a crucial strategy for achieving net zero carbon emissions in the aviation sector. Stakeholder engagement is another area of common emphasis, highlighting the need for collaboration with several industry peers, partners, government entities, regulators, and financial institutions. However, differences exist in financial performance indicators related to SAF adoption. While some frameworks, such as IATA and GFANZ, do not explicitly address financial KPIs like capital expenditure (CAPEX) or operating expenditure (OPEX) concerning SAF adoption, others, like ATAG, acknowledge the potential changes in CAPEX and OPEX due to the higher cost of SAF compared to conventional jet fuel. Including financial indicators would provide a more comprehensive understanding of the economic implications of SAF adoption and its integration into airline operations. Furthermore, the level of detail regarding the operational strategies for incorporating SAF into airline operations varies across the frameworks. Some frameworks provide insights into the need for aligning fuel procurement practices, investing in infrastructure and technology, and potentially changing operating practices to accommodate SAF usage (e.g. ATAG, 2021; FAA, 2021; NLR & SEO, 2021; UK DfT, 2022). However, other frameworks lack specific information, leaving a gap in understanding how airlines should effectively integrate SAF into their operations.

Additionally, the frameworks differ in terms of the specific metrics and targets they provide for tracking SAF uptake by airlines. While frameworks like IATA, ATAG, and EU D500 offer specific metrics such as total SAF delivered, SAF blend ratio, and life-cycle sustainable fuel emissions reductions, others do not provide a comprehensive list of KPIs. This variation highlights the need for consistent and standardized metrics to enable meaningful comparison and evaluation of SAF adoption across the industry.

While sustainability reporting frameworks focus more on GHG emissions measurement and target-setting, additional guidelines for SAF are available beyond the selected frameworks from Table 3 The WEF (2020; 2022) and the ICAO's CORSIA Sustainability Criteria (2022a) provide comprehensive SAF production and use guidance. CORSIA criteria cover numerous aspects such as GHG emissions, carbon stock, water and soil quality, air pollution, conservation, waste and chemical management, human and labour rights, land and water use rights, local and social development, and food security. In its methodology, ACT framework states that biofuels not respecting the ICAO standards cannot be considered low carbon, hence the same for aircraft using them. Transparent reporting is promoted through detailed information on costs, feedstock availability, and carbon accounting, with compliance requiring certification by an approved Sustainability Certification Scheme to ensure transparency and reliability of data. While compliance and enforcement mechanisms are not explicitly mentioned in the CORSIA document, the clear criteria for SAF production and use, along with the requirement for certification by an SCS, underscore the importance of accurate accounting. The WEF aligns with international standards and initiatives such as ICAO and CORSIA, recognizing the evolving nature of sustainability practices.

Other certifications (e.g. ASTM, 2022; EPRS, 2020, 2022; ISCC, 2022; RSB, 2023a, 2023a) offer independent verification, stakeholder engagement, and compliance monitoring frameworks. These certifications promote credibility, consistency, and compatibility with international standards while addressing sustainability criteria and promoting transparency. Mechanisms such as audits and periodic assessments are employed to maintain compliance, and the certifications undergo regular updates to incorporate emerging knowledge and challenges.

Operations: The transition lever of operational improvements encompasses various strategies to enhance the efficiency and sustainability of airline operations. These strategies include flight path optimization, weight reduction, engine maintenance, infrastructure improvements, demand management through pricing strategies and alternative modes of transport, as well as the promotion of virtual meetings as a substitute for air travel. By implementing these measures, airlines can contribute to reducing fuel consumption and emissions in the aviation sector.

The guidelines consistently underscore the significance of operational and infrastructure enhancements in mitigating emissions. These measures encompass optimizing flight paths, enhancing aerodynamics, and managing demand through effective scheduling and load management practices. Nevertheless, one notable disparity is the absence of specific metrics and targets within the IATA net zero tracking, whereas the ATAG implies that individual airlines should establish their own objectives.

Within the realm of disclosure guidelines, exemplified by the IFRS and the GFANZ, guidance is provided on aligning business activities and operations with prevailing regulations and policies. IFRS emphasizes setting targets based on scientific knowledge, evidence, research, and good practice. Conversely, GFANZ neglects to specify essential performance indicators (KPIs) for operational improvements. Both guidelines underscore the importance of engaging with diverse stakeholders, while IFRS additionally highlights the necessity of robust measurement and monitoring systems.

Target-setting and verification organizations, such as the SBTi, emphasize aligning business operations with climate objectives and the significance of stakeholder engagement. However, specific details regarding operational improvement alignment are notably absent. Unlike IFRS, SBTi underscores the importance of establishing comprehensive measurement and monitoring systems yet fails to enumerate specific KPIs for operational enhancements.

Assessment frameworks, such as the ACT initiative and the Aviation Carbon Accreditation Programme (ACAP), provide comprehensive guidelines for operational improvements. ACT outlines strategies encompassing the transition to low-GHG energy, augmenting energy efficiency, and influencing customer behaviour. It further advocates engagement with relevant stakeholders and the establishment of quantitative goals for measuring progress. Conversely, ACAP does not specify metrics and targets but suggests potential KPIs like sector growth and increased SAF production.

As demonstrated by the UK Jet Zero Strategy (UK JNZ) and the European Union's Destination 2050 report, jurisdictional expectations underscore the importance of operational and infrastructure improvements in attaining net zero emissions. UK JNZ establishes specific targets for emissions reduction and emphasizes partnerships and collaboration. Notably, it does not mention precise KPIs. The EU's Destination 2050 report acknowledges the potential emission reductions resulting from operational enhancements. Still, it omits explicit airline-specific strategies while accentuating the need for cooperative endeavours involving governments and the industry.

In conclusion, while shared themes such as the significance of operational improvements and stakeholder engagement are evident throughout the guidelines, disparities arise regarding the specificity of metrics, targets, and KPIs for operational enhancements. Addressing these gaps would significantly enhance corporations' capacity to effectively measure and report progress in operational improvements within their climate transition plans.

Technology: Critical advancements in aircraft design and propulsion technologies are pivotal in achieving net zero emissions. These advancements include improvements in aerodynamics, weight reduction, and the exploration of electric or hydrogen-powered aircraft (IATA, 2023a). By 2030, technologies like SAF, hydrogen-powered aircraft for mid- and short-range flights, and battery-powered aircraft for commuter flights will show promise. Efforts are underway to enhance in-flight energy efficiency through aerodynamic and weight reduction improvements, such as longer and thinner wings, composite materials, and more electric flight control systems.

Analysing various guidelines provides valuable insights into industry expectations and recommendations. Trade association guidelines, such as those provided by IATA and ATAG, emphasize collaboration among stakeholders and the gradual adoption of hybrid-electric, electric, and hydrogen-powered aircraft. Additional details on advanced aircraft configurations are available from IATA. However, both guidelines lack specific metrics and targets, placing emphasis on individual airlines to set their own objectives.

Disclosure guidelines, such as IFRS and GFANZ, acknowledge the significance of fuel-efficient aircraft technologies in managing greenhouse gas emissions. IFRS suggests incorporating these technologies into strategies and engaging with stakeholders, while GFANZ highlights alignment with SAF and the need for research and development. Nevertheless, both guidelines lack specific KPIs and targets for new aircraft technologies.

