THE SHIFT PROJECT

THE CARBON TRANSITION THINK TANK

FLYING IN 2050

What kind of aviation in a constrained world?

FINAL REPORT - MARCH 2021

SUPAERO DECARBO

THE SHIFT PROJECT

With the participation of:

CITOYENS POUR LE CLIMAT

THE SHIFTERS

Foreword

Aviation clearly stands out from other industries when it comes to energy transition. Either considered a cutting-edge industry with minimal climate impact for its advocates, or a whim of the ultra-wealthy prone to minimize their emissions for its detractors, aviation generates polarized opinions and sometimes pointless debates.

The authors of this report support the idea that there is another voice to be heard beyond these extreme positions.

In May 2020, a first report named "Crisis, climate: preparing aviation's future" outlined a series of carbon-reduction measures that the French government could demand in return for its support to the industry. The report supported the idea that recovering our pandemic-hit industry was not incompatible with launching an effective decarbonisation policy, and specifically proposed immediately actionable measures with potentials for significant impact at the 2025 horizon.

It indeed argued that delaying the aviation's energy transition would make the sector all the more vulnerable to the threat of climate change.

Contrasting events mark the nice months' period since the publication of the report. Airbus has committed to produce a hydrogen-powered aircraft in 2035 and public statements on aviation's decarbonisation have multiplied. Yet the health crisis has continued, impacting the financial health of many actors and causing an unprecedented risk of bankruptcy. At the same time, the report and its methodology have also appealed to a growing number of engineers, pilots, air traffic controllers, airline employees and aviation users. Many of them have engaged with the report, have highlighted its shortcomings and limitations, and have called for a deeper analysis.

These industry professionals are the main contributors to this new report. All have been willing to address the anxiety-inducing, yet inevitable question of which actions to take today in a finite world, in order to keep on flying tomorrow.

Without disregarding the suffering and helplessness created by the COVID-19 crisis, climate change, the depletion of fossil fuels and the collapse of biodiversity unfortunately represent much worse threats for human life in general, and for aviation in particular.

All of us share a passion for aviation, the majority of us even being industry professionals. We all also share a passion for technical matters and breakthroughs, for this prodigious human intelligence dedicated to flying machines. Yet all of us share an even greater passion and love for life, for nature and for science – the science that rigorously describes aerodynamics and climate phenomena, the same science which has offered us benefits but now also predicts unprecedented upheaval which cannot be ignored.

We, the aeronautical engineers, pilots, air traffic controllers, airline employees, travelers or simply aviation lovers, tired of polarized speeches, sign on this report with the ambition of creating the conditions for an informed debate on the aviation's ability to drastically reduce its greenhouse gas emissions, in proportions compatible with a viable world in 2100. We, the climate-conscious aero-lovers, claim that we can be part of the solution, not the problem, by carrying a transparent, unbiased and science-based analysis on what the aviation industry can – and cannot – do to decarbonise itself.

The editorial board.

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1. Introduction

The global health and economic crisis is unprecedented in many aspects. After a sudden and violent start, it is now set to last. It is taking a heavy toll on our globalized societies and highlights their vulnerabilities. The French society is no exception. The aeronautics sector in particular, a French industry flagship and vector of its international influence, undergoes, like air transport, one of the worst crises in its history. As one of the most directly exposed to the consequences of the Covid-19 pandemic, it was one of the first sectors to benefit from government assistance and be subject to a recovery plan presented on June 9, 2020 by the French government.

But this crisis must not let us forget that other threats are looming. The consequences of climate change, tensions over energy or essential resources supply and the alteration of biodiversity are all upheavals that will affect the French and international socio-economic system even further. The large-scale transformations that need to be undertaken to overcome these difficulties (carbon-free economy, adaptation to shocks) represent a historical challenge that concerns all, public and private, actors.

We are presented with the opportunity to steer the recovery of the aeronautics sector and the use of public funding towards trajectories compatible with climate issues and less dependent on fossil fuel supplies.

In May 2020, the Shift Project published a first report on air transport titled Crisis, climate: preparing aviation's future. **This study revises the measures identified in the previous version, broadens the scope and horizon of the proposals and integrates the remarks and the objections formulated since then, in particular by the professionals in the sector.** We offer here a factual and quantitative study, on a scenario-based analysis, of the aviation emissions trajectories by 2050. We adopted a holistic approach encompassing technological and energy hypotheses, the prerequisites for their achievement, as well as the impacts on uses and jobs. The use of resources (other than electricity and fuels) and its financing are well-identified (often decisive) dimensions but not quantified in the scenarios.

Air transport, international by nature, requires a consensus of all States (at least in Europe at first) in order to implement its decarbonization. **How would efforts made in a region of the globe indeed benefit if the emissions were not regulated in other regions?** In the event of non-alignment with the objectives and regulations, the highly competitive nature of air transport would inevitably penalize the first players to embark on a low-carbon strategy. In this respect, the report examines current elements of international governance, in this case the CORSIA[1] program of the ICAO (International Civil Aviation Organization) and the European carbon market EU-ETS (European Union Emissions Trading System), highlights their strengths and limitations and recommends adjustments.

Footnote 1: Carbon Offsetting and Reduction Scheme for International Aviation, cf. 4.6.2

While necessary, the implementation of an international agreement to decarbonize the aviation sector will take time. In the meantime, the French State, which has taken a particular interest in the sector through its aeronautics support plan presented on June 9, 2020, can intervene effectively at the national level without waiting for a wider consensus to be reached. In a context of climate emergency, where the time runs against us, this report thus defends the need to act jointly at the national and international levels.

Our analysis is structured as follows:

1. **First, we propose possible pathways for reducing the climate impacts of air transport** compatible with the objectives of the Paris Agreement, namely to "limit global warming to well below 2° C, compared to pre-industrial era." For this, we defend the imperative to agree on a carbon budget for air transport, which we calculate for 2050 on the basis of those defined by the IPCC.

2. **Secondly, we identify and quantify energy efficiency and decarbonization measures in the short, medium and long term** as well as their underlying prerequisites (technological, energetical, organizational), in order to minimize the impacts on air traffic and to preserve its role at the global level and its strategic importance for France, especially at the industrial level.

3. **In the event that these measures prove to be insufficient to achieve the goal of decarbonization, we list a set of additional sobriety measures** allowing to stay in a "2°C" trajectory, accompanied by a reflection on the modalities of their implementation as well as the uses and role of aviation by 2050.

4. **Finally, we study the consequences of these measures on employment in France** in air transport (airlines and airports) and the aeronautics industry. We discuss avenues for diversification and reconversion of professionals and production sites, inserting them in the proposal for a new industrial narrative.

2. Acronyms, abbreviations, and jargon

ACU, Air Conditioning Unit: Mobile air conditioning unit, it is the main alternative to the APU for air conditioning the cabin on the ground and generally uses a diesel engine on a mobile chassis. The ACU emits CO2 but in proportions much lower than the APU (ratio of 1 to 10).

ADEME: French agency for the environment and energy management

ADP, Aéroports de Paris: French company that builds, outfits and operates airports in Paris and its region, including Paris-Orly, Paris-Charles-de-Gaulle and Paris-Le Bourget.

AF, Air France: French airline.

AFOLU, Agriculture, Forestry and Other Land Use[2]: Sector responsible for around 25% of anthropogenic greenhouse gas emissions (mostly CO2, CH4 and N2O).

APU, Auxiliary Power Unit: Auxiliary engine intended to produce energy on board (excluding propulsion) when the main engines are off or in the event of a failure in flight (electricity on board, air conditioning, hydraulic pressure, etc.).

ART, Transport Regulatory Authority: French Independent Public Authority for the economic regulation of rail, motorway and air transport.

ATAG, Air Transport Action Group: Independent coalition of organizations and companies in the international air transport industry.

CESE, Economic, Social and Environmental Council: Potential organization to create and promote an official public portal for the long-distance transport sector in order to inform and raise awareness among stakeholders about the issues.

CI, Cost Index: Coefficient representing the ratio between the cost of time (duration) and the cost of fuel.

CITEPA, Centre Inter-professionnel Technique d'Études de la Pollution Atmosphérique: Inter-professional Technical Center for Atmospheric Pollution Studies.

CORSIA, Carbon Offsetting and Reduction Scheme for International Aviation: Adopted in 2016 by the ICAO, this "Carbon Offsetting and Reduction Scheme for International Aviation" forces airlines to offset CO2 emissions greater than those emitted in 2019.

SPC, Socio-Professional Category: The majority of flights are taken by a very high SPC, representing a minority of the population.

DGAC, Directorate General of Civil Aviation: French Administration responsible for air transport safety, air traffic management, market regulation, monitoring and certification of all players in civil aviation .

DGEC, Directorate General for Energy and Climate: French Administration responsible for defining France's energy

CDG, Paris Charles de Gaulle Airport (in Roissy): Airport operated by ADP, number one airport in France and number two in Europe for its passenger traffic.

EASA, European Union Aviation Safety Agency: The European Aviation Safety Agency is an agency of the European Union that deals with aviation safety.

EEA, European Economic Area: Zone considered in the carbon offset and reduction mechanisms.

ETS, Emissions Trading System: Carbon dioxide emission rights mechanism implemented within the European Union.

EUA, Emission Unit Allowance: Credits from the EU-ETS system.

FAA, Federal Aviation Administration: Equivalent to EASA in the United States.

FAO, Food and Agriculture Organisation: United Nations agency with the goal of eliminating hunger in the world, providing essential information on ethanol production, used for alternative fuels.

GHGs, Greenhouse gases: Gaseous components that contribute to the greenhouse effect, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

EIG, Economic Interest Group.

IPCC, Intergovernmental Panel on Climate Change: A group of experts providing detailed assessments of the state of scientific, technical and socio-economic knowledge on climate change, its causes, potential impacts and possible response options. They are available in multivolume assessment reports.

policy as well as the supply of mineral raw materials.

HLFC, Hybrid Laminar Flow Control: Low maturity concept to improve the flow of air and reduce drag.

IAG, International Airlines Group: One of the largest groups of airlines. They are committed to reducing their carbon footprint and achieving net zero CO_2 emissions target for 2050.

IATA, International Air Transport Association: International organization of air transport companies, makes information available such as demand for air transport and the impacts of the COVID crisis.

ICAO, International Civil Aviation Organization: UN International organization. Its role is to participate in the development of policies and norms that allow the standardization of international aviation transport (flights within the same country are not affected by ICAO).

LFC, Laminar Flow Control: Low maturity concept to improve the flow of air and reduce drag.

LRC, Long Range Cruise: Traditional speed for the cruise phase of flight.

LTO, Landing & Take-Off: Groups together the flight phases of take-off, start of climb to 3000ft (915m), approach and landing.

MRO, Maintenance, Repair and Overhaul: Actors in the aviation sector specializing in aircraft maintenance in operational conditions.

MRV, Monitoring, Reporting, Verification: Monitoring, reporting and verification process for carbon accounting.

GIFAS, French Aeronautical and Space Industries Group.

NAT, North Atlantic Tracks: Major Airways, where planes are forced to fly at similar speeds, imposed by air traffic control to ensure their separation distances throughout the journey.

NLF, Natural Laminar Flow: technology currently in use for aircraft wings design.

NEO, New Engine Option: Airbus aircraft family with technological improvements over previous models, including new generation engines

OECD, Organization for Economic Co-operation and Development: International Organization for economic studies, it provides, among other things, essential information on ethanol production, used for alternative fuels.

ORY, Paris Orly Airport: Airport operated by ADP.

PTL, Power-to-liquids: Type of alternative fuel, consists of the production of liquid hydrocarbons made from electrical energy, H2 and CO2.

R&D, Research and Development.

RPK, Revenue Passenger Kilometer: Metric that describes the number of kilometers travelled per revenue passenger.

RTK, Revenue Ton Kilometers: Metric that describes the number of kilometers travelled per revenue ton (used in particular for freight).

SAF, Sustainable Aviation Fuels: Certified drop-in alternative fuel whose social, environmental and economic considerations ensure an advantage over kerosene.

SES, Single European Sky: European project whose main objective is to overcome border restrictions between countries in order to optimize traffic flows.

SETI, Single Engine Taxi-In: The use of a single engine for the taxi-in phase after landing. Already used by airlines around 50% according to experts.

SETO, Single Engine Taxi-Out: Similar to SETI but for the phase before take-off (taxi-out).

SNBC, National Low Carbon Strategy in France.

SNICAC, National Union of Civil Aviation Engineers and Executives.

SR15, IPCC 1.5 ° C Special Report: 15th IPCC Special Report on Global Warming of 1.5°C[3].

SRIA, Strategic Research and Innovation Agenda.

STAR, Aircraft Traction System during taxi.

TLS, Toulouse-Blagnac Airport.

WTO, World Trade Organization: International organization that regulates international trade between countries.

Footnote 2: https://www.ipcc.ch/report/ar5/wg3/agriculture-forestry-and-other-land-use-afolu/

Footnote 3: https://www.ipcc.ch/sr15/

3. Presentation of the groups of contributors

A. The Shift Project think tank

The Shift Project is a think tank working for a post-carbon economy. A non-profit public interest organization, guided by the requirements of scientific rigor, its mission is to inform and influence the debate on energy and climate transition in Europe. Enlighten: we set up **working groups** around the most delicate and decisive issues of the transition to a post-carbon economy; we produce robust and quantified **analyses** on the key aspects of the transition; we develop innovative **proposals**, with the aim of providing answers at the right scale. Influence: we conduct **lobbying** campaigns to promote the recommendations of our working groups to political and economic decision-makers; we organize events that foster discussions between stakeholders; we build **partnerships** with professional organizations, academia, and international actors.

The Shift was founded in 2010 by several personalities from the business world with experience in associations and the public - including its current president Jean-Marc Jancovici (also a member of the High Council for the Climate and partner of the firm Carbone 4). The Shift is supported in 2020 by several **large French and European companies**, as well as some public bodies and business associations.

The Shift was created in order to mobilize companies and public authorities on the risks, but especially on the long-term opportunities generated by **energy supply and climate change** in a French tradition of constrained optimization, where it is essential to properly prioritize the potential effectiveness of the various ways of tackling the issue. The Shift Project is primarily aimed at decision-makers and intermediary bodies.

Since its creation, The Shift Project has initiated **more than 20 study projects**, participated in the emergence of 2 international events (Business and Climate Summit, World Efficiency), and organized more than 60 seminars, forums, workshops and conferences. It was able to significantly influence several important political decisions for the energy transition, in France and within the European Union.

The Shift's approach is marked by a particular **prism of analysis**, based on the conviction that energy is a key factor in development: therefore, the risks induced by climate change, closely linked to the use of energy, arise from a particular systemic and transdisciplinary complexity. Climate and energy issues condition the future of humanity, and it is necessary to integrate this dimension as quickly as possible into our model of society.

B. The SUPAERO-DECARBO collective

SUPAERO-DECARBO is a collective of more than 100 former and current students of the ISAE-SUPAERO school, more than half of whom work in the aeronautical industry or air transport. Passionate about aviation and intimately concerned by the issue of climate change and its consequences for life on earth, they are keen to introduce a scientifically supported discourse on the true contribution of the aviation sector to climate change, allowing us to consider aviation's future on a sound basis in a low-carbon world.

Views expressed by SUPAERO-DECARBO are independent from those of the ISAE-SUPAERO school, the collective's work and positions do not commit the latter in any way.

C. The non-profit organization The Shifters

The Shifters is a network of volunteers supporting the Shift Project. With a wide variety of profiles, experiences and skills, they are united by their interest in the carbon transition of the economy and are dedicated to three types of missions:

1. Support The Shift Project in its work, by making their workforce and / or skills available to the Shift's team from time to time.

2. Learn, discuss and train on the decarbonization of the economy (in its scientific as well as technical and political aspects, in the broad sense, and in terms of issues, actors, solutions and current affairs).

3. Disseminate the ideas and work of The Shift in their own networks and develop new networks in the decarbonization of the economy. To do this, they rely on the five fundamental values of scientific and technical standards, openness, impartiality, professionalism and friendliness.