Assessment frameworks like ACT focus on evaluating alignment with low-carbon transition objectives. They highlight the importance of moving away from fossil fuels, enhancing energy efficiency, and fostering innovation. ACT provides a comprehensive range of performance indicators and targets companies can use to assess their progress in adopting and promoting new aircraft technologies. These indicators encompass various aspects of the transition, including emissions reduction targets for transport services, the time horizon of targets, past target achievements, trends in emissions intensity, alignment of past performance with carbon budgets, locked-in emissions from the fleet, the proportion of low-carbon vehicles and energies, and investments in low-carbon vehicles, energies, digital solutions for transport optimization, and human capital. By considering these indicators, companies can effectively track their advancements in adopting and promoting new aircraft technologies, ensuring their efforts are aligned with climate objectives.

Target-setting and verification frameworks like SBTi focus on setting greenhouse gas intensity targets but lack specific details on new aircraft technologies and relevant KPIs. Individual airlines are expected to develop their own climate action plans in this regard. Jurisdictional expectations, such as those outlined in UK JNZ and EU-D500, highlight government commitments to support new aircraft technologies. Both emphasize partnerships, collaboration, and clear emissions reduction targets. However, they do not provide specific KPIs related to new aircraft technologies. The US ACAP document addresses the adoption of new aircraft technologies, implementation strategies, engagement, and potential KPIs. It highlights aligning operations with new technology objectives and collaboration with stakeholders. However, specific metrics and targets are not provided.

In conclusion, while the guidelines recognize the importance of new aircraft technologies, specific metrics, targets, and KPIs related to their adoption are often lacking. To develop comprehensive climate transition plans that encompass advancements in new aircraft technologies, corporations in the aviation industry are advised to consider a combination of guidelines. By integrating the analysis of these guidelines, leveraging a McKinsey style approach, and avoiding bullet points or lists, organizations can develop robust strategies that align with industry-specific targets and metrics. This holistic approach will drive the aviation industry towards achieving net zero emissions and contribute significantly to global efforts in combating climate change.

Regulation: Proactive involvement in reducing aviation emissions and promoting sustainability involves shaping and complying with government and international regulations. This includes advocating for feasible policies, supporting incentives for SAFs, endorsing efficiency improvements, and participating in carbon pricing mechanisms. Engaging with regulators, policymakers, and stakeholders is crucial to establish a clear policy framework, encourage international collaboration, and promote research and development of innovative technologies. Airlines should also encourage modal shifts towards alternative transportation and engage customers and investors through communication campaigns and alignment with sustainability goals. Forming partnerships with research institutions and technology companies fosters innovation. Challenges include corporate reluctance to support specific policies, but there is increasing support for SAF obligations and the need for globally recognized sustainability standards. Potential measures include taxing jet fuel and CO2, implementing emission trading schemes, eliminating subsidies, and promoting alternative transport options. Proactive involvement and collaboration are vital to driving the aviation industry's transition towards decarbonization and sustainability.

IATA and ATAG are trade associations that aim to influence policy negotiations and engage with governments to accelerate the commercial production and deployment SAF. Both stress the need for supportive policies and incentives to reduce project risk and foster a compelling business case for SAF. However, IATA specifically advocates for aviation to opt into existing ground transport policies, while ATAG emphasizes aligning business activities with new regulations and policies. Information gaps exist regarding specific metrics, targets, and KPIs for advocacy efforts.

ISO and GFANZ provide guidance on aligning business activities with regulations and policies, engaging with stakeholders, setting targets, and measuring emissions. ISO recommends specific targets for different emission scopes and emphasizes the importance of measurement and monitoring. GFANZ emphasizes developing transition plans and sectoral pathways but lacks an explicit discussion on aligning operations with regulations and policies. Both guidelines lack specific KPIs for the adoption of new regulations and policies.

ACT and SBTi offer approaches for aligning operations with regulations and policies, engaging with stakeholders, and setting targets. ACT emphasizes aligning activities with regulations, influencing customer behaviour, and engaging with local authorities. SBTi highlights the importance of engagement and aligning with regulations but lacks details on specific strategies. Both frameworks suggest setting quantitative goals for measuring progress, but KPIs for adopting regulations and policies are not explicitly mentioned.

UK JNZ outlines the UK's implementation strategy, emphasizing international leadership and commitment to CORSIA. The document highlights engagement through COP26 and the International Aviation Climate Ambition Coalition. US ACAP focuses on domestic regulations, compliance, and collaboration with government entities. The EU-D500 report emphasizes cooperation between governments and the industry but lacks details on aligning operations with regulations and policies. These documents do not provide specific KPIs for adopting regulations and policies.

Overall, there are similarities in recognizing the importance of regulations and policies, engagement with stakeholders, and the need to align with climate goals. However, differences exist in specific approaches, such as IATA's focus on opting into ground transport policies, ISO's emphasis on measurement and monitoring, and ACT's mention of engaging with subcontractors and infrastructure operators. Information gaps include the absence of specific metrics, targets, and KPIs in several documents.

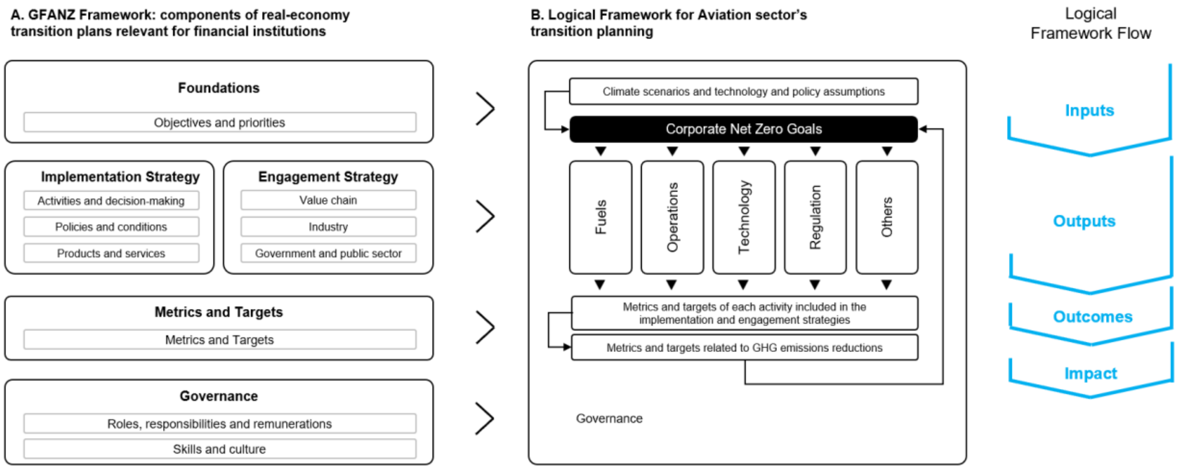
4. Scoring the integrity of transition plans in the airline industry

This section provides the results from our evaluation of the credibility of publicly accessible transition plans within the airline industry based on a scoring system derived from climate pathways and sustainability reporting guidance discussed in the previous sections. Our methodology adheres to the principles outlined by the UN High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities (2022), emphasizing integrity, transparency, and accountability in net zero commitments. Furthermore, we evaluate the alignment of transition levers in the transition plans, considering the GFANZ framework, as well as sector-specific guidance for the aviation industry that facilitates tracking progress across the identified levers.

We adhere to the GFANZ transition planning disclosure expectations for the real economy, which provide a comprehensive framework for financial institutions to facilitate efficient capital allocation and accelerate the net zero transition. The framework comprises foundations, implementation and engagement strategies, metrics and targets, and governance. To effectively plan and manage the transition, we complement GFANZ with the widely used LFA (e.g. GCF, 2022; USAID, 2021; WWF, 2005). LFA is a matrix-based framework that organizes and defines the objectives, activities, outputs, and outcomes of projects or programmes (IBRD, 2004). We use the LFA to structure the transition planning process.

We define corporate climate ambition by analysing science-based climate scenarios, technology advancements, and policy assumptions. These inputs identify the key levers for transforming business models aligned with a net zero economy. Each lever sets specific objectives, operationalised through various activities in our implementation and engagement strategies. To track progress and evaluate effectiveness, activities are linked to KPIs contributing to GHG reduction metrics and targets for our corporate net zero goal (Figure 2).

Figure 2. Mapping out the transition planning process based on the Logical Framework Analysis and GFANZ Framework



Source: Authors' concept using data from GFANZ, 2022a.

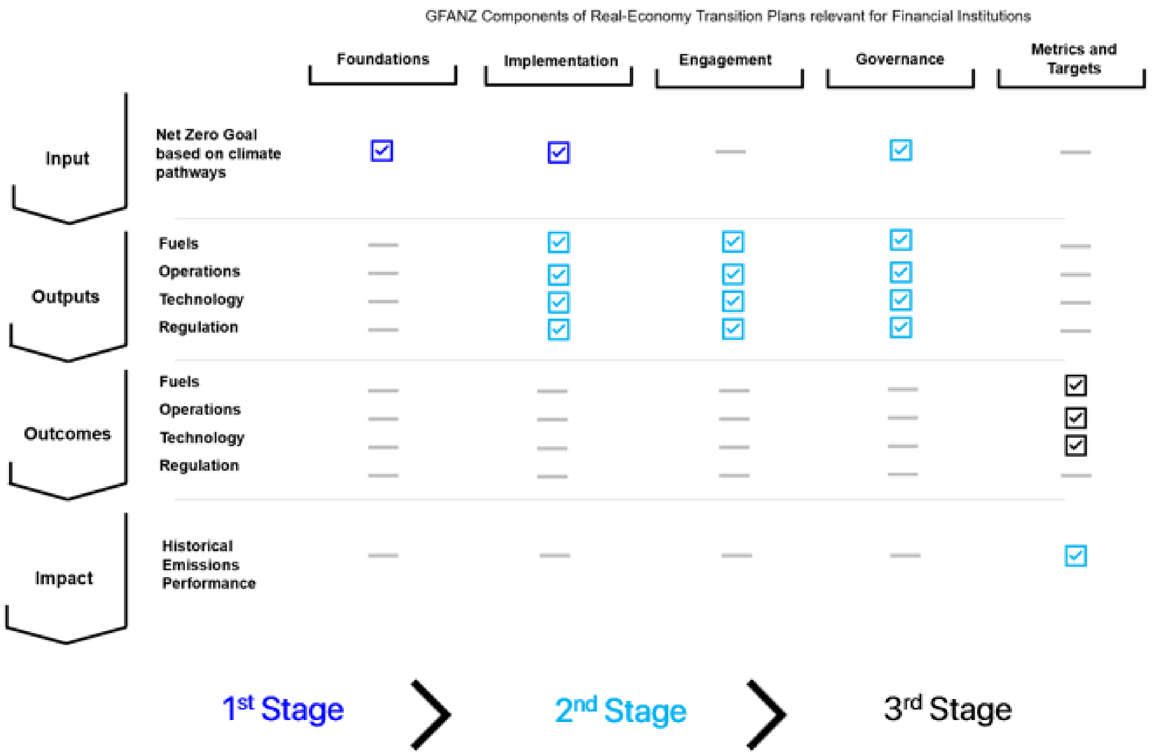
This conceptual framework represents the cornerstone of our scoring system, the CTIS. Scores or ratings represent a valuable tool for financial institutions when evaluating corporate sustainability performance. In line with such common practice, we devise a scoring system to assess the integrity of corporate climate transition plans. We argue that CTIS allows for comparisons across companies within the airline industry, enabling financial institutions to effectively manage climate-related risks, identify companies committed to the low-carbon transition, and generate long-term value.

The CTIS assesses six levers: climate ambition, SAF, operational improvements, low-carbon technology integration, regulatory environment, and additional levers as deemed relevant. It aligns with the transition plan components expected by financial institutions, as defined by GFANZ. The CTIS aims to evaluate transition plans, identify strengths and opportunities, and mitigate the risk of greenwashing. It benchmarks climate performance against established standards and uncovers best practices.

The scoring system follows an LFA framework with four phases: input, outputs, outcomes, and impact. Each element is evaluated against specific criteria in three stages (Figure 3). An element must pass earlier stages to be assessed in subsequent ones. Scores of 1 or 0 are assigned based on the element's adherence to questionnaire criteria and guidance in Appendix A. The final score reflects the cumulative evaluation result.

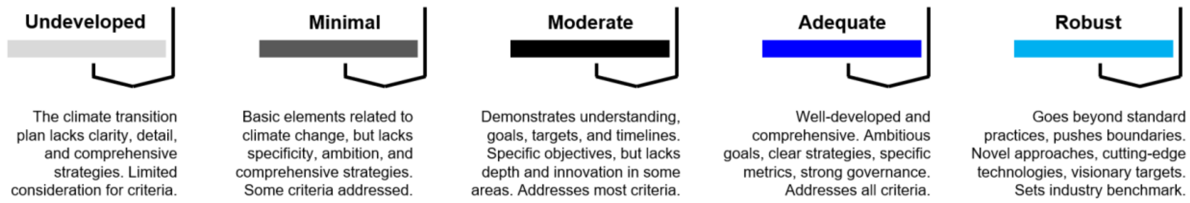
A climate target is a foundational requirement in climate transition plans. Without a climate target, the assessment of levers lacks coherence and is not considered in our evaluation. For detailed score calculation information, please refer to the Supplementary Information.