D. Citoyens Pour le Climat (CPLC)

Citoyens Pour Le Climat[4] is a collective born in the fall of 2018 during the first climate marches, which followed Nicolas Hulot's resignation from his government post. **It is a non-partisan, non-violent collective whose vocation is to popularize climate issues and inform the general public on the basis of established scientific facts.** The collective is sponsored by Valérie Masson-Delmotte, co-chair of Working Group 1 of the IPCC and member of the High Council for the Climate.

Footnote 4: https://citoyenspourleclimat.org/

4. Energy and climate issues: what are we talking about?

4.1 Global warming: where does it come from?

Before we get to the heart of the matter, a few essential concepts should be explained to understand how human activities in general, and air transport in particular, contribute to global warming.

Our planet absorbs energy from the sun which warms it up. Just like any other object, the warmer our planet is, the more energy is in turn radiated back into space, which cools the planet down. A balance is then struck between the power absorbed (i.e. energy per second) and the power emitted. When warmer, the power emitted is greater than the power absorbed, which cools the temperature down; when colder, the power absorbed is greater than the power emitted, which warms it up. In either case, a balance is eventually reached.

Before 1750 and the beginning of the industrial revolution[5], our planet was at its equilibrium temperature. The balance between absorbed and emitted energy had been at an average of 235 $W.m^{-2}$[6].

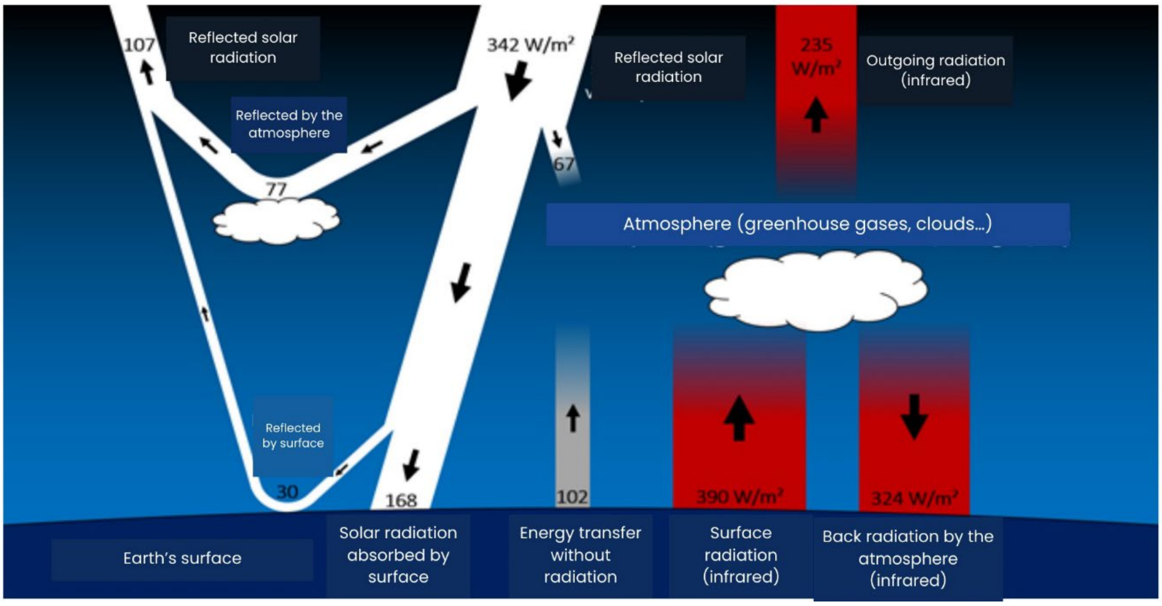

Figure 1 - Simplified illustration of the Earth's annual and global mean energy balance in pre-industrial times, from Working Group I to the Fourth Assessment Report of the IPCC, FAQ 1.1, Figure 1, p.96 (https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf)

But since 1750, humans have increased CO2 concentration in the atmosphere by a factor of almost 1.5, while adding other greenhouse gases. These gases, known as GHG (greenhouse gases), absorb part of the infrared radiation emitted by the Earth and thereby reduce the amount of energy released into space. Consequently, the earth is reaching a higher temperature, which will result in a new balance between the energy absorbed and the energy emitted. In other words, as long as we emit GHG, we raise the Earth's equilibrium temperature, with the risk of amplifying the phenomenon through complex feedback loops (albedo decrease, permafrost melting, etc.). Stabilising the warming process will therefore require net zero emissions, which can be achieved by intentionally cutting all our greenhouse gas emissions or, more realistically, by dividing our emissions by 10 and increasing the capacity of terrestrial carbon sinks to absorb the remaining emissions, through reforestation for example[7]. The final deviation from the current temperature will be determined by the amount of GHG emitted before reaching net carbon neutrality.

Footnote 5: Wikipedia : article on The Industrial Revolution, The First Industrial Revolution

Footnote 6: Based on FAQ1.1 in IPCC, 2007, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Footnote 7: P1 scenario, page 14 and explanations in the following pages, in IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

To quantify the disruption of the Earth's energy balance compared to the pre-industrial equilibrium (1750), scientists have historically developed the notion of radiative forcing (RF) and then that of effective radiative forcing (ERF). For detailed explanation of these terms, please refer to the 5th IPCC report (2013) previously cited, but in simpler terms, the ERF is more relevant because, unlike the RF, which only takes stratospheric adjustments into account[8], it also accounts for what we call 'rapid climate adjustments' (tropospheric adjustments[9] and adjustments linked to land use[10]): the RF leads to rapid adjustments, which in turn alter the RF to produce the ERF, as in a feed-back loop. The ERF is useful because it estimates the magnitude AND the rate of global warming: greater effective radiative forcing leads to larger AND faster warming.

The effective anthropogenic radiative forcing estimate for 2011 was 2.29 [1.13 - 3.33] $W.m^{-2}$ [11], which means that if we were to take the equilibrium of the Earth in 1750 and instantly apply the 2011 atmospheric composition and land use, the additional heat flux measured at the Earth's surface would be 2.29 $W.m^{-2}$ [12].

CO_2 is by far the largest contributor to anthropogenic effective radiative forcing. In 2011, CO_2 emissions alone contributed to 73% (1.68 [1.33 to 2.03] $W.m^{-2}$) of human-induced effective radiative forcing. This is why the emissions of other greenhouse gases are reported as "CO2 equivalents".

Footnote 8: The stratosphere is the layer of the atmosphere whose height varies from at least 6 km at the poles to at least 16 km near the equator.

Footnote 9: Tropospheric adjustments, i.e., those occurring in the troposphere (lower layer of the atmosphere, up to 6 km at the poles and 16 km at the equator), include changes in the strength of convection, precipitation efficiency, cloud fraction, lifetime or water content of clouds, and the formation or suppression of clouds in remote areas due to altered circulation. In the case of aviation, adding aerosols to the atmosphere increases the number of clouds directly and instantly as seen with aircraft condensation trails.

Footnote 10: Land use changes, which alter the overall color of the land and therefore the proportions of absorbed and reflected energy.

Footnote 11: Figure SPM.5. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Footnote 12: This figure does not include slow variations, such as warming that spans over several decades and restores the energy balance back to 0 W/m^2 at the new equilibrium temperature, nor does it include indirect variations, such as feedbacks (e.g. the melting of the highly reflective ice sheet, which is replaced by a dark ocean, which increases the energy absorbed).

4.2 An uncertain future, risks with high potential impact[13]

Global warming, which is caused by anthropic GHG emissions, means risks and disruptions of unprecedented scale for life on Earth as a whole, and for human societies in particular. These risks, as described and assessed by the IPCC[14], not only threaten the human habitability of land areas, access to essential resources (water and food), peace but are also likely to cause substantial disruptions to societal structures and economic systems[15].

In order to best address these risks, an international consensus emerged in 2015 with the Paris Agreement on the need to commit to reducing GHG emissions at country level. Cutting GHG emissions and adapting to the impacts of climate change is the cornerstone of a comprehensive project for transformations related to the energy and climate issues of mitigation and adaptation.

Similarly, these transformations are characterized by their magnitude and uncertainty. Without guidance and anticipation, these developments will be endured, to some extent, and could occur in a chaotic way through major technological, political, diplomatic, economic, and social disruptions. These are a threat to the stability of the global socio-economic system.

Footnote 13: This excerpt is largely derived from a previous Shift Project report published with the French Association of Large Companies (Afep): "Energy-Climate Scenarios: Assessment and Instructions for Use" [« Scénarios énergie-climat : Évaluation et Mode d'emploi »](2019) pp. 17-20. It has been updated and expanded.

Footnote 14: IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

Footnote 15: In practical terms, this means, at the global level, an increase in droughts, the frequency, intensity and duration of heat waves, the frequency of cyclonic events, sea level rise (and therefore a decrease in habitable land areas), a fall in agricultural yields, which in turn leads to the risk of famine, massive population flows towards better preserved areas and conflicts over access to resources. International tensions will be further exacerbated by the uneven distribution of these risks over the Earth's surface.

4.2.1 Energy is the main factor of climate issues

The challenges posed by climate change and its impact on society have never been more acute. There is now a general consensus on the source of this disruption - the growing emissions of GHG and their increasing concentration in the atmosphere are fueling global warming at an alarming rate. It is not so much the levels that are reached, but the speed at which this is happening that causes concern.

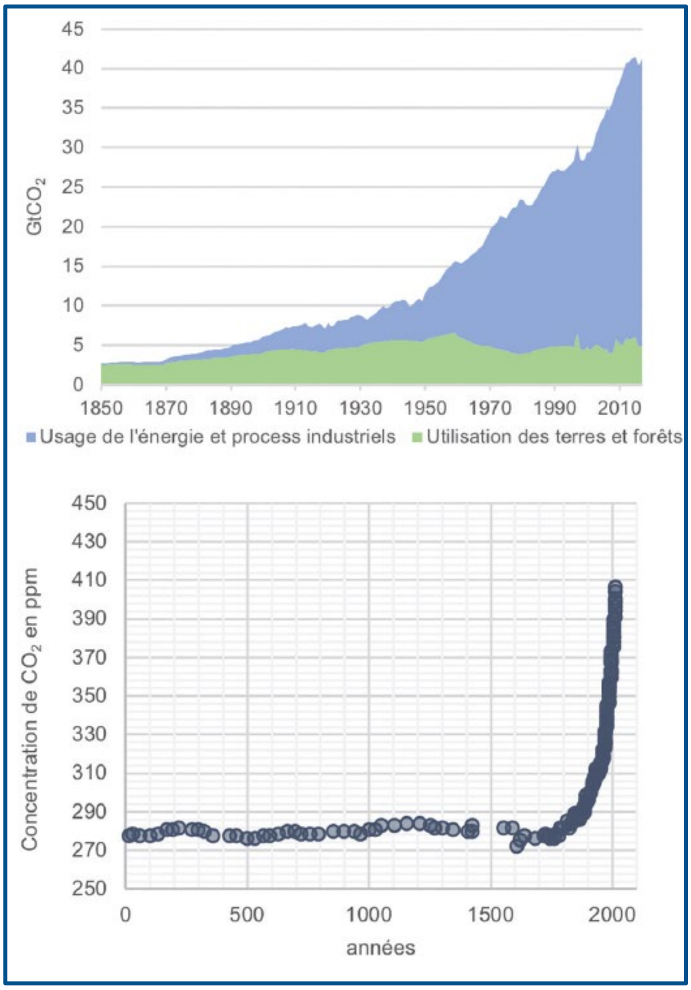

Figure 2 - evolution of atmospheric CO_2 emissions from 1850 to the present day, by source (top) and evolution of CO_2 concentration in the atmosphere from the beginning of the modern era to 2019 (bottom) [Source: Global Carbon budget and Scripps CO_2 Program].

$GtCO_2$ / Energy and industrial processes emissions / land use-related emissions Atmospheric CO_2 concentration in ppm / years

The consequences of this physical process have been understood for a long time: after the discoveries of Arrhenius, at the end of the 19th century, they were already cause for scientific concern as early as 1953[16], for widespread collective concern since the end of the 1960s[17], and for virtual consensus since the Rio Summit in 1992.

Between 1876 and 2017, some 2,220 $GtCO_2$ were released into the atmosphere (out of a total of about 3,000 $GtCO_2$, which would limit warming to 2°C), causing a temperature rise of around 1°C above pre-industrial levels. If the current rate of temperature increase continues, global warming is expected to hover around 1.5°C by 2040[18].

Footnote 16: See "Energy in the future" by Palmer Cosslett Putnam, consultant to the United States Atomic Energy Commission, 1953.
Footnote 17: See "The Historical Roots of Our Ecologic Crisis" by Lynn White, Jr. – Science, 1967 (Lynn White, 1967).
Footnote 18: See Chapter 2 of the 1.5°C Special Report, IPCC (2018), Figure 2.3, p. 105.

CO_2 emissions, which peaked in 2017 at about 42 billion tons of CO_2[19] (excluding other Kyoto Protocol gases) can be broken down into three categories:

1. **Energy emissions** (i.e. production of heat and mechanical energy by combustion. Air transport emissions are included in this category) are the most important and account for almost 35 $GtCO_2$/year.

2. **Non-energy industrial emissions**, which cover emissions linked to industrial processes (production of cement[20], heavy chemicals, etc.) and which account for 2 to 3 $GtCO_2$/year[21].

3. **Land use-related emissions**, which account for nearly 5 $GtCO_2$/year.

Figure – *CO2 emissions can be broken down into three categories / Non-energy industrial emissions 2 GtCO2/year / Land used-related emissions 5 GtCO2/year / Energy emissions 35 GtCO2/year / Total of 42 GtCO2/year (in 2017)*

The "energy" factor has always been and remains a key driver of social development.

By definition, energy is the physical quantity that measures the "change of state of a system". In other words, when a system is transformed, it requires the use of energy. The amount of energy used characterizes the scale of the transformation. Among other things, this applies to changes in temperature, shape, speed, or chemical composition.

Now, from a resource and energy perspective, a human society can be seen as a system that extracts, transforms, processes, and transports mineral or biological resources from the environment in order to produce goods and services that individuals use to fulfil their needs.

As a result, the discovery and increasing use of primary energy[22], especially through "converters " that can transform it into mechanical energy (steam engines, internal combustion engines, turbines, etc.) - as well as the increase in all the physical flows that support production activities - have been instrumental in boosting labor productivity and in driving the economic, social and demographic expansion of human societies.

Footnote 19: Ibid p.107.

Footnote 20: The calcination of limestone, which is involved in the production of clinker (main component of cement), is the transformation of limestone (calcium carbonate or $CaCO_3$) into lime (CaO). This process chemically leads to the generation of CO_2. Annual non-energy CO_2 emissions associated with cement production amounted to 1.4 $GtCO_2$ in 2010. See IPCC 5th Assessment Report chapter 10, p. 749.

Footnote 21: Annual non-energy CO_2 emissions associated with industrial processes amounted to 2.6 $GtCO_2$ in 2010. See IPCC 5th Assessment Report chapter 10, p. 749.

Footnote 22: Primary energy is an energy form found in nature that has not been subjected to any conversion process.