Figure 3. Conceptual framework to calculate Climate Transition Integrity Score



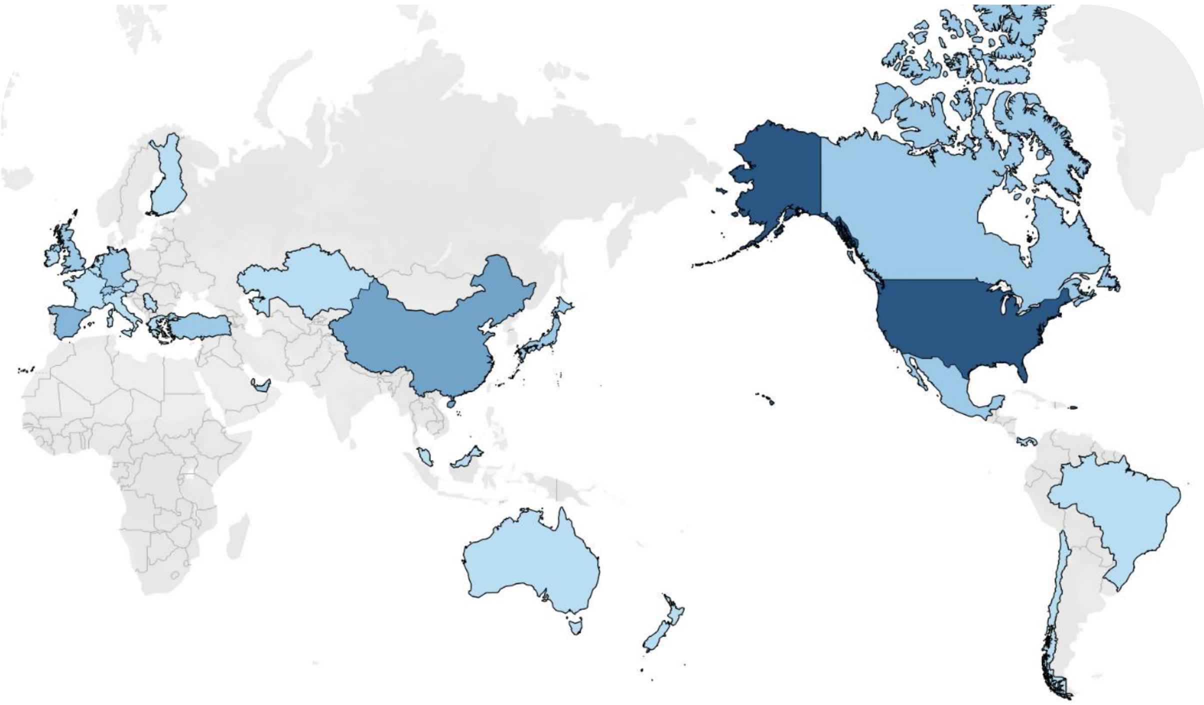
The CTIS outcomes could be translated into different levels within the airline industry and range from undeveloped to robust (Figure 4). Undeveloped plans lack clarity and comprehensiveness, while minimal plans provide basic elements but lack specificity and ambition. Moderate plans demonstrate a reasonable understanding of climate change challenges but may lack depth and innovation. Adequate plans are well-developed and comprehensive, addressing all criteria and setting ambitious goals, based on the latest sector guidance, technology pathways and policy frameworks. Robust plans go beyond standard practices, incorporating novel approaches and serving as industry benchmarks.

Figure 4. Climate Transition Integrity Score tiers



In our sample selection, we review all members of IATA since they have endorsed a net zero carbon emissions commitment by 2050. We collected information from 305 airline members of IATA, representing over 80% of global airline operations. Among the IATA-affiliated companies, only 49, which is less than 30% of the total members, have publicly available climate strategies (Figure 5). Additionally, only 8 of these companies have had their climate targets verified by SBTi. We gathered data by reviewing official reports on airline websites, including sustainability, climate, and annual reports. To enhance the efficiency and accuracy of the website content scanning and analysis, we use OpenAI plugins (OpenAI, 2023), enabling tasks such as data extraction, sentiment analysis, content categorization, and anomaly detection.

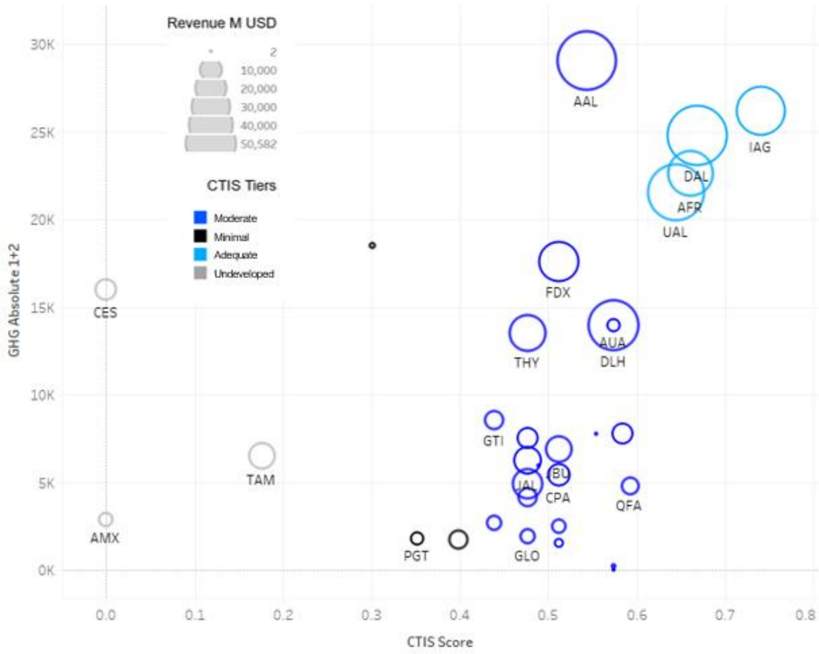
Figure 5. Geographical distribution of airlines with publicly available climate transition plans



Note: Number of airlines per country: Australia (1), Austria (1), Belgium (1), Canada (2), Chile (1), China (5), Finland (1), France (1), Brazil (1), Germany (2), Greece (1), Ireland (1), Italy (1), Japan (2), Kazakhstan (1), South Korea (1), Malaysia (1), Mexico (2), Netherlands (1), New Zealand (1), Panama (1), Qatar (1), Serbia (1), Singapore (1), Spain (3), Switzerland (2), Turkey (2), UAE (2), UK (2), United States (8)

To analyse the scores, we focus first on the relationship between absolute GHG emissions, revenue, and CTIS results of airlines' climate transition plans, as depicted in Figure 6. This examination encompasses two perspectives: one asserts that higher GHG emissions and revenue indicate better climate transition plan scores, while the other raises concerns regarding potential greenwashing practices. The former perspective argues that airlines with greater GHG emissions and revenue possess the necessary resources, technical expertise, and economies of scale to effectively implement climate transition plans. Conversely, larger companies with high GHG intensity may exploit their financial resources to engage in greenwashing practices, which involve conveying misleading information or presenting a false impression of environmental practices to project a more sustainable image than what is achieved. To ensure the credibility of climate transition plan assessments and address concerns related to greenwashing, our approach offers a transparent mechanism that enables the breakdown of overall scores according to key transition levers.

Figure 6. CTIS, GHG emissions, and revenue in millions of USD for selected airlines in 2021



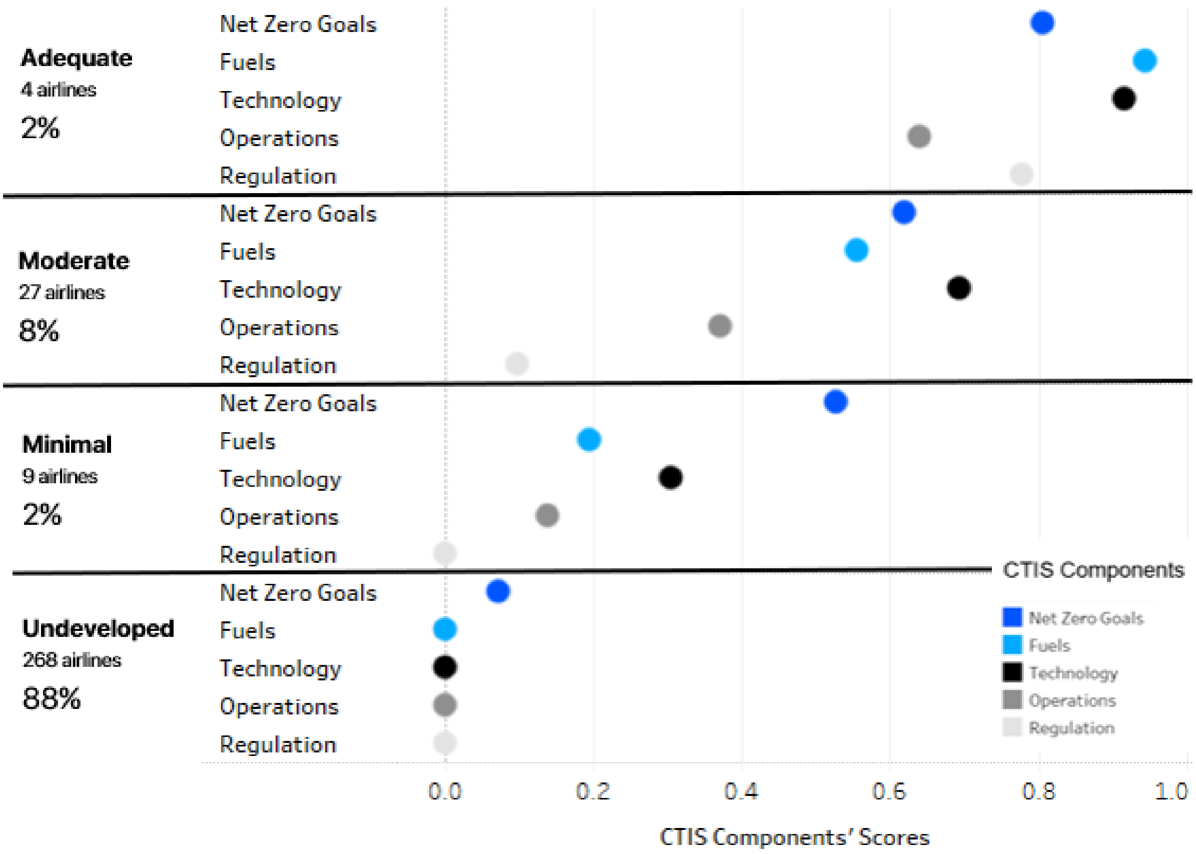
Code	Airline	Score
IAG	IAG	0.74
DAL	Delta Air Lines	0.67
AFR	Air France-KLM	0.66
UAL	United Airlines	0.65
QFA	Qantas	0.59
SIA	Singapore Airlines	0.58
SWR	SWISS	0.57
EDW	Edelweiss Air	0.57
DLH	Lufthansa	0.57
DLA	Air Dolomiti	0.57
AUA	Austrian	0.57
MAS	Malaysia Airlines	0.55
ASA	Alaska Airlines	0.55
ANA	ANA	0.55
ETD	Etihad Airways	0.54
AAL	American Airlines	0.54
JBU	JetBlue	0.51
FIN	Finnair	0.51
FDX	FedEx Express	0.51
CPA	Cathay Pacific	0.51
ANZ	Air New Zealand	0.51
VIR	Virgin Atlantic	0.49
CAL	China Airlines	0.49
THY	Turkish Airlines	0.48
KAL	Korean Air	0.48
JAL	Japan Airlines	0.48
GLO	GOL Linhas Aereas	0.48
EVA	EVA Air	0.48
ACA	Air Canada	0.48
VOI	Volaris	0.44
GTI	Atlas Air	0.44

Sources: Data retrieved from corporate reports, Bloomberg (2023) and FactSet (2023).

When we analyse the scores of each transition lever across the CTIS tiers (Figure 7), we find that adequate transition plans show greater quality in establishing specific SAF uptake strategies, investments, and certifications. Even though few guidelines suggest metrics related to new aircraft technologies, adequate transition plans show financial KPIs and specifics regarding aircraft models and expected emissions reduction. Adequate transition plans also stand out as strategies that demonstrate a leadership position in promoting a regulatory environment that unlocks the potential of all transition levers, particularly SAF production support by the government. For instance, IAG airlines are committed to reaching 10% SAF usage by 2030 and achieving net zero emissions by 2050. Their SAF goals typically include CAPEX-related metrics. Moreover, British Airways, which is part of IAG, has been actively involved in the Jet Zero Council in the UK. This council serves as a collaborative platform, bringing together government officials and high-level executives to facilitate the development and implementation of innovative technologies to reduce emissions in the aviation sector. The focus of this collaboration includes expediting processes related to the design, manufacturing, testing, certification, and infrastructure necessary to adopt these new technologies.

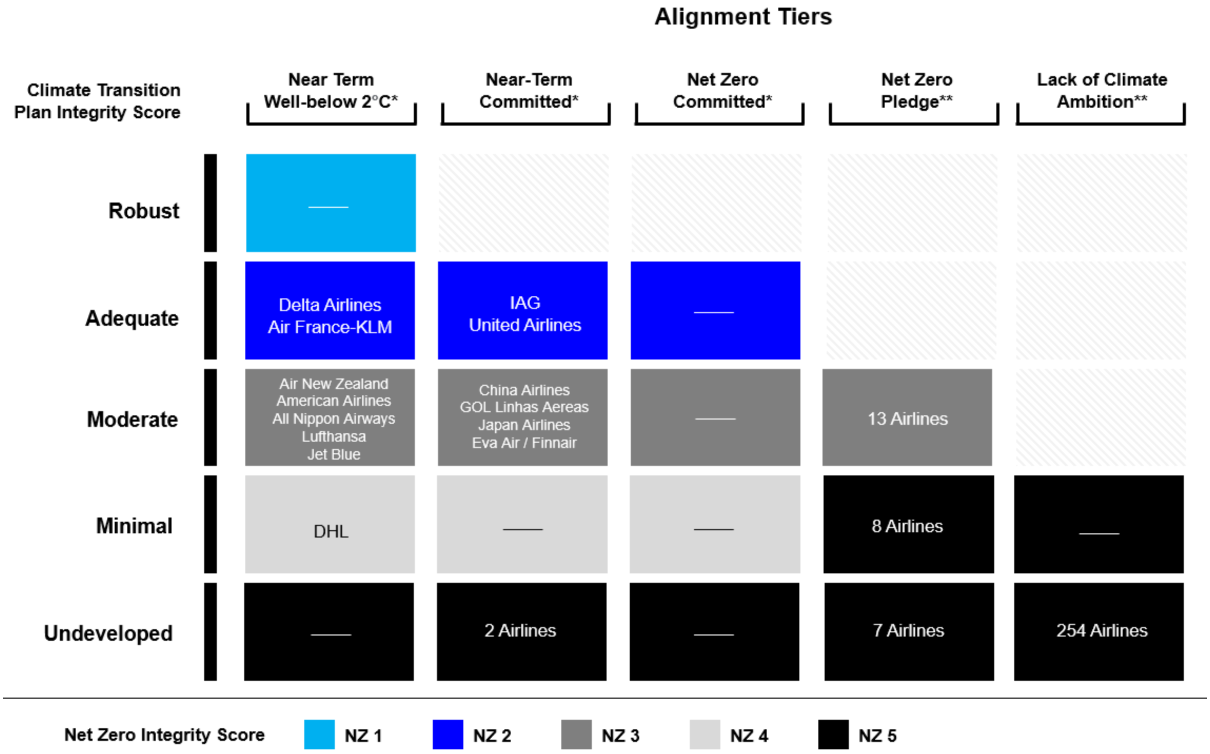
Most airlines assessed fall in the tier of transition plans with moderate credibility and integrity. They represent 9% of the total members of IATA. The lack of engagement and advocacy to promote policy frameworks that encourage a faster sector transition distinguishes them from adequate plans. These airlines typically play a passive role in their initiatives, and their net zero pledges lack detailed implementation strategies across all levers, particularly when determining KPIs. Of the rest of the airlines assessed, 90% do not have a climate transition plan or even a public net zero pledge. To sum up, by breaking down scores for each lever, we can argue that the overall CTIS accurately reflects advanced practices regarding transition plan reporting. The positive relationship between the size of companies and their carbon footprint could be explained by the fact that they are under greater public scrutiny like large oil and gas companies. This scrutiny leads to increased transparency and compliance with more CTIS elements regarding their sustainability transition efforts.