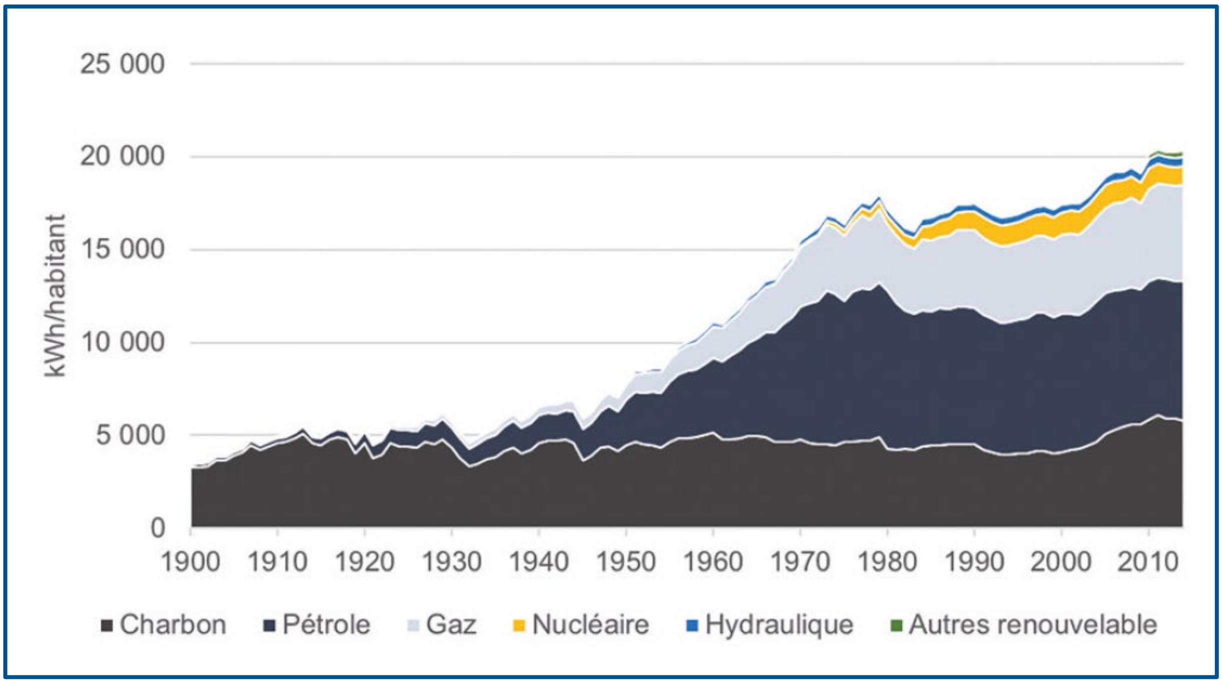

Figure 3: Primary energy consumption per capita worldwide from 1900 to 2015 (excluding wood). [Source : TSP data portal et UN statistics division]
kWh per capita / Coal / Oil / Gas / Nuclear / Hydro / Other renewables

This expansion has gained momentum worldwide in the 19th century with the massive use of fossil fuels across all sectors of the economy, from agriculture to industry and transport. In 2016, for instance, around 13,760 Mtoe of primary energy was used worldwide, of which 32% was oil, 22% gas and 27% coal[23].

For nearly 200 years, our societies have based their development on an unprecedented wealth of fossil energy. Electricity production, industrial activities (mainly metallurgy, cement production and chemicals), land development, trading with shortened distances and time, increased agricultural yields, but also social progress (material comfort, health improvements, education, security, mass tourism, etc.), and more recently digital technologies[23] have been made possible by such abundance.

For this reason, tackling climate change in a 'developed' country is a particularly difficult and complex issue. This shift means we must reconsider the use of fossil fuels, which up to now have kept modern economies running and expanding GDP growth as a goal.

Today, the growth of 'developing' countries is primarily based on the use of fossil fuels, which is also increasing as a result. In this context, the problem of climate change and resource scarcity poses a threat to their growth and calls into question the equity of access to "developed" lifestyles, which were seen initially as a path of progress for societies, but which cannot be sustained in practice if implemented on a global scale.

Footnote 23: See IEA statistics. The energy mixes of the world's largest economies are predominantly hydrocarbon-based (74% in the EU, 81% in OECD countries, 88% in China, 92% in India and 86% in the US in 2015).

Footnote 24: The so-called "dematerialized economy" is also highly resource intensive and is only possible in a highly energy-intensive world (The Shift Project, 2018).

4.2.2 Transition risks and physical risks

For the economy and its various stakeholders, the energy and climate challenges pose two types of risk[25].

The "transition" risks cover all the risks associated with the fundamental restructuring of the economic system resulting from the evolution of the energy mix, which is itself constrained by the decrease in CO_2 emissions into the atmosphere and by the reduced availability of fossil resources[26]. The transition to a low-carbon economy implies a radical transformation of the **energy production** and **consumption system** - the industrial infrastructure and lifestyles are still built around the use of hydrocarbons. This transformation will have to be fast (a 5 to 10% drop in greenhouse gas emissions each year) to meet the goals set with the Paris Agreement. It will impact most physical flows (of energy, raw materials, goods), will directly or indirectly affect all economic sectors and will also have consequences for both jobs and organizations. On top of these elements, which need to be factored in immediately, comes the political issue of balancing the efforts required from developing countries and from those countries regarded as "developed", in order to implement a socially acceptable transition on a global scale.

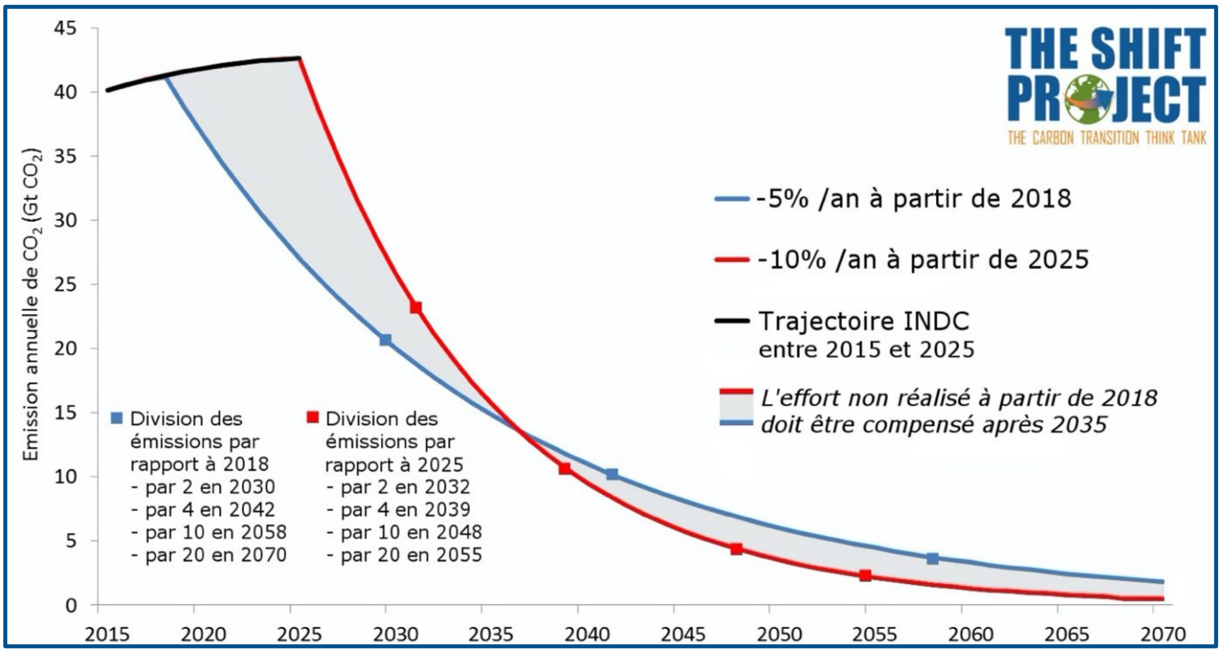

Figure 4 - Global emission pathways compatible with a 2°C temperature increase. These theoretical pathways show the cost of inaction, and the need to implement a decarbonization strategy that can be launched as soon as possible, even if it means reviewing it periodically. On the other hand, a plan to cut emissions by 5% per year will be worthless if it is not implemented before 2025.
Annual CO_2 emissions ($GtCO_2$) / Compared to 2018 level, cut of emissions per 2 in 2030 / per 4 in 2042 / per 10 in 2058 / per 20 in 2070 / Compared to 2025 level, cut of emissions per 2 in 2032 / per 4 in 2039 / per 10 in 2048 / per 20 in 2055 / -5% /year starting in 2018 / -10% /year starting in 2025 / INDC pathway between 2015 and 2025 / The effort not done from 2018 forward will need to be compensated after 2035.

Footnote 25: See in particular the now-famous speech by Bank of England Governor Mark Carney at Lloyds in September 2015.
Footnote 26: See in particular the study published by the Shift Project in June 2020: "The EU can expect to suffer oil depletion by 2030" https://theshiftproject.org/en/article/eu-oil-depletion-2030-study/.

"Physical" risks are associated with the physical consequences of climate change, such as the increased frequency and intensity of extreme weather events, rising sea levels, specific public health challenges, or disruption of river flows. These events could have a significant impact on the economic system, especially on production activities and supply chains. The recent negotiations on the opening of new shipping routes in the Arctic Ocean[27] and the low level of the Rhine river during the autumn of 2018[28] are examples of risks (or opportunities) involving the flow of materials and goods. The materiality of this risk is the focus of an increasing amount of detailed work - by international scientific and political bodies, and now also by business sectors such as insurance, or certain other industries - both on the prospects for impacts and on the adaptation and resilience of organizations and institutions (states, companies, etc.).

These risks **differ from other types of risk** because of - among other things:

- their novelty, and for this reason the inability to use historical values to forecast and understand them or even to test any model (back-testing);
- Their magnitude and their global and irreversible nature (these risks will directly or indirectly affect all sectors of the economy);
- The uncertainty surrounding the timeframe of their occurrence, their spread and their manifestation;
- The (partial) dependence of their magnitude on the actions taken as of today.

4.2.3 Carbon budget

Progressive engagement, which was driven by the determination to mitigate and manage climate risk, culminated in the signing of the Paris Agreement in December 2015. Under this Agreement, the signatory countries committed to work toward holding the increase of the global average temperature to well below 2°C and to pursue efforts to limit the temperature increase to 1.5°C. **Limiting global warming to well below 2°C above pre-industrial levels is an objective that has progressively become the norm in international deliberations.**

Given the close link between the concentration of GHG in the atmosphere and the rise in average temperature, setting such a global warming limit involves, by design, the establishment of a **"carbon budget"**. This refers to the total amount of GHG that can be emitted to hold their concentration in the atmosphere below a certain level which corresponds to the targeted warming limit.

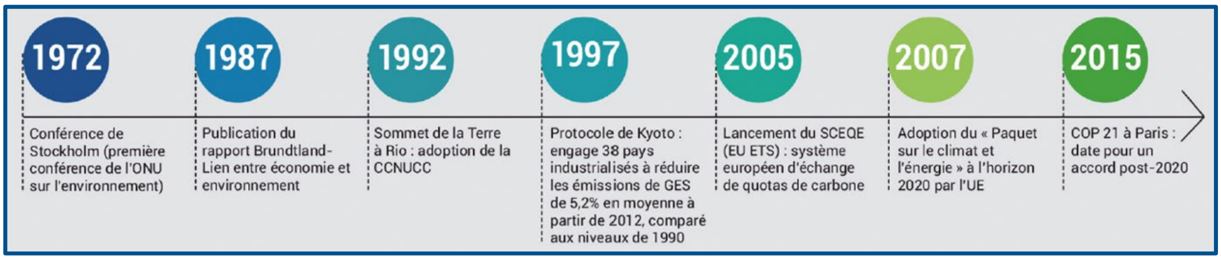

Figure 5: Timeline of main events in climate action

1972 - Stockholm Conference (first United Nations Conference on the Environment)
1987 - Publication of the Brundtland Report - linking the economy and the environment
1992 - Rio Earth Summit : adoption of the UNFCCC
1997 - The Kyoto Protocol: 38 developed countries committed to limiting their GHG emissions by 5,2% on average from 2012 onwards compared with 1990 levels
2005 - Launching of the European Union Emissions Trading System (EU ETS): the european carbon emissions trading system
2007 - Adoption of the 2020 climate & energy package by the EU
2015 - Paris COP21: date for a post-2020 agreement

In the 1.5°C Special Report (SR15) published in 2018[28], IPCC experts determined the carbon budgets available between 2018 and 2100 for different temperature targets and uncertainty ranges. These are illustrated in this graph, on which we have added a few elements for further reading:

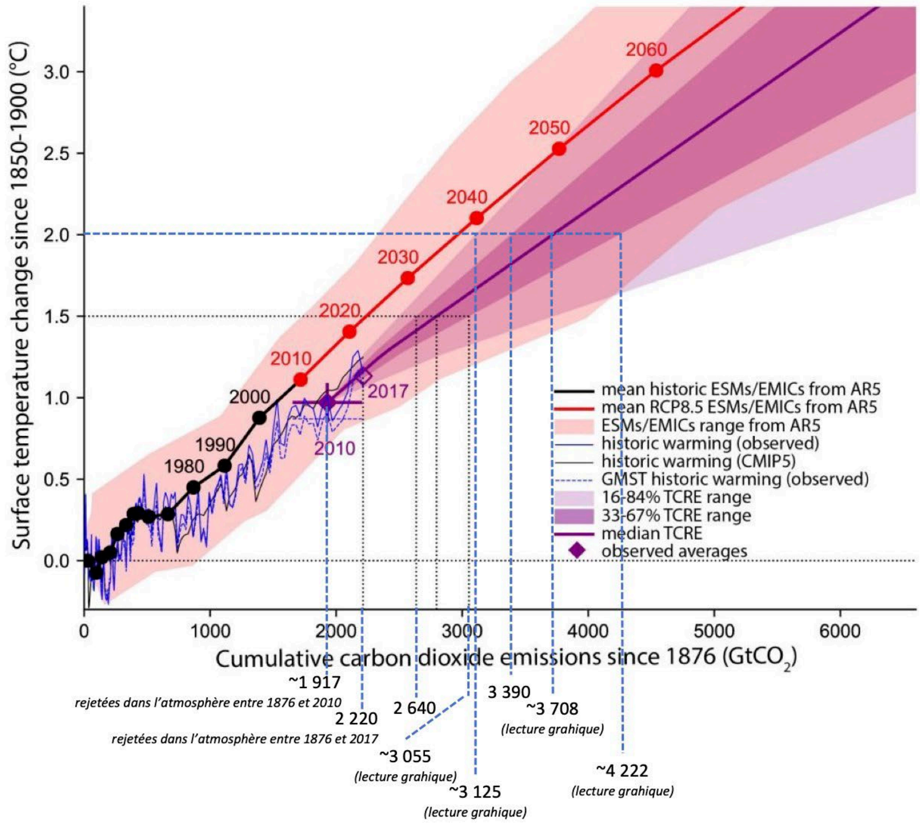

Figure 6 - Carbon budgets, temperature targets and uncertainties [Source: IPCC SR15, chapter 2]

Emitted in the atmosphere between 1876 and 2010 / Emitted in the atmosphere between 1876 and 2017 / graphical interpretation

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Footnote 27: "Estimating the impact of new polar routes on the world trade geography" CEPII (Oct. 2018).

Footnote 28: "Rhine water levels become 'critical' for navigation and industry". L'Alsace newspaper (31/10/2018). 'The poor navigability of the Rhine is believed to be one of the reasons for Germany's economic slowdown. See " Europe's mightiest river is drying up, most likely causing a recession in Germany. Yes, really.", Business Insider France (22/01/2019).

Footnote 29: See Chapter 2 (Table 2.2) of the "1.5°C Special Report", IPCC (2018) https://www.ipcc.ch/sr15/chapter/chapter-2/. This budget only covers energy and non-energy CO_2 emissions, but the calculation includes emissions of other GHG (mainly methane and nitrous oxide). See section 2.2.2.2. p106. The authors note that there are still many uncertainties about its value (amounting to several hundred $GtCO_2$).

This graph allows us to deduce carbon budgets available from 2018 according to risk levels, as follows:

Temperature rise in 2100 compared to pre-industrial level	Probability of falling below this level	Carbon budget available from 1876 ($GtCO_2$)	Carbon budget available between 2018 and 2100 ($GtCO_2$)	Year the budget is used up if emissions are stabilized at 2018 levels
+1,5 °C	67%	2640	420	2028
+1,5 °C	33%	3055	835	2038
+2 °C	84%	3125	905	2040
+2 °C	67%	3390	1170	2046
+2 °C	50%	3708	1488	2053
+2 °C	33%	4222	2 002	2066

Table 2 - World Carbon Budgets based on climate targets

The Paris Agreement does not explicitly mention a carbon budget. Yet the following quote from the Paris Agreement resolution can be considered in the light of the above graph: *"Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C"*[30].

The IPCC RCP2.6 scenario is the one that best aligns with the Paris Agreement. In this scenario (available budget of 550 to 1,300 $GtCO_2$ from 2011), keeping temperature change below "+1.5°C" was described in 2014 by the IPCC[31] as "more unlikely than likely", and staying below "+2°C" was qualified as likely. Using the above graph, in 2018, this scenario translates into an available budget of 803 to 1,603 $GtCO_2$.