Figure 7. Breakdown of average results for Components of Climate Transition Integrity Scores by tier



To explore further the use cases of the CTIS, a valuable exercise is to compare it with climate alignment tiers such as Moody's framework (2022). We utilize three tiers based on SBTi's verification labels in this context. The first tier is "Committed", indicating organizations' intention to develop and validate targets within 24 months. Failure to submit targets within this timeframe results in the "Commitment removed" label. Near-term targets delineate emission reduction plans for the upcoming 5–10 years, driving actions required for substantial reductions by 2030 and serving as a prerequisite for establishing net zero targets. Long-term targets, essential for achieving net zero, should adhere to SBTi's Corporate Net-Zero Standard criteria by 2050 (or 2040 for the power sector). Temperature alignment on the dashboard reflects how companies align with the global temperature increase targets outlined in the Paris Agreement's goals: 1.5°C, well below 2°C, or 2°C. Additionally, we include two tiers reflecting whether airlines have a publicly available net zero pledge and where there is a total lack of public climate ambition. Figure 8 shows the matrix of how our scoring system relates to different levels of climate alignment. The key findings reflect that our scoring system rates high companies that have any SBTi verification and that most airlines, over 90% of the IATA members do not have an SBTi verification. This exercise reflects a useful combination of transition plans and climate alignment approaches. The assessment of transition plans is often limited to verifying the veracity of disclosed actions and metrics, but combining it with temperature alignment assessment could enhance the robustness checks of the credibility of companies' climate strategies.

Figure 8. Climate Transition Integrity Scores of selected airlines in relation to Climate Alignment Tiers



Note: (*) Science-based Targets Initiative registry and (**) information obtained from publicly available corporate reports.

Although achieving greater accuracy and transparency in ESG ratings or scores is necessary, it is essential to note that the discrepancies between our approach and other similar assessments should not be considered limitations. The divergence in ESG ratings is not necessarily problematic because each rating system focuses on different aspects within the broad range of sustainability performance. By definition, a score will be limited because it represents a unique aggregation exercise and, in terms of transition plans, they have different use cases in contrast with credit rating that have clearer purposes like managing risk or driving alpha. The key factor is ensuring the transparency of methodologies so that those preparing and using transition plans can interpret the results, understand the components, verify the data sources, and recognize the limitations.

5. Implications of credible transition plans for financial institutions

Upgrading monitoring, reporting, and verification: Financial institutions can enhance their monitoring, reporting, and verification (MRV) systems by leveraging high-integrity corporate transition plans in the aviation sector. These plans provide valuable data for informed decision-making and effective risk management. By collaborating with aviation companies and accessing their transition plans, financial institutions can incorporate specific strategies, targets, and timelines for reducing carbon emissions and transitioning to a sustainable business model. Integrating this data into their MRV systems allows financial institutions to better assess environmental risks in aviation investments and make informed decisions. For instance, in 2022, HSBC and Temasek collaborated to launch Pentagreen (2023), a debt financing company focused on decarbonizing aviation portfolios. Through Pentagreen, stakeholders share data to scale up SAF adoption. The initiative also offers technical assistance services, developing methodologies to monitor sustainability performance and analyze key indicators such as carbon emissions, fuel efficiency, and sustainable practices. In another instance, in April 2022, six major lenders in the aviation sector (Bank of America, BNP Paribas, Citi, Crédit Agricole CIB, Société Générale, and Standard Chartered) partnered with RMI's Center for Climate-Aligned Finance (RMI, 2023). Together, they established the Aviation Climate-Aligned Finance Working Group to develop a climate-aligned finance (CAF) framework supporting decarbonization efforts in aviation. The CAF framework enables financial institutions to evaluate emissions associated with aviation loan portfolios, fostering accurate reporting in collaboration with clients. This framework promotes consistency and transparency in reporting, aligning with MRV system enhancement. Based on these cases, financial institutions can take the following actions:

- Establish partnerships with aviation companies to gain access to their high-integrity transition plans and data.
- Develop robust data collection and reporting frameworks to effectively monitor and assess aviation companies' progress towards sustainability goals.
- Use the collected data to create sustainability indices or rating systems specifically for the aviation industry, providing investors with reliable metrics for making informed investment decisions.

Sustainable finance frameworks focused on transition levers: Financial institutions can enhance the credibility of their transition strategies by formulating sustainability financing frameworks (SFFs) customized for the aviation industry. These frameworks should outline essential performance indicators (KPIs) and targets that companies should consider when seeking loans or issuing bonds. By aligning the cost of capital with transition-related goals, sustainability-linked finance incentivizes aviation firms to adopt sustainable practices and enhance their climate performance. Consequently, this fosters stronger lending relationships between financial institutions and issuers, promoting ongoing collaboration and engagement. The ICMA (2023) recently updated their recommendations for climate transition finance, offering a bond issuance framework that incorporates KPIs aligned with climate transition plans. These recommendations specifically address the issuer's climate transition strategy, the environmental impact of their business model, science-based targets, and transparency in implementation. Financial institutions can adapt these principles to establish aviation-specific green loan frameworks, ensuring that funds are directed towards projects and initiatives that facilitate the sector's transition towards a low-carbon future.