One could reasonably consider that a pathway that makes every effort to comply with the Paris Agreement would aim for an "84% chance of staying below +2°C" or a "67% chance of staying below +1.5°C". Still, the great majority of scientific papers so far have taken the baseline climate target of remaining below +2°C with a 67% probability, which means a remaining budget of 1,170 $GtCO_2$ in 2018. This budget is consistent with the IPCC RCP2.6

scenario (high range). This target and budget will therefore also be used as a reference in this report.

In 2018, annual global emissions amounted to 42.1 $GtCO_2$ (including AFOLU)[32]. Aiming for a budget of 1,170 $GtCO_2$ from 2018 and by 2100 (67% chance of staying below +2°C, less than 20% chance of staying below +1.5°C) means cutting emissions by 3.39%[33] each year. This is a budget that can be regarded as a "maximum", allowing us to claim compliance with the Paris Agreement.

It is worth noting that meeting the 905 $GtCO_2$ budget and so increasing our chance of staying below "+2°C" to 84% would require a 4.55% annual decrease in emissions starting in 2018.

It is also worth noting that the remaining 1,170 $GtCO_2$ between 2018 and 2100 amounts to ~34% of the total budget of 3,390 GtCO2 which started in 1876.

Of course, these targets are global in scope and do not apply identically to different geographical areas or business sectors. The efforts to be made by each country were bitterly negotiated at COP21, even though they are not worded in terms of a carbon budget. In any case, and given the state of scientific knowledge, whatever the distribution of efforts (by country, by sector of activity, etc.), the overall carbon allowance is not open to negotiation. In other words, if one of the parties emits more than planned, others will have to make up for the carbon budget overshoot by scaling up their own efforts.

Footnote 30: https://www.undocs.org/FCCC/CP/2015/L.9
Footnote 31:
https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIIAR5_SPM_TS_Volume_fr-1.pdf
Footnote 32:
https://www.globalcarbonproject.org/carbonbudget/archive/2019/GCP_CarbonBudget_2019.pdf
Footnote 33: Based on the model of a constant annual decline pathway. See Calculation Note

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4.2.4 Low-carbon transition could be disorderly and uncertain

The fight against global warming faces the "tragedy of the horizon"[34]. The significance of energy and climate risks is not yet adequately appreciated by economic stakeholders, who are caught in the standard prisoner's dilemma[35]. This leads to postponing action, which in turn favours the development of more brutal or radical GHG emission reduction policies in the future to counter the delay.

Reducing hydrocarbon consumption implies very significant transformations (energy use, productive system and land-use planning). The existing economic system was built on the abundance of hydrocarbons, which leads de facto to a large number of "organizational reliances" that could require a considerable commitment from the public authority to be removed. These reliances may delay action as a whole, and may also trigger strong social reactions.

Cutting back on resource consumption, whether related to energy or non-energy, could also be a chaotic process. Hydrocarbon supply is bound by geological availability and the technical and economic capacity to exploit oilfields[36]. Raw material supplies, especially for metals (copper, lithium, nickel, cobalt, etc.) are also limited in the long run (Hache, 2019). The shocks resulting from biodiversity losses or other environmental impacts (extreme weather events, droughts, floods, etc.), and the steps taken to address them, add to the complexity and uncertainty.

The dynamics of climate change are complex and its modelling is still clouded by significant uncertainties. While the extensive work of IPCC researchers provides a basis for assessing how climate change might affect natural and human ecosystems (Working Groups 1 and 2), these estimates are surrounded by uncertainties (over the location, magnitude and frequency of changes especially). This makes it harder to predict the physical manifestations of climate change[37] (Hallegate, 2009).

The consequences of these events (and their spread), particularly in socio-economic terms, are also difficult to foresee. The sudden bankruptcy of PG&E after the California fires in 2017 and 2018 is one example[38].

Footnote 34: This phrase describes the discrepancy between the perceived horizon of occurrence of climate risks and the management horizon of organizations, particularly financial organizations. It was used by Mark Carney, Governor of the Bank of England, in a speech given at Lloyds of London in 2015.
Footnote 35: As long as the cost of externalities remains low, stakeholders can even put themselves at a 'competitive disadvantage' if they act 'virtuously too early' compared to their competitors.
Footnote 36: Basically, the extraction of any finite resource always reaches a peak, after which the amount extracted each year stabilizes and/or decreases. Hydrocarbons, starting with oil, are no exception to this rule. In 2018, the annual report of the International Energy Agency (IEA), the World Energy Outlook (WEO), warned: "The risk of a supply crunch looms largest in oil. The average level of new conventional crude projects approvals over the last three years is only half the amount necessary to balance the market out to 2025, given the demand outlook in the New Policies Scenario. US tight oil is unlikely to pick up the slack on its own. Our projections already incorporate a doubling in US tight oil from today to 2025, but it would need more than triple to offset a continued absence of new conventional projects" (IEA (International Energy Agency), 2019). In 2019, researchers at IFPEN confirmed this risk: 'The possibility of an oil crunch is nowhere near zero' (Hacquard,

2019). Whether by 2025 or later, the supply capacity of the economic system is ultimately limited.
Footnote 37: In the IPCC assessment reports, the authors supplement their conclusions with wording such as "medium evidence" or "high confidence" etc. See for example the 1.5°C Special Report (2018).
Footnote 38: PG&E Corp, owner of the largest electric utility in the US by customer base, filed for bankruptcy in January 2019, crushed by the financial burden of wildfires in 2017 and 2018. PG&E's stock was considered "investable" by credit rating agencies until November 2018, when the company's credit rating was rapidly downgraded until it filed for bankruptcy. See for example Moody's website.

The COVID-19 pandemic is another reminder that uncertainties persist, some of which may be exacerbated by environmental damage. While there is no established direct causal link between climate change and the COVID-19 pandemic, the rise in atmospheric temperature and oceanic temperatures coupled with the alteration of our ecosystems, resulting from or caused by climate change (deforestation, desertification, thawing of permafrost, acidification of the oceans, etc.), provide a fertile breeding ground for increased frequency, intensity and/or duration of weather, health, food or social events. These range from heat waves to armed conflicts, fires, floods, cyclones, epidemics, uprisings, migratory crises, etc.[39]. When crises hit, the focus naturally moves to emergency management, preserving human life and health, addressing direct material damage and then short-term economic recovery. Crisis management suspends, at least in the short term, transformation pathways, meaning additional risk, unknown factors and efforts in the face of an already challenging situation. In the medium term, while periods of recovery are a chance to learn the lessons of the crisis and open up opportunities for change, there is often a strong temptation to get back to business as usual before going ahead with change. The proliferation of crises of all kinds, given the favorable conditions created by climate change, could severely hamper the implementation of all the necessary steps to curb climate change. This is why seizing the opportunities for radical change - that arise during recovery and stimulus phases - is more essential than ever if we are to break free from this vicious circle. In this regard, the role of public authorities is fundamental. They should set out and target recovery paths, assist weakened economic stakeholders so that they can adhere to these paths, and ensure the effort is shared in a socially acceptable way.

The commercial and geopolitical environment is in turmoil. The tariff war affecting international trade[40] (something that was unimaginable only three years ago despite the challenges facing the WTO), the Brexit and the foreign policy stance of several states (much less "multilateral" now) are all factors that could undermine international climate cooperation and add further uncertainties. The potential introduction of border carbon taxes[41], as well as the difficulties governments have experienced in setting an increasing carbon price signal (e.g. France where the government has decided not to further increase the carbon tax), seem to point in the direction of a growing resort by States to regulatory mechanisms potentially drawn up in an abrupt and uncoordinated manner with their partners[42].

Footnote 39: These risks and their causal link to climate change are documented by the IPCC (AR 15 §2): https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf
Footnote 40: See "International Trade Under Attack: What Strategy for Europe?", French Council of Economic Analysis (2018)
Footnote 41: See "Initiative for Europe - Emmanuel Macron's speech for a sovereign, united, democratic Europe. "(September 2017). See also "How to design carbon taxes", The Economist (18/08/2018). The proposal is now championed by European Commission President Ursula von der Leyen.
Footnote 42: See also "The material scenario of potential carbon border taxes", Beyond ratings (July 2019) : « To put it simply, the development of carbon border tariffs is a scenario to consider in the fundamental analysis of sovereign and corporate assets. It is, of course, uncertain (as illustrated for example by the recent trade deal between the EU and Mercosur), but it deserves attention as its impacts could be significant for investors. If climate issues are more integrated in trade in the future, there will unavoidably be losers and winners. Such changes could be more or less progressive or non-linear, strong or moderate, but they would be meaningful. »
Footnote 43: Colbourn et al. The time scale of the silicate weathering negative feedback on atmospheric CO2 », Global Biogeochemical Cycles, vol. 29, no 5, 2015

4.2.5 The best way to lower risks: start now!

The concentration of GHG (carbon dioxide, methane, etc.) in the atmosphere determines their warming power. Considering the activity time in the atmosphere (e.g. a few centuries for most of the CO_2 to be absorbed by oceans, a few hundred thousand years for it to completely disappear from the atmosphere[44]) and the warming power of each GHG compared to CO_2, we can determine a "carbon budget" which is the amount of GHG (in tons of CO_2 equivalent, tCO_2eq) that can still be emitted and stay below a limit set by the IPCC to maximize the chances of staying within the 2°C threshold.

So if we set a carbon budget for 2050, the sooner we start cutting back, the more progressive the shift in activities will be. By contrast, the longer we wait, the more dramatic the future disruptions will be. This, coupled with the risk of crises described above, should prompt us to set a carbon budget and implement short-, medium- and long-term reduction measures that allow us to decrease emissions as progressively as possible within the budget. The implementation of short-term measures, the "easiest" and least structural, will provide more time for deeper and riskier transformations, requiring more preparation, research, organization and negotiations.

The Paris Agreement did not specify the provision of a carbon budget per country. Instead, each contributing country is committed, on a non-binding basis, to define a strategy, targets and a roadmap for reducing its GHG emissions, and to transparency on its actions and policy measures reported at each COP.

It should be noted that to date, the compilation of targets submitted by countries is not consistent with the global GHG reduction targets set out in the Paris Agreement at COP21, which aim to keep global warming below 2°C above pre-industrial levels, i.e. "reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties (…), and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty."[44]

France's commitment to implement the Paris Agreement is reflected in its National Low Carbon Strategy (SNBC)[45]. The SNBC sets a carbon budget and a pathway targeting carbon neutrality of French territorial emissions in 2050, i.e. going from 445 MtCO2eq in 2018 to 80 MtCO2eq in 2050 of emissions absorbed by carbon sinks (forests, artificial captures, etc.). Within this framework, the share of transport falls from 137 MtCO2eq to around 4 MtCO2eq. Regrettably, the scope of transport thus quantified excludes emissions related to international transport, even though they account for 80% of emissions in the case of air transport. The SNBC includes international air transport in the section "Reducing the carbon footprint of French people", which covers all imported goods and services used by French people as well as international transport. The average carbon footprint in France is 11.2 tCO2eq per capita in 2018, compared to 6.2 tCO2eq for territorial emissions per capita, which reflects the significant contribution of imports and international transport in France. It should be noted that the contribution of transport to the carbon footprint is roughly similar to that of territorial emissions (around 30%). **Even though the SNBC does not fail to mention it, it does not set a quantified target for the reduction of the carbon footprint.**

Footnote 44: Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015 (COP21, Article 4, Section 1) https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf
Footnote 45: The SNBC is available here https://www.ecologie.gouv.fr/strategie-nationale-bas-carbone-snbc

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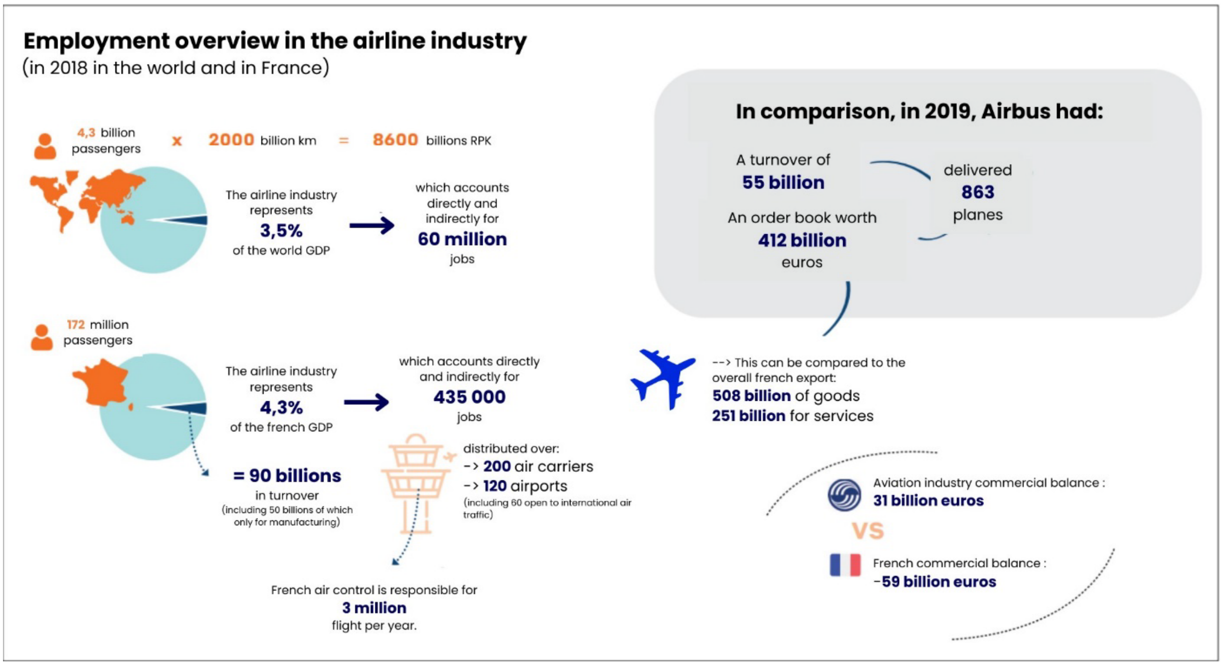
5 The situation of the airline industry today



5.2 Employment pools

In France, Air and Space industries combined represent **200,000 direct jobs** according to the GIFAS (French Air and Space Industries Association)[46] and **150,000 indirect jobs**[47]. The French industry covers all sectors (aircraft, engine and equipment manufacturers) and hires over the whole national territory through subcontracting chains[48]. Most of its 376 firms, including 176 small or medium ones, are located in the south west of France[49]. They rely on highly qualified profiles, mainly French engineers, who work in environments with extremely high quality standards and bring major economic added value and innovation.

Since 1990, French industries have lost 1.5 million jobs on the whole whereas the aeronautical industries have created jobs. Over that same period of time, the number of aircraft delivered per year has quadrupled worldwide. In France, the aeronautical industries now represent over 35% of the total French manufacturing industries[50].

Footnote 46: GIFAS, 2018-2019 annual report.
https://res.cloudinary.com/gifas/image/upload/rapport/rapport-annuel_2018_2019.pdf
Footnote 47: https://www.helloworkplace.fr/emploi-aeronautique/
Footnote 48: Therefore Airbus has 12,000 subcontractors

Footnote 49: But also an employment pool with a very strong aerial tradition in "Pays de Loire"
Footnote 50 : Focus sur l'emploi dans l'industrie française, IFRAP, march 2019

The air transportation industry counts **85 000 direct jobs**, 75% of which are for passenger transportation[51]. Over the 2010-2018 period, the workforce of the branch globally shrank by 8% (i.e -1% per year). The evolution of the workforce over the air sector[52] shows that only the air freight transportation industry (5% of the workforce) increased over this period.

5.3 Missions

What is the use of air transport? In addition to military, security (such as Fire fighters Canadairs for example), sanitary (typically repatriation) and diplomatic uses, air transport plays an important part in opening up territories and boosting national and international exchanges, whether commercial or touristic.