Bridging the greenium in low-carbon technologies: In certain sectors, carbon-neutral technologies are expected to become more cost-effective than existing high-carbon technologies. However, there are sectors where a price premium, known as the "green premium" or "greenium", is likely to persist even in the long run. Aviation is one such sector, with SAF projected to remain significantly more expensive than conventional jet fuel for decades (ETC, 2023). The cost differential between SAF and conventional jet fuel poses a major challenge to the advancement of credible transition plans in the aviation industry. Financial institutions can play a crucial role in bridging this gap by providing liquidity and financial support to SAF production companies. By investing in SAF production facilities or providing loans and credit lines to SAF producers, financial institutions can help reduce production costs, scale up SAF production, and enhance economic viability. This, in turn, can contribute to lowering the price of SAF, making it more competitive with conventional jet fuel, and accelerating the industry's transition to sustainable fuels. An example of such efforts is the United Airlines Ventures Sustainable Flight Fund (Singh, 2023), launched by United Airlines and five corporate partners (Air Canada, Boeing, GE Aerospace, JPMorgan Chase, and Honeywell). The fund, starting with $100 million, aims to invest in start-ups and technologies that expand the availability of SAF. It seeks to build a new industry around SAF, a promising solution for reducing aviation's greenhouse gas emissions, despite its current limited supply and high cost. The fund allows its partners to play a significant role in SAF-related start-ups and gain access to environmental attributes associated with United's SAF supply. United Airlines is also engaging the public by offering frequent flyer miles to customers who donate to the fund and providing carbon footprint estimates for flights on its website and app. United estimates that if all passengers from 2022 donated $3.50 to the fund, it could build an SAF refinery producing up to 40 million gallons annually.

Book and Claim system to support SAF production: The "Book and Claim" system is a financial mechanism that allows companies, such as airlines, to invest in the production of sustainable fuels without physically receiving or using these fuels (RSB, 2023b). By purchasing credits or certificates, they financially support the production of these sustainable fuels, demonstrating market demand and encouraging further production. This investment can be claimed as a contribution to reducing greenhouse gas emissions, even if the company does not directly use the sustainable fuel. The system ensures unique credits to prevent double claiming, functioning much like a tradable commodity. For financial institutions, this represents an opportunity to invest in the green energy sector, support decarbonization efforts, meet sustainability targets, and benefit from the growing market for sustainable fuels. Credible transition plans are crucial in supporting the “Book and Claim” system by providing a roadmap for companies to shift to sustainable fuels. These plans establish clear goals and timelines, enabling companies to determine the necessary investments in sustainable fuels through the system. Additionally, well-structured transition plans build stakeholder confidence, including financiers, increasing participation in the system, and boosting demand for sustainable fuels. By effectively managing risks associated with the transition and demonstrating progress through tracked metrics, companies can showcase the impact of their investments in sustainable fuels using the “Book and Claim” system.

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Supplementary Information

Appendix A. Climate Transition Integrity Framework

Questionnaire

Our questionnaire uses binary responses instead of a traffic light system for scoring. Binary options are preferred because they are simple, standardised, and quantifiable. Given the complex nature of the aviation sector's transition, which encompasses global climate pathways and limited guidance for corporations, it is crucial to consider the limitations of a traffic light system. Despite its apparent nuance, a traffic light system may still fall short in capturing the intricate details of the transition, potentially resulting in misleading comparisons between entities. Conversely, binary options also have their limitations in capturing nuanced information. To address this, we provide clear guidance on evaluating each question within the binary framework, ensuring granularity. By including specific instructions or criteria, the questionnaire allows for a more detailed framework for assessment, enabling researchers to consider a broader range of factors or levels within the binary options. Table A.1 presents the questionnaire and guidance, while subsection C.3 provides the calculation method for the scoring system.

Table A.1. Climate Transition Integrity Framework Questionnaire

	Code	Question	General Guidance	References
Net Zero Goals	**A1**	Does the company publicly disclose its short-, medium, and long-term GHG emissions targets?	Check if the company publicly discloses its short-, medium-, and long-term greenhouse gas (GHG) emissions targets, including Scope 1, 2, and potentially Scope 3 emissions. Evaluate the transparency of their reporting by considering the context, methodology, and any exclusions from the targets. Utilize industry frameworks such as IATA RP 1678 for emissions allocation and consider reporting in consistent units like kgCO2e/tonne.km or kgCO2e/passenger.km. Additionally, look for the inclusion of interim targets within a 3–5-year range and assess whether emissions sources are differentiated based on fleet usage.	CA 100+, ACT, TPT, GFANZ, TPI, CBI, US, CDP, ISO, ATAG, SBTI
	A4	Has the climate transition plan of the company been reviewed by a third-party verifier?	Verify if the climate transition plan of the airline has undergone an independent third-party review and if the findings and scope of the assessment have been disclosed. Explore the SBTi registry to identify any targets that have been verified and are aligned with a science-based scenario, specifically targeting a 1.5-degree Celsius pathway. This verification adds credibility to the plan and demonstrates the company's commitment to transparency and accountability.	CBI, GFANZ, ACT, CDP, TPT, ISO, SBTI

	A5	Does the company state how its objectives and actions align with any science-based climate scenario?	Evaluate whether the company explicitly states how its objectives and actions align with science-based climate scenarios. Look for a clear rationale behind the chosen scenario and assess how the company's goals and measures contribute to that scenario. If possible, seek information on the percentage contribution of each lever to the overall emissions reduction targets. Consider referencing climate pathways such as IEA NZ, MPP, OGCI, ICAO, and nationally determined contributions, which provide different strategies for achieving net-zero emissions.	SBTI, CA100+, GFANZ, ACT, TPI, US, CDP, ISO, ATAG, CBI
Sustainable Aviation Fuel	**B1**	Does the company publicly report on its SAF uptake approach?	Assess whether the company publicly discloses its Sustainable Aviation Fuel (SAF) initiatives, goals, and progress. Look for transparent reporting on the adoption and scaling-up of SAF, including metrics such as total neat and blended SAF delivered, lifecycle emissions factors per SAF type, and CO2 emissions reductions achieved. Consider ICAO standards and IATA recommendations for reporting, considering differentiating factors like domestic vs international flights.	SBTI, IATA, ACT, US, ATAG
	B2	Does the entity disclose the certification of the purchased SAF?	Verify if the company discloses the certification of the SAF it purchases. This demonstrates a commitment to ensuring that the SAF meets recognized sustainability standards and contributes to emissions reductions.	——
	B3	Is the company transparent about its engagement strategy with SAF suppliers?	Evaluate if the company publicly discloses its engagement strategy with SAF suppliers. Look for information on the criteria used to select and engage with suppliers, as well as the approach to assessing and managing environmental and social risks within the SAF supply chain. Disclose any initiatives involving policymakers and regulators to promote feedstock sustainability, expand SAF supply, and stimulate demand. Examples of such initiatives can include signing offtake agreements, research, and development co-funding, offering SAF support options, investing in production facilities, and integrating biofuels into fuel tendering.	GFANZ, ACT, US, ATAG, IATA, IEA
	B4	Has the company allocated financial resources to promote SAF adoption or development?	Determine if the company has allocated financial resources for SAF development or adoption. Look for information on investments made in SAF production facilities or research projects. Disclose the expected outcomes of these investments and clarify how they align with the company's chosen climate scenario and overall strategy.	GFANZ, ACT, US, ATAG
Aircraft Low-carbon Technology	**C1**	Does the company disclose investments in fuel-efficient and low-emission aircraft technologies?	Evaluate disclosed investments in fuel-efficient and low-emission aircraft technologies, including progress in implementation, impact on emissions reductions or fuel savings, replacement of carbon-intensive assets, and percentage of fleet targeted for upgrades or replacement. Consider the maturity levels of pursued technologies and distinguish between airframe and propulsion advancements.	SBTI, IATA, GFANZ, TPI, EU, ISO, ATAG, CBI
	C2	Is the information about the company's aircraft technology investments independently verified?	Verify if a third-party auditor or verification agency has independently verified the information about the company's aircraft technology investments. This independent verification adds credibility to the disclosed investments and assures that the reported progress and impact are reliable.	——
	C3	Does the company disclose an engagement strategy with aircraft manufacturers or R&D initiatives for new technologies?	Assess whether the company discloses its engagement strategy with aircraft manufacturers and its involvement in research and development (R&D) initiatives focused on advancing low-emission technologies. Look for partnerships or collaborations to develop electric or hydrogen-powered aircraft or other innovative solutions. Additionally, evaluate the company's approach to exchanging relevant market data and insights with suppliers to foster the advancement of low-emission technologies across the industry.	IATA, GFANZ, ACT, US, ISO, ATAG