Aviation contributes to positioning France as the first tourist destination worldwide. Our country received 89.4 million visitors in 2018[53] and was aiming at 100 million by 2020 before the Covid crisis. Tourism represents in total more than 7% of national GDP. In 2018 international visitors generated 52.6 billion euros (+5%) in revenue, an all-time high.

A recent information report by the French Senate on the Contribution of air transport to opening up and linking territories[54] underlines **the importance of peripheral flights**. For example, the Paris-Quimper line is identified as essential to the economic vitality of Finistère Sud department and the Dublin-Rodez and Charleroi-Rodez lines bring 2.14 million euros to the Aveyron department.

Based on research work by economists specialized in air transport, the same report highlights the correlation between the growth of air traffic on one hand, and that of GDP, salary levels, direct foreign investments and local demography on the other hand. **It also shows the cross benefits of economic growth and that of air traffic**[55], with cause and effect depending on the typology of the areas. In central areas, economic growth attracts air transport whereas it works the other way round in peripheral areas where air traffic stimulates local economy[56]. "Traffic is not a consequence of, but a boost to the local economy". It plays a major role in linking up regions economically, an argument which can be used to justify public subsidizing in land development.

5.4 Uses and customers

Personal trips

Business trips

A survey carried out in 2015-2016 by the DGAC[57] highlights a reversal of use over 40 years: when in 1974, 62% of customers flew for professional reasons versus 38% for private reasons, the latter represented 72% of flights in 2016, 48% of which for leisure and 25% for affinity travel (family visits)[58].

Footnote 51: FNAM branch report 2019
https://www.fnam.fr/files/download/52ad76e1f84ae6b
Footnote 52: Nomenclature of French activities.
https://www.insee.fr/fr/information/2406147
Footnote 53: https://www.lesechos.fr/industrie-services/tourisme-transport/la-france-reste-la-premiere-destination-touristique-mondiale-1021925#:~:text=La%20France%20demeure%20la%20premi%C3%A8re,d'%C3%A9tablir%20un%20nouveau%20record.
Footnote 54: http://www.senat.fr/rap/r18-734/r18-7344.html
Footnote 55: E. Van De Vijver, B. Derudder, F, Witlox, « Air passenger transport and regional development: Cause and effect in Europe », Promet -Traffic & Transportation, 2016.
Footnote 56: K. Mukkala, H. Tervo, « Air transportation and regional growth : which way does the causality run ? », Environment and Planning A, vol. n°45, 2013.
Footnote 57: https://www.ecologique-solidaire.gouv.fr/sites/default/files/ENPA_2015_2016.pdf

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Besides, the same survey shows that French high executives fly 17 times more than French workers although workers make up a larger part of the population (12.1% vs 9,4%). A recent GIFAS publication[59] reported that 40% of French people have never flown and that only 30% fly once or more per year, and that according to ministerial statistics[60], half of French flyers are among the 20% whose income by consumption unit is the highest. In France again, the 5% of the most frequent travelers emit 50% of greenhouse gases due to transport. This group is strongly over-represented among people whose income exceeds 7500 euros monthly.

30% of French people fly once or more per year.

60% of French people have flown at least once in their lifetime.

40% of French people have never flown.

The polarization of air transport towards the higher socio-professional groups is not a French exception. Currently about half of all people in rich and developed countries never fly. Although this mode of transportation is being extended to all segments of populations, it remains the privilege of the wealthiest: in the UK and in the USA for example, between 12% and 15% of people are on 65% to 70% of flights[61]. In the UK again, the highest socio-professional group is on 75% of all tourist flights[62]. Such differences also exist on a larger scale as is clearly shown on the graph below drawn from a recent survey about emerging countries:

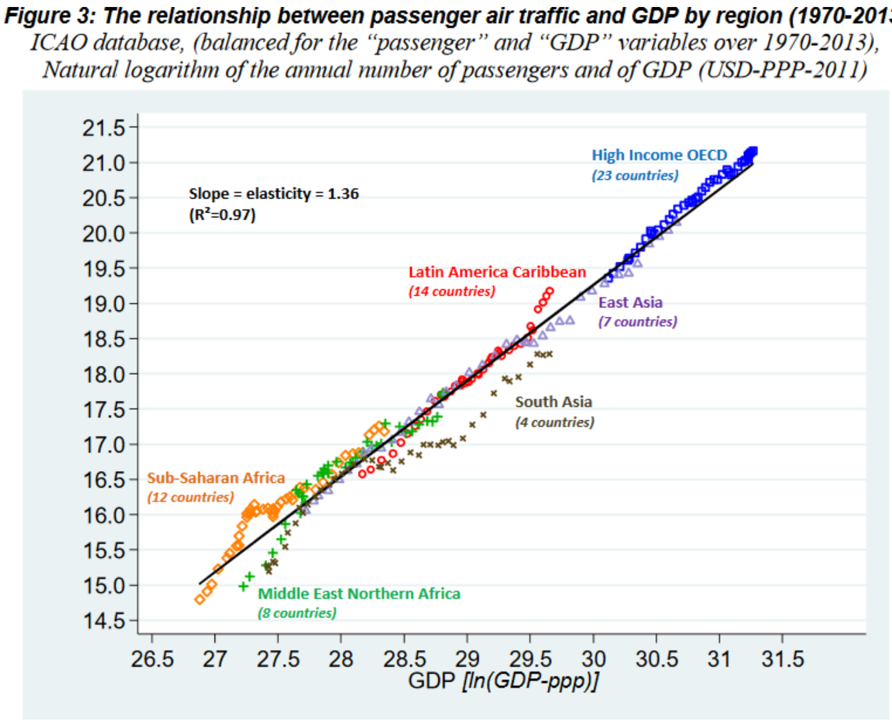

Figure 6 - Source of the graph: https://halshs.archives-ouvertes.fr/halshs-01305412/document, François Bourguignon, Pierre- Emmanuel Darpeix, Air traffic and economic growth: the case of developing countries (2016)

Lastly it is estimated that only 10% of the world population flies at least once a year[64] and, as declared by Boeing CEO himself, 80% of the world population has never flown[65]. So air transport, like any other mode of transportation, is consistent with the Schäfer model[65] which points out a strong correlation between the average distance covered and the income level.

Footnote 58: A recent survey for AMADEUS carried out on a panel of international travelers reveals that visiting family and friends is the main reason for 52% of respondents planning to go on a leisurely journey after the end of restrictions due to the COVID-19 sanitary crisis. https://amadeus.com/documents/en/retail-travel-agencies/infographics/destinationx-wheretonext-travelplanning-1-infographic.pdf
Footnote 59: https://res.cloudinary.com/gifas/image/upload/v1582625311/Documents/GIFAS_DOC_VRAI_FAUX_bd_pap_rotzzf.pdf
Footnote 60: https://www.statistiques.developpement-durable.gouv.fr/enquete-nationale-transports-et-deplacements-entd-2008
Footnote 61: https://www.nytimes.com/interactive/2019/10/17/climate/flying-shame-émissions.html.
Footnote 62: Hopkinson, L., Sloman, L., Newson, C., & Hiblin, B. (2019). Curbing aviation with a

Frequent Flyer Levy and aviation fuel duty – a fair tax package.
Footnote 63: https://www.lemonde.fr/idees/article/2011/11/01/7-milliards-en-avion_1596821_3232.html
Footnote 64: https://www.cnbc.com/2017/12/07/boeing-ceo-80-percent-of-people-never-flown-for-us-that-means-growth.html
Footnote 65: SCHÄFER A., HEYWOOD J., JACOBY H., WAITZ I., 2009, Transportation in a Climate-Constrained World , Cambridge (Ma.), MIT Press, 329 p.

Such disparity is due to the fact that long-distance travel is limited partly by the cost of air transport, even though it is nowadays very low, but also by the cost of accommodation and on-site activities and the possibility of devoting free time to travelling. **So lower costs have not actually made travelling much more accessible to lower-income families, but it has made it possible for the wealthy to travel short distances more frequently**, whether for business or for leisure. One traveler out of four has no other choice but to travel low-cost on a dwindling holiday budget. The others conversely make good use of low-cost travel to enjoy more leisurely activities on the spot but also to travel more frequently and farther distances[66].

Consequently 1% of the world's population accounted for 50% of aviation's GHG emissions in 2018[67] with a group of frequent flyers covering about 56,000km yearly.

Upper socio-professional category is overrepresented among air travelers

In France: High executives / 9,4% of total population / Workers / 12,1% of total population / 17 more trips / 50% of emissions of GHG are due to the 5% of people who travel most. / 50% of air travel is due to the 20% of the population with the highest income. / In the UK and in the USA / 14% of the people = 68% of flights / 75% of all leisure flights are used by the highest socio-professional group.*

Air transport is to be considered as part of the overall transport sector. In the US, the average distance covered per inhabitant was 80km a day in 2000, 10 km of which by plane[68], most of the transport being done by car.

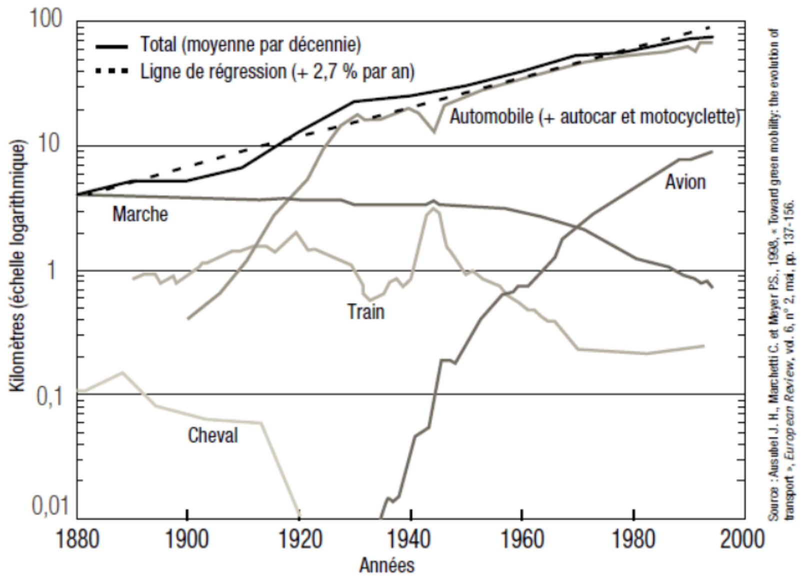

Figure 7- Source: AUSUBEL J.H., C. MARCHETTI, P.S. MEYER, (1998), Towards green mobility: the evolution of transport, European Review, Vol. 6, N. 2, pp.137-156.

In France 80% of transport is done by car - with 38 km daily (14,000 km yearly) covered by each of our fellow citizens. Air transport is much lower with less than 5% of kilometers covered in domestic flights[69] but its share in long-distance flights is constantly increasing, from 8% in 2009 to more than 9,5% in 2016. Air transport is mainly used for journeys over 1,000km. The distances covered grew by 5% from 97 to 102 billion km between 2015 and 2016[70].

Figure 8: Source : AUSUBEL J.H., C. MARCHETTI, P.S. MEYER, (1998), Toward green mobility: the evolution of transport, European Review, Vol. 6, N. 2, pp.137-156

Footnote 66: https://www.lefigaro.fr/conso/2015/01/28/05007-20150128ARTFIG00138-portrait-du-voyageur-low-cost-en-cinq-chiffres.php
Footnote 67: The Guardian, 1% of people cause half of global aviation emissions – study, 2020. https://www.theguardian.com/business/2020/nov/17/people-cause-global-aviation-emissions-study-covid-19
Footnote 68: https://www.alternatives-economiques.fr/economie-de-vitesse-ivan-illich-revisite/00081433
Footnote 69: https://www.culture.gouv.fr/Media/Thematiques/Etudes-et-statistiques/Files/Publications/Questions-de-culture/Culture-medias-2030_variables/Culture-medias-2030_fiche-21_Mobilites-geographiques, and computation of transportation accounting of 2007 and 2020

5.5 Technical progress: where do we stand?

The never-ending search for energy efficiency is part of aeronautics' DNA. Many industry stakeholders criticize the temptation of "aviation-bashing", reminding their detractors that aviation has been and continues to be a sector of technical innovation and although it emits GHG it can rely on a state-of-the-art industry and on the inventiveness of its engineers to activate the levers of decarbonation. What is the exact situation?

5.5.1 Planes and engines

The transition from propeller planes to turbojets that started in the fifties resulted in a gain of speed at the cost of a sharp increase (almost double) in fuel consumption per passenger. Later, technical progress mainly in engines (turbojets) but also in the aircraft themselves improved the fuel consumption. Thus, the improvement in energy efficiency, as measured in fuel consumed per passenger and per km, was about 3,5 % yearly between 1973 and 2018[71]. Such progress results from a combination of technological advances and a renewal of the fleet and to a lesser extent, the improvement of cabin occupation rate[72] and densification.

The most recent aircraft can consume up to 15% to 20% less than the former generation.

Implementing a new ambitious program of aeronautical development aiming at reducing climate impact represents an opportunity to give a new boost to innovation which has always been a priority in aeronautics and to renew the trend in aircraft energy advances which had been slowing down.

The challenge is huge as future planes will have to face constraints and meet requirements, which are:

-**The decrease in total climate impact per passenger.km**: reducing fuel consumption (energy efficiency) and reducing the non-CO_2 effects (cf. 5.7.2), maximum compatibility with alternative energy source to kerosene (cf. 5.5.2) and drastic improvement in energy efficiency of the aircraft compared to the most recent generation of commercial turbojets.

- **The evolution of needs of air mobility**: climate change is likely to bring about deep changes in mobility needs and therefore lastingly change travel habits, whether short or long-distance. New aircraft will have to adapt to these new needs.

- **Climate evolution**: as climate changes, so are modified the physical characteristics of the atmosphere i.e. the environment in which the aircraft is propelled: temperature, humidity, distribution of atmospheric layers and turbulence etc... Flight conditions (altitude, speed, ...) might then be modified. New aircraft will therefore have to anticipate such changes in order to maintain optimum performances in these conditions.

Footnote 70: https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2018-11/datalab-essentiel-138-mobilite-longue-

distance-2016-fevrier2018.pdf
Footnote 71: Référentiel ISAE - SUPAERO Aviation et Climat, May 2022, section 3.2. This takes into account the improvements of propulsion (~1.5 %/year) as well as aerodynamics, trajectories, structure...
Footnote 72: That means fewer empty seats.

Technically speaking, in order to meet these requirements, improvements in energy performance and emission reduction of planes and engines are available. As of today, the main lines are:

- At aircraft level:

- Making the aircraft lighter (materials, structure, ...)
- Improving airflow around the plane (e.g. laminarity, engine integration, shape optimization)
- New architectural design (flying wings, ingestion of boundary layer...)

- At engine's level:

- Improving thermal efficiency (controlling emissions of NOx and fine particles, thereby sharply reducing the occurrence of contrails)
- Improving propulsive efficiency: increasing bypass ratio from turbojets to turbo propellers
- Open-Rotor technology, which aims to combine thermal and propulsive efficiency
- Improving the rate of incorporation of alternative fuels (cf.5.5.2)

There are also projects of aircraft built on disruptive technology, based on the use of an alternative energy source to kerosene: Hybrid Electric planes, Hydrogen planes. The use of these energies does not merely consist in adapting or even replacing engines, but in reconsidering the aircraft architecture. These points are broached in paragraph 5.5.2.

Turbo propeller technology is available and could be applied in a shorter term to small capacity domestic flights (see paragraph 7.2.1.2.). Integrating the other technologies implies designing new aircraft. They should hit the market in the longer term. These different technological pathways and their expected efficiency are studied in paragraph 7.2.2.2.

5.5.2 Alternative energies

For aviation as for all other sectors that consume liquid fossil fuel, using alternative energy sources (Jet A1 fuel in Europe) is an important lever in emissions reduction. Besides, it is a key argument highlighted by the sector, as detailed in paragraphs 5.9.1 and 5.9.5.2. There are 4 different types of alternative energy sources targeted by the airline industry.

5.5.2.1 Biofuels

More recent aircraft which are currently flying are certified to be able to operate with up to 50% of biofuel. However, production level is far from being sufficient to reach this rate, and available biofuels are from the first generation. First generation biofuels come from plant seeds, either oilseeds (rapeseed, sunflower) or cereals (wheat or corn-derived ethanol). Airline industry however targets biofuels from the second generation or beyond. What they have over the first generation is that they do not compete with farming, housing or forest areas since they can be made from agricultural, forest or municipal waste.

5.2.2 PTL (Power-to-Liquid)

PTL (Power-to-Liquid) are artificial fuels that can be made from CO_2 and hydrogen (H_2). CO_2 can be captured in the air or from the emissions released by industrial plants. This technology may seem appealing for decarbonation purposes but its impact on climate depends on its implementation, especially how green is the energy used to produce PTL. And the same applies to the upstream processes to produce the hydrogen needed here.

5.5.2.3 Hydrogen

Airbus published a "ZEROe" pre-project which promised a short/medium-haul hydrogen-propelled flight by 2035. By doing so, hydrogen was publicized as a mean to decarbonate the industry in this segment.

Hydrogen can be used as a gas or a liquid, directly through combustion in the engine or with a fuel cell which generates electricity during the flight. Hydrogen conveniently does not emit CO_2 during its combustion with oxygen (it only produces water). On the downside, it has a very low energy density, volume wise, almost three times lower than that of kerosene in its liquid form (which means storing it at -253°C and 3 bars) and seven times lower if stored as a gas at 700 bars. For identical purposes, it will therefore use up to 3 times more space (at best) when stored on board. Hydrogen as a gas also presents an issue security wise. It is likely to explode when in contact with Oxygen. “Non-CO2” effects of hydrogen combustion at high altitude could also be lessened, but research is scarce on this topic.

Hydrogen does not naturally exist in the atmosphere. It has to be processed. Therefore, as for PTLs, its decarbonating power lies in its production process. Nowadays, **95% of the hydrogen produced in the world for industrial processes, especially in refineries, is produced with fossil fuels**[73] through various processes (hydrocarbons oxidation, steam methane reforming and coal gasification) which release CO_2. The production lines would require massive transformation (for example by replacing existing production lines with water or brine electrolysis powered by renewable electricity and/or by developing CO_2 capture and sequestration solutions - CSC - on power plants using natural gas or coal) and setting it to the scale of the aviation industry and any other sectors that could use hydrogen. Furthermore, reducing GHG emissions will also require major airport infrastructure adaptations for which international cooperation and synchronization will be crucial.

5.5.2.4 Electricity

Some tourist airplanes fly on electrical batteries. Hybrid planes (fuel / electrical battery) for very short (commuters) or regional travels are currently under study. Once again, its decarbonation power lies in its electricity production process (leaving aside the battery production process). There is another downside to using batteries in aeronautics as they have a very low energy density by mass unit. Nowadays, the best batteries have a 1kWh/kg of energy density whereas kerosene has a 10kWh/kg energy density, which means that the battery weight to take on would be 10 times higher than the weight required by kerosene for the same energy. This technology will drastically limit the range and/or the payload.

Footnote 73: https://www.ifpenergiesnouvelles.fr/enjeux-et-prospective/decryptages/energies-renouvelables/tout-savoir-lhydrogene

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5.5.2.5. Synthesis

Biofuels and PTL are conveniently "drop-in", i.e. they require no or little evolution on engines and already existing aircraft. Conversely using hydrogen or electricity means having to design different aircraft with disruptive technological breakthroughs.

The decarbonating power of biofuels and PTL is not apparent at the stage of combustion, which releases as much emissions as kerosene. It comes from the upstream CO_2 absorption necessary for their making.

Therefore, real decarbonation resulting from the use of these energies can only be assessed if we consider the whole life-cycle from their making to their combustion in flight. This is the reason why it is necessary to also take into account the emissions prior to the actual combustion of kerosene (oil extraction, making, transport, ...) in order to really measure the impact of emissions reduction (cf. 5.9.2).

The use of alternative fuels and of resulting externalities is studied in detail in paragraphs 7.2.2.2 and 7.2.2.3 concerning hydrogen aircraft.

5.5.3 Fleet renewal

Fleet renewal is not a technical innovation per say but rather the means to spread technical progress and concretely reach expected achievements concerning GHG emissions in the atmosphere.

According to the ICAO **today's world fleet is renewed every 25 years**[74]. The renewal pace depends on airlines' requirements (therefore on their investment capability and their financial health) and on the industry's output capacity - which is planned on a medium-to-long term timeframe based on forecast demand from airlines. As production lead times and material and human investments are long-term processes, the industry must avoid risks from variation in demand and constantly anticipate them. Raising or lowering production capacity is a structuring decision: sudden variations in demand such as those occurring since the beginning of the COVID crisis are particularly disrupting. So, speeding up the pace of fleet renewal can be contemplated as a measure to reduce emissions, but it has substantial effects on the industry and entails financial investments. Within a context of reduced growth, a fortiori in times of crisis, such investments can't be financed by the sector itself as they used to be but they need public funding. They have to be part of an overall long-term policy aiming at speeding up the spreading of technical progress in existing fleets. Further details on this issue are provided in 7.2.2.1.

In order to foresee the real emission impact of innovations on aircraft and engines, alternative energies and fleet renewal, several scenarios combining these technological paths are studied in paragraph 7.2.3.

Footnote 74: According to the 2019 Environmental Report of OACI (https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf), p279, the average age at which a plane is renewed is 25 years old.

5.5.4 Operations optimization

Operations optimization makes it possible to minimize the time of usage of engines and the energy needed to provide an identical service for place-to-place transport. These operations are divided into 2 distinct categories:

- ground operations: boarding, disembarking, taxiing out, taxiing in.

-flight operations: LTO phases ("landing and taking-off "which includes take-off and climb up to 3000ft, approach and landing), different from cruise, the top of climb and the beginning of descent.

These different phases and subphases have their own specificities, complexity and constraints. Besides, they are under the responsibility of different teams in air control. But they all have something in common: they all require kerosene. This means that, to reduce emissions during those different phases, one solution will not fit all.

5.5.4.1 On ground

For on-ground activities solutions under review consist in:

- Reducing or electrifying the energy coming from the Auxiliary Power Unit, a "small" turbojet usually installed in the plane's tail in charge of maintaining electrical power on board, air conditioning or managing hydraulic power until the main engines are started. It is also used in case of emergency (ie: main electrical circuits breakdown).

- Reducing propulsive power during taxi or electrify taxi phases

We must bear in mind that if the electricity produced has high CO_2 emissions and comes from coal burning power stations for example, the problem will just have shifted. Decarbonization of on-ground activities could be implemented in a foreseeable future. See paragraph 7.2.1.1 for in depth analysis.

5.5.4.2 In-flight

With a large set of factors to take into account (increase in traffic, increase in the number of planes in an unchanging airspace, pressure from competition and for commercial performance, difference in management across countries, conflict zones, dealing with weather, technical or any other hazards), optimizing flight trajectories is becoming more and more complex.

For a given flight, airlines can arbitrate between fuel consumption and flight duration. This arbitration is translated into the "Cost index" indicator. Reducing the Cost index to 0 could be implemented in the short term. See paragraph 7.2.1.4.

Many other projects are under study, but they require at least some harmonization and synchronization between countries and stakeholders that are sometimes competing. This tends to slow down their implementation. We can mention the Single European Sky (SES) project which aims at cross-border traffic flows optimization, and its technological project «SESAR». This project is part of the ASBU elements[75] of 2019 GANP[76] of the ICAO. ATM elements of this plan, which were sketched out in the ICAO 2019 environmental report, are also studied and gradually implemented by member states.

Optimizing routes is **possible, but it is difficult, even impossible with heavy traffic, and its benefits are yet to be proven**. See paragraph 7.2.2.1.

There are also eco-friendly flying practices which gather all these best practices and whose big data tools make it possible to oversee the crew's collective or individual behavior. According to specialists, these tools have a powerful impact on raising pilots' awareness and creating a healthy competition environment.

Footnote 75: Aviation System Block Upgrade https://www.atmmasterplan.eu/exec/icao-blocks
Footnote 76: Global Air Navigation Plan

5.5.5 Fly at a lower speed?

It would be justified to consider the possibility of reducing speed to reduce fuel consumption. After all, doesn't slow steaming allow sea transport to significantly save on fuel?

Unfortunately things do not work the same way for aviation. If a ship can slow its speed to reduce its drag, a plane has to maintain itself in the air. So in order to generate the necessary lift, it can adapt either the wingload (that is to say the deviation of the flow) or the speed of the aircraft (Mach). The former mechanism bears on the induced drag whereas the latter bears on the friction drag. Two antagonistic mechanisms bear on the aircraft's overall drag. While reducing the speed, it is necessary to increase the wingload, which results in an increase in the friction drag. To sum it up, the friction drag increases with the flight Mach but the induced drag decreases with the flight Mach. So, contrary to other vehicles which consume more as they go faster, the aircraft saves on fuel when flying at an optimal medium speed.

So, do planes actually fly at this optimal speed or do they fly faster to save time? In fact, they don't need to deviate from optimal speed as this speed depends on air density. In order to increase its speed without consuming more fuel, the plane only has to climb, where the air is less dense. Its speed will eventually be limited only by physical mechanisms linked with transonic phenomenons (apparition of shockwaves on the profile which drastically increase the drag and jeopardize the aircraft's structure).

So, for an already existing plane, only a very small consumption gain could be contemplated by increasing the flight's duration, as the gain depends on minor parameters. However, it would be interesting to mobilize this gain, especially because this lever is explicitly used through the "cost index" (cf. 7.2.1.4), a piloting parameter through which airlines indicate how much more fuel they agree to consume per time unit gained. However, agreeing to fly at lower speed can substantially save energy by switching to more efficient motorisations (turbojet, open rotor), which entails changing the aircraft's architecture.

5.5.6 Fly heavier?

In sea transport, gathering goods on fewer ships that are as big as possible saves fuel per ton transported. That is why all sorts of ships, from container ships to steamers, are on a race to gigantism. This is also true on the road: bus passengers consume significantly less than car passengers, with a comparable load factor. We are therefore entitled to wonder whether comparable scale effects exist in air transport, which would then make it possible to save fuel by gathering passengers in aircraft that are as large as possible.

Unfortunately, the physics behind the design of a plane does not work this way and the energy performance that can be achieved is rather uncorrelated to the size of the plane. Therefore, although air traffic has been widely developed, the size of aircraft has not changed. Evidence is given by both Airbus, which brought its 380 program to a halt in early 2019, and Boeing which stopped its 747 [77] more recently.; even though there are many reasons for these decisions, such big aircraft belong to the past.

Footnote 77: Boeing 747, which started flying half a century ago, were already as large as the largest aircraft sold today.

5.6 The governance organs

Decarbonation cannot efficiently be implemented in each country through independent policies because the airline industry is international. To convince ourselves of this, we need only to remember that International flights account for 60% [78] of CO_2 emissions and international commitments (INDC) taken by the parties after the Paris Agreement only mention domestic flights [79]. In France 80% of the carbon footprint comes from international flights [80] and as mentioned earlier these are not taken into account in the SNBC [81]. Consequently, however efficient the national policies of reducing GHG within the INDC might be, they would only address a minor part of the problem.

Besides, even if one country decided to take measures to reduce the carbon footprint of international flights that it is responsible for, these would be efficient only within a framework of international coordination on rules and decarbonation efforts. Indeed, any local policy of reducing supply or demand for air transport (for instance through quotas, slot reduction or taxation) that were to be implemented without coordination would instantly result in national stakeholders being jeopardised. Users would then only need, in order to circumvent a too strict legislation, either turn to a foreign rival airline submitted to a less coercive taxation system or fly from a neighbouring country with less severe restrictions weighing on airlines or airports. In either case the result would be an imbalanced market that would benefit foreign operators. It is then a double penalty: not only are the sector's global emissions not reduced but the national economy suffers! What can be done about this? [82]

5.6.1 Emission Trading scheme (EU-ETS)

The Emission Trading Scheme or European Union Emission Trading Scheme (EU-TS) is a mechanism of CO_2 emissions rights implemented within the European Union. It sets a limitation of gases that can be emitted and puts into place a carbon market allowing each firm to buy or sell emission quotas, aiming to reduce the overall emissions of CO_2 and reach the targets set by the European Union within the Kyoto protocol. The firms that make an effort are thereby rewarded while those that have exceeded their emission limits have to buy emission quotas from more environmentally virtuous firms.

EU-ETS is heralded by the EU as the centerpiece of its climate change policy and a key tool for cost-effective greenhouse gases emissions reduction. It is the world's first and largest carbon market. EU-ETS operates in the 31 countries of the European economic Space. It currently covers the emissions of about 11,000 energy providers and industries on the European Union's territory, i.e. 45% of its GHG emissions.

Footnote 78: Owen, Bethan; Lee, David S.; Lim, Ling (2010). "Flying into the Future: Aviation Emissions Scenarios to 2050". Environmental Science & Technology. 44 (7): 2255–2260. doi:10.1021/es902530z. PMID 20225840.

Footnote 79: https://unfccc.int/files/adaptation/application/pdf/all__parties_indc.pdf
Footnote 80: https://www.ecologique-solidaire.gouv.fr/sites/default/files/Emissions_gazeusesVF.pdf
Footnote 81: Low carbon national strategy (stratégie nationale bas-carbone) https://www.ecologique-solidaire.gouv.fr/strategie-nationale-bas-carbone-snb
Footnote 82: This point is linked to the larger issue of a network of point to point connections in line with a Hubs and Spokes model. The type of organisation which would be more relevant than any other is not addressed in this report and would deserve an in-depth comparative study, which we might do in a further publication!

Its deployment will be fourfold over 25 years, from 2005 to 2030 and should help to reach a 43% GHG reductions compared to 2005 across Europe [83].

Starting from 2012, EU-ETS had to incorporate CO2 emissions from civil aviation (following the November 19th 2008 directive 2008/101/CE. If they served the European Union, airlines of all nationalities were supposed to obtain quotas in order to cover emissions generated by their aircraft serving European airports. Every aircraft crossing the European airspace is considered as a source of CO2 emissions, just like a factory or a power station.

In 2010, EU-ETS was planning to force any operator with at least one flight to or from Europe:

- to report yearly emissions of associated flights to a competent authority within one of the EU member states
- to annually refill credits of CO2 tons in the same amount as those released during the same year

Airlines had to buy 15% of their emissions on the CO2 market (multi-industry), the rest was given for free [84]. The proceeds were to be used in the fight against climate change.

26 countries outside the EU stood against including the aviation industry in the EU-ETS in front of the ICAO. In 2013, in order to come up with a comprehensive and believable solution, the EU made its legislation more flexible at least until 2021. The actors of the aviation sector have used the borrowed time to offer an alternative solution: CORSIA

Footnote 83: https://ec.europa.eu/clima/policies/ets_fr
Footnote 84: The free part is to decrease year after year (the "European green deal" having set a roadmap to phase out free allocations on the short-term for the airline industry).

5.6.2 CORSIA

CORSIA (for Carbon Offsetting and Reduction Scheme for International Aviation) originated from the sector's proposals. This carbon offsetting mechanism is defined by ICAO, supported by IATA and airline companies, and implemented on a global scale since it was adopted by the ICAO member states, including France, in 2016

The carbon offsetting project defended by CORSIA aims to cap these emissions to their 2019 level for international flights only (therefore excluding domestic flights such as intra-USA or intra-China). The European Commission and the member states of the European Union are currently assessing this proposition in order to ensure that aiming at making the project acceptable will not hinder climate ambition. A public consultation was launched in July 2020 by the European Commission about CORSIA and the possibility of its coexistence with EU-ETS

Carbon offsetting is taken on by the commercial aviation operators with over 10MtCO2 annual emissions. Carbon accounting relies on a route-by-route approach that allows an equal treatment for all operators. To that end, a monitoring, reporting and verification (MRV) process, under the authority of member states (whether they are included in CORSIA or not) and ICAO was implemented in 2019 in order to assist operators in accounting their annual emissions and offsetting credit purchased. CORSIA members are to purchase carbon credits on an international specific market to offset their emissions above their 2019 level, these credits being issued by firms that have GHG reduction activities.