	C4	Has the company allocated financial resources for advanced aircraft technology investments?	Companies should provide specific examples of investments in fuel-efficient and low-emission aircraft technologies, such as fleet renewal programs. Some indicators might include the percentage of R&D as a total of R&D.	GFANZ, ACT, US, EU, ISO, ATAG, SBTI
Operations improvements	**D1**	Does the company disclose operational improvements and their impact on emissions reduction?	Evaluate disclosed operational improvements and their quantifiable impact on emissions reduction. Look for specific examples of improvements, such as payload optimization, route optimization, and flight path optimization. Assess the methodology used to measure emissions reduction resulting from these actions and consider additional strategies like demand management and implementation of lightweight materials.	SBTI, GFANZ, ACT, US, EU, ATAG
	D2	Has the company sought third-party verification or assurance for the reported impact of its operational improvements?	Verify if the reported impact of the company's operational improvements on emissions reduction has been independently verified or assured. Look for disclosure of the third-party verifier's name and a summary of the verification process.	SBTI
	D3	Has the company engaged with stakeholders to develop operational improvements for climate transition?	Assess the company's stakeholder engagement related to operational improvements for climate transition. Look for evidence of collaboration with industry partners and examples of improvements achieved through these engagements. Consider initiatives to improve transportation modes and infrastructure, including partnerships with airports.	SBTI, GFANZ, ACT, US, EU, ATAG
	D4	Has the company invested in technology or infrastructure to support emissions reduction through operational improvements?	Evaluate whether the company has made investments in technology or infrastructure to support emissions reduction through operational improvements. Look for information on critical investments, including financial indicators, and highlight the achieved outcomes or benefits, such as emissions reduction or fuel savings.	SBTI, GFANZ, ACT, EU, ISO, ATAG
Regulatory environment	**E1**	Does the company disclose engagement with regulators and policy initiatives?	Evaluate the company's disclosure of its engagement initiatives with regulators and policymakers. Look for transparency in reporting on policy positions, outcomes of interactions, official submissions, public statements, and lobbying activities. Specify the jurisdictions involved in these engagements.	SBTI, CA100+, GFANZ, ACT, US, EU, ISO, ATAG
	E2	Has the company received external validation or recognition for its engagement efforts with regulators and policymakers?	Assess whether the company has received external validation or recognition for its engagement with regulators and policymakers. Look for disclosure of validating organizations, certificates or awards received, and details about validation criteria and processes.	CBI
	E3	Has the company actively co-developed, advocated for, or supported policies with regulators and policymakers to demonstrate its	Evaluate the company's commitment to driving change by actively co-developing, advocating for, or supporting policies with regulators and policymakers. Look for evidence of collaborative efforts, such as participation in multi-stakeholder initiatives, joint research projects, and sharing of best practices. These actions demonstrate the	SBTI, CA100+, GFANZ, ACT, US, EU, ATAG

		commitment to driving change?	company's dedication to advancing climate transition goals beyond its own operations.	

Sources: Authors' analysis using information from ATAG, 2021; FAA, 2021; GFANZ, 2023; IATA, 2022a, 2022b, 2023, 2023; IFRS, 2018; ISO, 2022; Moody's, 2021, 2022; NLR & SEO, 2021, 2021; SBTi, 2021; TCFD, 2021; TPI, 2021a, 2021b; UK DfT, 2022; UK TPT, 2022.

C.3 Climate Transition Integrity Score (CTIS) calculation

Our Climate Transition Integrity Framework evaluates corporate net zero goal and four levers against five criteria following Figure 3 and using binary responses from the questionnaire detailed in Table A.1. To calculate the score, we define a binary evaluation matrix $E \in \mathbb{R}^{nxm}$, where $E_{i,j} = 1$ if lever i is assessed by criterion j, otherwise $E_{i,j} = 0$:

$$E_{i,j} = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Next, we define a weight matrix $W \in \mathbb{R}^{nxm}$ as a diagonal matrix to adjust the weights so that each row (lever) has a maximum value of 1:

$$W_{i,j} = \begin{cases} \dfrac{1}{\sum_{k=1}^{m} E_{i,k}} & if\ i = j \\ 0 & otherwise \end{cases}$$

$$W_{i,j} = diag\left(\frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{4}. \frac{1}{4}\right)$$

We then compute the weighted scores matrix $S \in \mathbb{R}^{nxm}$ by performing element-wise multiplication (Hadamard product) of the binary evaluation matrix E and the weight matrix $W_{i,j}$:

$$S_{i,j} = E_{i,j}\, W_{i,j} = \begin{bmatrix} 1/4 & 1/4 & 0 & 1/4 & 1/4 \\ 0 & 1/4 & 1/4 & 1/4 & 1/4 \\ 0 & 1/4 & 1/4 & 1/4 & 1/4 \\ 0 & 1/4 & 1/4 & 1/4 & 1/4 \\ 0 & 1/4 & 1/4 & 1/4 & 1/4 \end{bmatrix}$$

To compute the scores for each lever, we sum the elements in each row of the weighted scores matrix $S_{i,j}$. This results in a score vector $v \in \mathbb{R}^{n}$:

$$v_i = \sum_{j=1}^{m} S_{i,j}$$

For the overall score, we sum the scores in the score vector. The maximum overall score is 6.

$$overall\ score = \sum_{i=1}^{n} v_i$$

We can apply a log transformation to the overall score, resulting in the **Climate Transition Integrity Score (CTIS)**. The rationale for applying a log transformation to the overall score is mainly to address the issues of non-linearity and to stabilize the variance in the scores.

$$CTIS = \log\left(overall\ score + 1\right)$$

The rationale for adding 1 inside the logarithm is to handle cases when the sum of the score vector is 0. Logarithm of 0 is undefined; therefore, by adding 1, we ensure that we can always calculate the log-transformed score.

Our proposed framework for assessing lever scores based on qualitative thresholds provides a more objective approach than traditional multi-criteria decision analysis (MCDA) methods. MCDA typically involves identifying and weighing different criteria, which are combined to obtain an overall score. The subjective nature of the weighting process can lead to bias and inconsistency in the decision-making process, as the weights assigned to each criterion may vary depending on the preferences and values of expert groups. Additionally, our approach does not rely on the use of min-max normalization methods since they can introduce several pitfalls, such as being sensitive to outliers, requiring domain knowledge to determine the range of values, and producing inconsistent results when the input data changes.