The criteria that any CORSIA carbon credit must meet are listed in the Emissions Units

Eligibility Criteria[1] and approved by ICAO. ICAO also runs a Technical Advisory Body formed of 19 experts named by the governments of participant states. Their job is to determine which carbon credits will be authorized. Besides, ICAO works with a list of organizations[2] that connect stakeholders of the sector with initiators of compatible projects - such as reforesting damaged areas, reducing the use of nitrogenous phytosanitary intrants in agriculture, restoring wetlands, capturing and storing carbon, developing renewable energies.

The program is split into two phases: the first phase running from 2021 to 2026 (including a pilot phase from 2021 to 2023) during which only volunteer states are included (today 88

1 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Emissions-Units.aspx

2 The organizations registered for the 2021-2023 period are: American Carbon Registry, China GHG Voluntary Emission Reduction Program, Clean Development Mechanism, Climate Action Reserve, Gold Standard, VCS Program.

states[3] that make up for 77% of international scheduled flights), then from 2027 to 2035 including all the ICAO member states who account for a sufficient part of international aerial activity. Members from the Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing Countries (LLDCs) are not included in CORSIA.

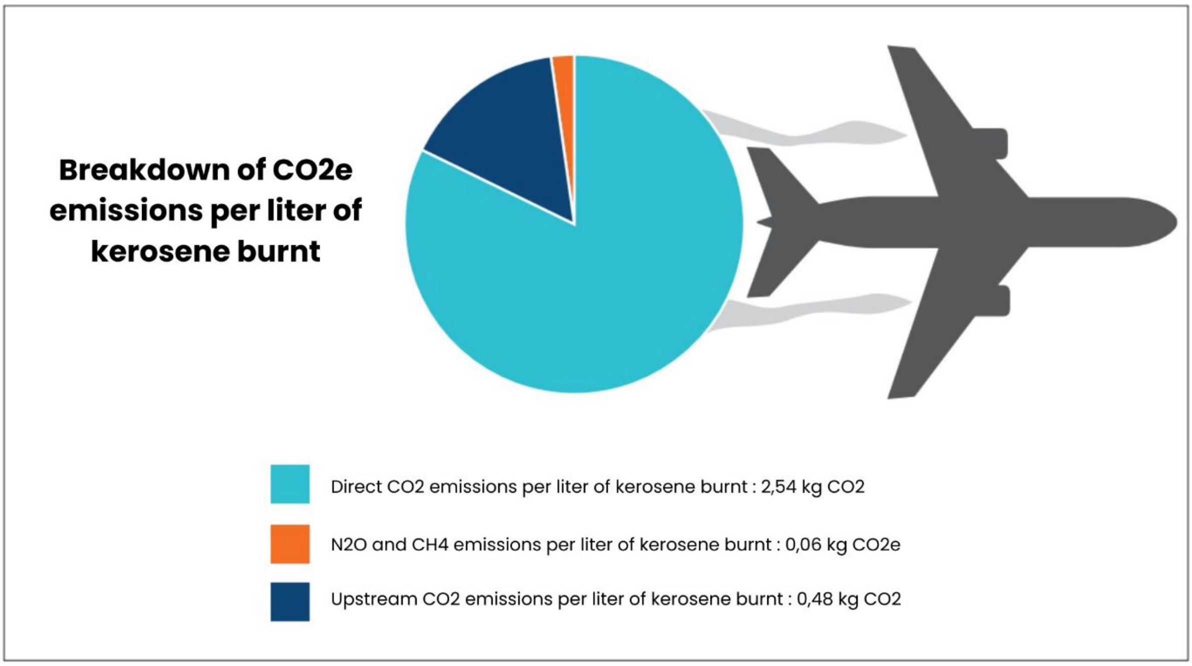
NB: it is important to differentiate covered emissions from offset emissions. Covered emissions are emissions that CORSIA include in the calculation base. These are accounted for by the various stakeholders that will report to the legislator. Offset emissions are the part of the covered emissions that will actually be exchanged on the carbon market and lead to the funding of projects said to be with "negative" emissions. CORSIA is designed to offset international emissions above their 2019 level only. Therefore, with zero growth of international traffic, there would be no offsetting, all other things being equal.

5.7 Contribution of air transportation to climate change to this day

In order to comprehend what follows, it is necessary to have in mind the notions exposed in paragraph 4.1.

3 https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Newsletter_Oct2020.pdf

5.7.1 CO2 emissions in 2018



The combustion of one liter of kerosene emits 2.540 kg of CO_2 to which must be added 0.479 kg for upstream emissions (extraction, refining and transport) - a total emission factor of 3.019 kg of CO_2 per liter of kerosene burnt[4]. When methane (CH_4) and nitrous oxide (N_2O) emissions are included, the total comes to 3.075 kg equivalent CO_2 per liter of kerosene burnt.

On a global scale, civil aviation emitted 905 Mt of CO_2 in 2018[5] (upstream excluded), or 1.077 Gt of CO_2, upstream included. The table below shows the part it takes in global CO_2 emissions.

		Contribution of aviation to the world CO2 emissions in 2018[6]

[4] According to the BaseCarbone® de l'ADEME, given in kg of kerosene, these numbers become: 3.150 kg of CO_2 per kg of kerosene burnt and 3.750 kg of CO_2 upstream included. With methane (CH_4) and nitrous oxide (N_2O) emissions included, it gives 3.825 kg CO_2 equivalent.

[5] Amount of CO_2 alone in 2018 (other greenhouse gases excluded), taken for the table "June 2020" in IATA, Airline Industry Economic Performance – June 2020 – Data Tables. Other sources provide other numbers but in the same range, which is sufficient for our present study: 918 Mt according to ICCT, 905 Mt according to EESI, or 918 Mt according to OACI.

[6] See Le Quéré, 2019, Global Carbon Project. The numbers in this document mention CO_2 alone.

Emissions of the airline industry in 2018 (CO2 alone)		Deforestation and change of land use excluded	Deforestation and change of land use included
Combustion alone	905 Mt CO2	2.5% of 36.6 Gt CO2	2.1% of 42.1 Gt CO2
Combustion + upstream	1,077 Mt CO2	2.9% of 36.6Gt CO2	2.6% of 42.1 Gt CO2

Table 3 - Contribution of aviation to global CO2 emissions in 2018

The contribution of aviation to the world CO2 emissions differ whether upstream is accounted for or not in the numerator, and whether deforestation and change of land use are accounted for or not in the denominator.

5.7.2 Non-CO2 impacts

Aviation also contributes to anthropogenic climate change through a set of complex chemico-physical processes, grouped under the term of “non-CO2 impacts”[7]. These impacts come from high altitude emissions of nitrogen oxides (NOx), water vapor and particle aerosols (sulphate compounds and carbon soot) in exhaust gases from engines.

The different mechanisms at stake are detailed below, after a study published in the Atmospheric Environment review in 2020 by Lee et al.[8], and which gives a full overview of the existing knowledge on this topic.

[7] Other human activities also generate non-CO2 effects on climate change: agriculture (with nitrous oxide and methane emissions) and sea-transport (fine particles, soot and sulphate compounds).

[8] D.S. Lee, D.W. Fahey, A. Skowron, M.R. Allen, U. Burkhardt, Q. Chen, S.J. Doherty, S. Freeman, P.M. Forster, J. Fuglestvedt, A. Gettelman, R.R. De León, L.L. Lim, M.T. Lund, R.J. Millar, B. Owen, J.E. Penner, G. Pitari, M.J. Prather, R. Sausen, L.J. Wilcox, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Atmospheric Environment, 2020, 117834, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2020.117834 (http://www.sciencedirect.com/science/article/pii/S1352231020305689)

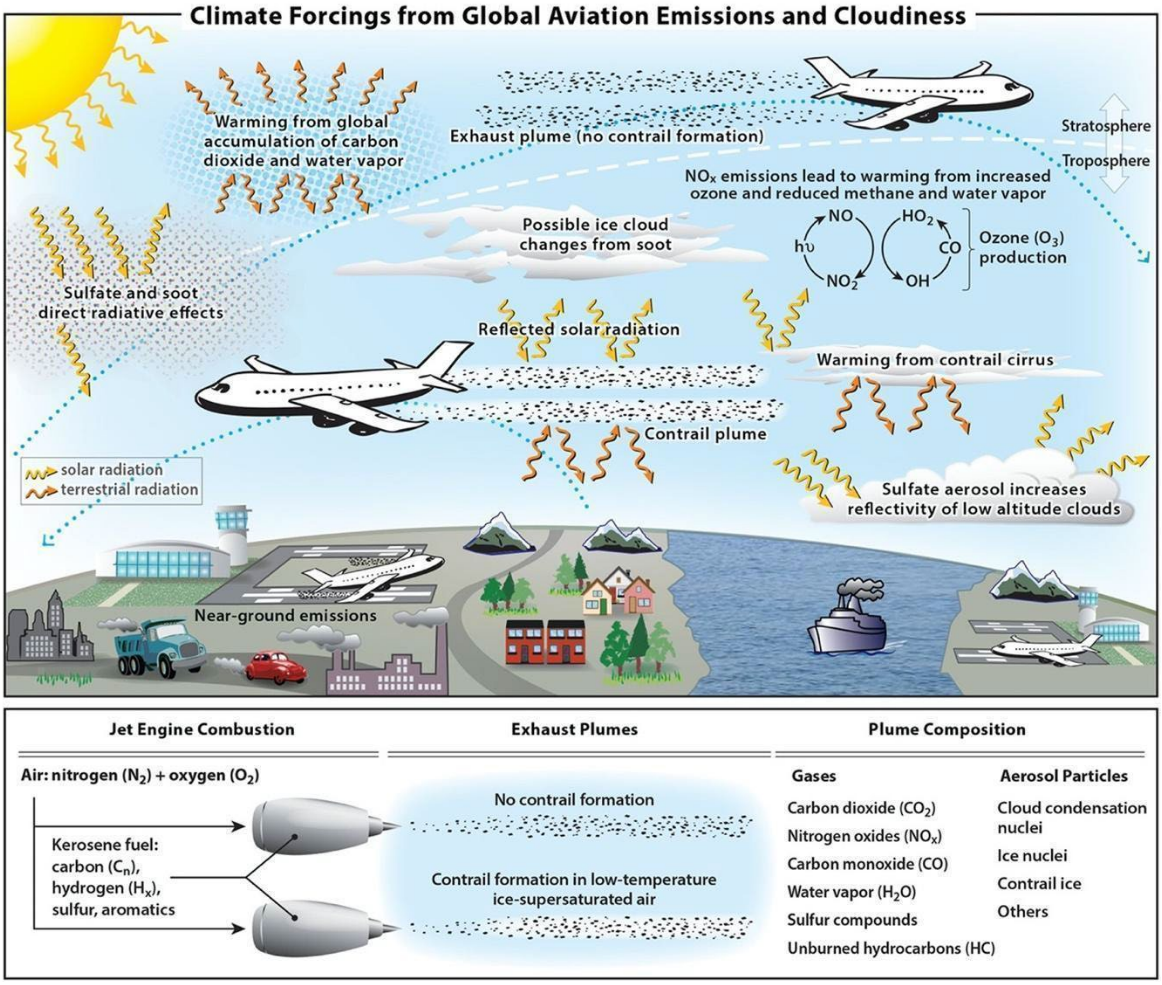


Figure 9 - Climate forcings from CO2 emissions, water vapor, particle aerosols and cloudiness as a result of aviation[9]

The mechanisms described above apply to current engines and fuels. The influence of a change in the type of fuel (biofuels, PTL, hydrogen…) is yet unknown.

Under certain conditions of temperature, humidity and pressure, the water vapor and aerosols contained in exhaust gases from engines will locally create condensation trails (or contrails) that may transform into cirrus. These high-altitude anthropogenic clouds are thin ice clouds that form at an altitude of 5 to 14 km (planes generally cruise at an altitude of 9 to 12 km)[10]. They disappear after a time ranging from some minutes to some days at most. They have a warming effect because they offer a very high temperature contrast with the surface and therefore generate a greenhouse effect that surpasses their albedo effect.

[9] Figure 1 in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018

[10] See Wikipedia article: Nuages anthropogéniques, section Cirrus créés par les avions à réaction and Traînées de condensation

Nitrogen oxides (NOx) undergo photochemical reactions that increase the formation of tropospheric ozone (O_3)[11] in the short term and decrease the lifetime and concentration of methane (CH4)[12] in the atmosphere. The decrease in methane concentration then generates a slow and long-term decline of ozone as well as water vapor (H2O) concentrations in the stratosphere. These various phenomena add up to a net warming effect owing to the prevalence of the warming effect of tropospheric ozone.

Radiative interactions also occur with aerosols made of soot (absorption of short-wave radiation[13], leading to a warming effect) and aerosols made of sulphate compounds (scattering of incoming radiation, leading to a cooling effect).

For high-altitude flights, during the cruise-phase, water vapor emission in the lower stratosphere disturbs the radiative equilibrium of water vapor which has a warming effect.

Lastly there is another type of non-CO2 effect: interaction between aerosols (carbon soot, sulphate compounds) and clouds which affects the formation of clouds. According to Lee et al., current knowledge does not allow to draw any conclusion on a reliable estimate of the radiative forcing effect resulting from such interactions, both for aviation and overall human activities.

5.7.3 Net effective radiative forcing induced by aviation

The study of Lee et al. provides the best estimate available today of effective radiative forcing of CO2, of the main part of non-CO2 effects, and of net radiative forcing of aviation, for each year between 2000 and 2018, computing it since 1940. Year 1940 is taken as a reference year since commercial aviation was almost non-existent before then: it basically means comparing to year 1750 as traditionally done.

Only the contribution of interactions between clouds and aerosols is not taken into account, in the absence of reliable estimations to this day. For the part of non-CO2 effects that are quantified, the 95% confidence intervals remain sizable. It is however necessary to take these numbers into account, as these effects account for a large proportion of net effective radiative forcing of aviation.

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[11] Ozone, a powerful greenhouse gas, is qualified as "tropospheric" to differentiate it from its presence in higher altitude, then named stratospheric ozone, which plays a part in the protection of the living from ultraviolet radiation.

[12] Methane ranks second relatively to the importance of emissions of greenhouse gases, after CO2. In addition to flows that are naturally emitted by ecosystems, its main emissions come from the agricultural and oil and gas sectors.

[13] Radiations with wave-length between 0.4 and 0.9 µm. It includes visible light, near infrared and near ultraviolet radiations (see : Futura Sciences, Bilan Radiatif de la Terre).

Aviation thus generates a net effective radiative forcing of 100.9 [55-145] mW.m^{-2} for 2018, with a CO2 contribution of about ⅓, at 34.3 [28-40] mW.m^{-2}, non-CO2 effects contributing to ⅔ (66.6 [21-111] mW.m^{-2}).

The inventory of numbers and 95% confidence intervals is shown below[14] in ascending order

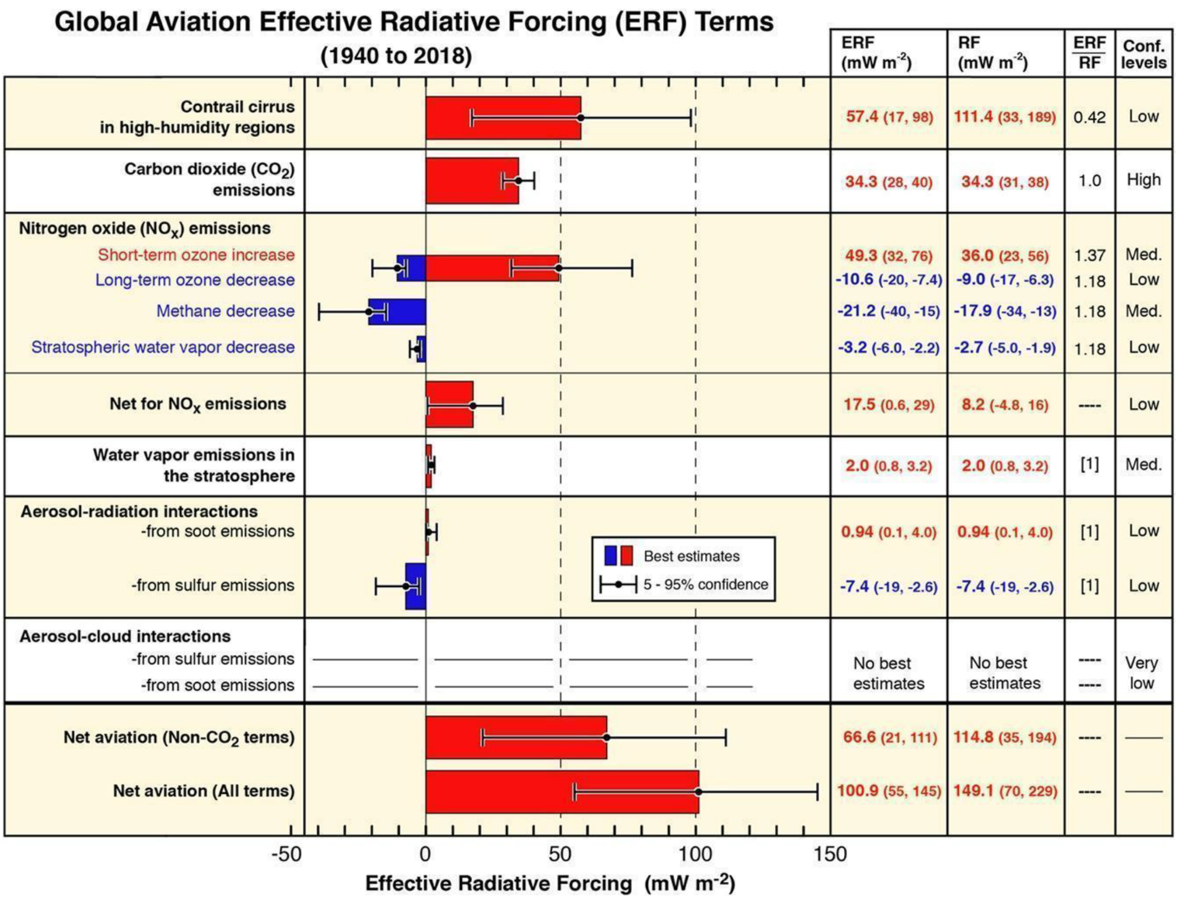
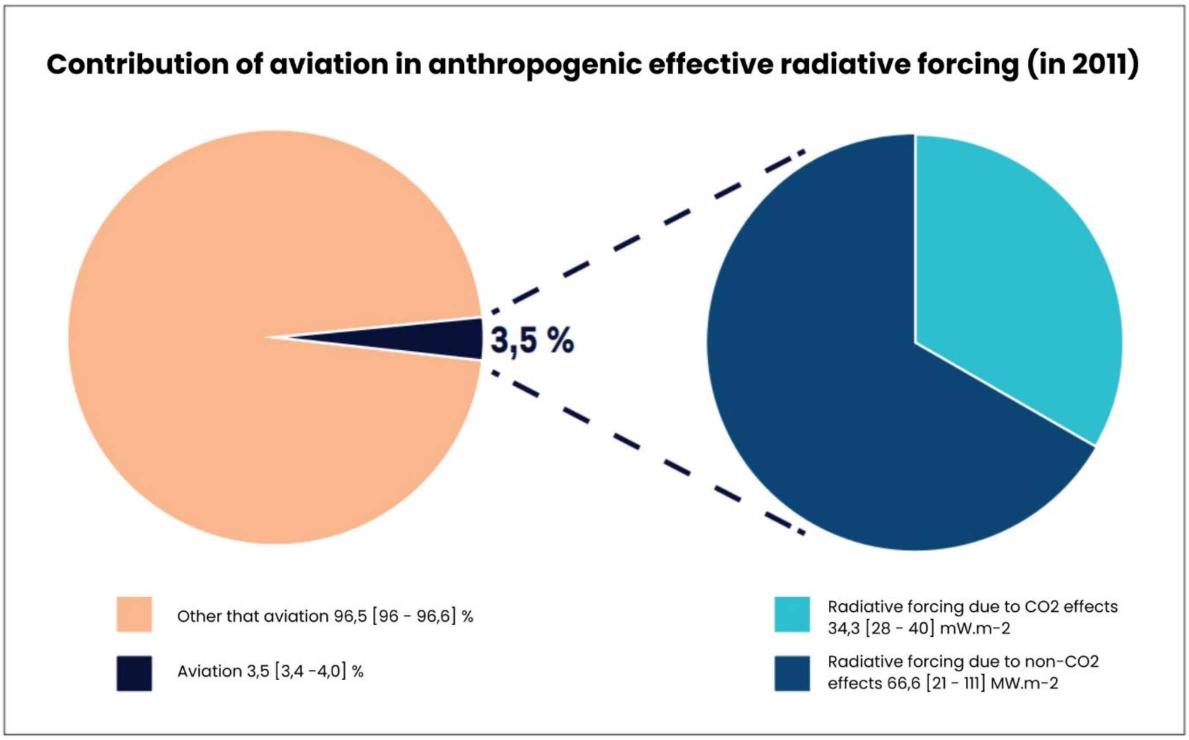


Figure 10 - Components contributing to effective radiative forcing of aviation, in descending order

It is notable that in 2018, effective radiative forcing of contrails and of anthropogenic cirrus is 1.7 times higher than that of CO2 emissions. In other words, at any given moment in 2018, clouds formed during the previous days due to aviation (clouds formed earlier having already disappeared) generate an effective radiative forcing almost twice as high as that

[14] Figure 3 in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. The net totals of the effective radiative forcings from non-CO2 effects and from aviation (CO2 and non-CO2) do not equal the arithmetic sum of the estimation of each effect, because of the separate probability distribution of values, requiring a Monte-Carlo analysis in order to be determined.

of all of CO2 emissions in the history of aviation since the first flights of the Wright brothers in 1903, more than a 100 years ago. These clouds therefore play a major part in global warming by speeding it up sharply.



To compare net effective radiative forcing of aviation to anthropogenic effective radiative forcing, Lee et al. take 2011 as a reference, as anthropogenic radiative forcing between 1750 to 2011 is now reliably estimated (2290 [1130 - 3300] mW.m^{-2}). **In 2011, the contribution of aviation to anthropogenic net radiative forcing thus stood at 3.5 [3.4 - 4.0] %, CO2 and non-CO2 effects included, or 1.59 [1.56 - 1.65] % for CO2 alone**[15] (net total effective radiative forcing of aviation is estimated to 80.4 [45 - 114] mW.m^{-2} and to 29.0 [24 - 34] mW.m^{-2} for CO2 alone, computed from 1940 to 2011).

5.7.4 Key figures of the total contribution of aviation to anthropogenic climate change and basic principles for the reduction of this contribution

To determine the key figures of the total contribution of aviation to anthropogenic climate change, including kerosene combustion, upstream phase and non-CO2 effects, the first

[15] Table 2 in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018

thing that comes to mind would be **quantifying emissions of climatic pollutants[16] generated by air traffic in "CO2 equivalent" by using the GWP_{100}[17] metrics**, compatible with the standards currently used for the assessment of greenhouse gas emissions.

This method provides a way to calculate the amount of CO2 that would induce the same mean effective radiative forcing over the next 100 years as a given amount of climatic pollutant. It takes into account that over this period some mechanisms eliminate CO2 and the said pollutant from the atmosphere. For example, the production of 1kg of methane is equivalent in CO2 on 100 years to 32 kg CO2e[18] (read "CO2 equivalent"), which means that 1 kg of methane generates the same mean effective radiative forcing over 100 years as 32 kg of CO2 that would have been produced instead.

For the year 2018, by using the GWP_{100} metrics, Lee et al. show that CO2 equivalent emissions of aviation (including CO2 and non-CO2 effects, excluding upstream phase) amount to 1797 Mt CO2e - 1.7 times the contribution of CO2 from combustion alone[19]. The net part of non-CO2 effects in this figure is 764 Mt CO2e - 0.7 times the part of CO2 produced during the flight. Non-CO2 effects of contrails and cirrus are its main contributors, with 651 Mt CO2e - 85% in CO2 equivalent of the non-CO2 effects, and 63% of the CO2 effect alone.

Lee et al. have obtained these figures from a CO2 emissions basis of 1034 Mt CO2, itself based on the fuel used by aviation as a whole (civil and military aviation and a small part of kerosene sold but not consumed)[20]. It exceeds CO2 emissions of civil aviation - 905 Mt CO2 in 2018 - used as reference in this report (see chapter 5.7.1). By relating to this reference the figures from Lee et al., (with a 0.875 factor corresponding to the ratio of 905 Mt to 1034 Mt CO2), we get the following numbers: 1.573 Gt CO2e (including CO2 and non-CO2 effects, excluding upstream phase); 668 Mt CO2e for net non-CO2 effects, of which 570 Mt CO2e due to contrails and cirrus generated.

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[16] By "climatic pollutant", we refer in this document to greenhouse gases (CO2, methan, water vapour, ozone…) and the contributors to non-CO2 effects of aviation (nitrogen oxides, anthropogenic clouds, aerosols, etc.).

[17] Global Warming Potential. These metrics are used by UNO and various states including France, and in France, the DGAC, the ADEME, the Bilan Carbone® method, etc.

[18] Etminan, M., Myhre, G., Highwood, E. J., and Shine, K. P. (2016), Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing, Geophys. Res. Lett., 43, 12,614– 12,623, doi:10.1002/2016GL071930.

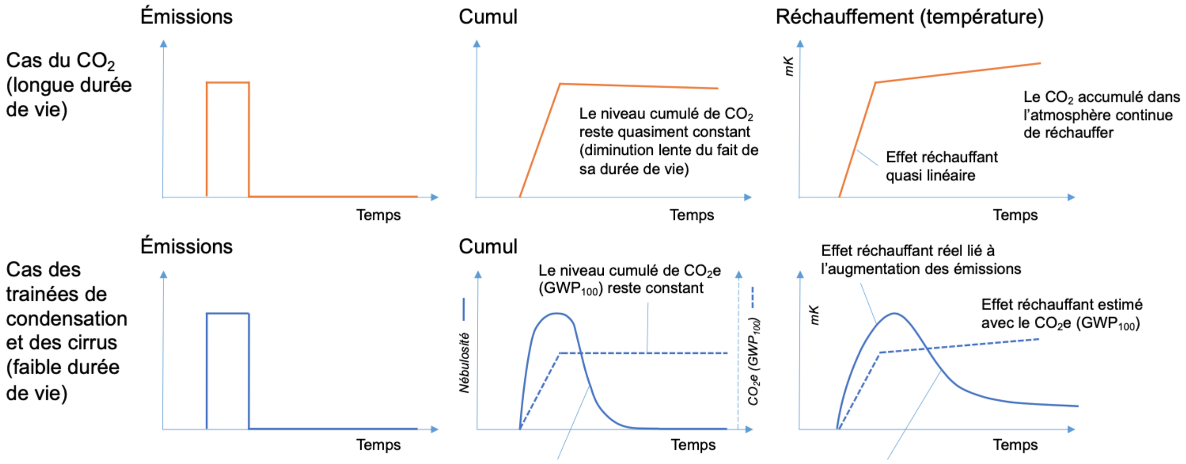
[19] Table 5, column GWP_{100}, in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018.

[20] See appendix A in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018.

However, as Lee et al. explicitly state in their publication[21], concerning non-CO2 effects of aviation, that the figures to these effects do not illustrate properly their real impact on climate change. They also point out that the method consisting in assessing non-CO2 effects of aviation in CO2 equivalent by multiplying CO2 emissions due to combustion by a constant factor computed with the GWP_{100} metrics, does not properly bring out the temporal dynamics that characterize these non-CO2 emissions.

Indeed, according to the computing method associated with the GWP_{100} metrics the warming dynamics generated by climatic pollutants produced by aviation are counted in the same way whether the pollutants have a long lifetime (here, CO2) or a short lifetime (eg. contrails and anthropogenic cirrus, the main contributors to non-CO2 effects of aviation, that only remain in the atmosphere for a few hours to a few days at most).

Yet, these dynamics are radically different, as shown by the example hereafter that compares the temperature rise caused by CO2 emissions peak (long lifetime), with that caused by an intensity peak of contrails and cirrus from aviation (short lifetime). Concerning this second peak, the example shows the results computed from the modelisation for CO2 equivalent in the GWP_{100} metrics. The diagrams in the figure below illustrate the example with no quantitative value: the scales differ from one graph to another. Only the shape of the graphs built by analogy with the results of a study from Lynch et al. are examined. These results are computed with climate models applied to methane emissions, another short lifetime climatic pollutant.[22]



[21] See chapter 6 in Lee *et al.*, 2020, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018.

[22] John Lynch *et al.*, 2020, Demonstrating GWP*: a means of reporting warming-equivalent emissions that captures the contrasting impacts of short- and long-lived climate pollutants, Environ. Res. Lett. 15 044023, https://doi.org/10.1088/1748-9326/ab6d7e

Case of CO2 (long lifetime)	Emission Time	Cumulative The cumulative level of CO2 remains almost steady (slow decrease due to its long lifetime) Time	Warming (temperature mK CO2 amassed in the atmosphere continues to warm Warming effect almost linear Time
Case of contrails and cirrus (short lifetime)	Emission Time	Cumulative Cloudiness------ The cumulative level of CO2e (GWP_{100}) remains steady Time The cloudiness vanishes because clouds have a very short lifetime	mK Real warming effect due to the increase in emissions Warming effect estimated with the CO2e method (GWP_{100}) Time Temperature drop due to the dissipation of clouds

Figure 10 - Illustrating the climate dynamics induced by CO2 emissions peak or by an intensity peak of anthropogenic clouds caused by aviation (contrails and induced cirrus)

In the case of the CO2 emissions peak, the rise in temperature is almost linear until the end of the peak, because CO2 gradually builds up in the atmosphere. Once the peak is passed, the CO2 build-up[23] causes the temperature to continue rising slowly due to its long lifetime. The warming and its amplitude are respectively caused by the amount of CO2 build-up due to its long lifetime and by the amount of CO2 built up.

In the case of the intensity peak of contrails and induced cirrus, a sharp rise in induced warming is observed at first, followed by a sharp decline when emissions stop as these clouds dissipate fast (in some days at most). It is from the variations in the emissions of these short-lived climatic pollutants and from the recent level of these emissions that is

[23] Progressive degradation of CO2 is shown on the cumulative graph for CO2, explaining its slow decline.

determined the variation of temperature induced - rising as the levels of emissions increase or declining as they decrease.

The example above also shows that using the GWP_{100} metrics to compute the spot CO2 equivalent of contrails and induced cirrus during the peak, and then adding on these CO2 equivalent emissions, result in warming dynamics similar to that of the CO2 alone case. Therefore, in the case of a strong rise in short-lived climatic pollutant emissions, the GWP_{100} metrics thus underestimates their climatic impact, since the immediate warming effect of these pollutants is in fact faster and stronger. Conversely, in case of a fast decline or stop of these emissions, the metrics overestimate their climate impact.

As the GWP_{100} metrics are unable to properly model the short-term and long-term climate impact of non-CO2 effects due to aviation, it is preferable to draw on the warming dynamics induced in order to issue recommendations about the evolution of non-CO2 effects due to aviation rather than value them in a non-representative CO2 equivalent figure.

In order to compute the radiative forcing, Lee et al. use different metrics - GWP* (Global Warming Potential with an asterisk signifying an improvement) that allows to capture these transient effects in a simplified manner. Whereas GWP_{100} models all effects , even short-lived, as prorated to the effects of CO2 which is long-lived, a study by Lynch[24] shows that GWP* takes two effects into account: the recent variation of emissions, prevailing, and the build-up over time, minor[25].

Taking the variations of short-lived effects into account as prevailing is crucial. Indeed, Lynch shows in his study that:

- in the case of a strong rise in emissions with short-lived effects, GWP_{100} underestimates their effect. That has been the case over the last years, with an exponential rise of air traffic and therefore of its short-lived non-CO2 effects like cirrus
- in the case of a slow rise, stagnation, decline or stop, it overestimates them. That is the case for the year 2020 with the traffic drop due to the COVID crisis.

[24] J. Lynch, M. Cain, R. Pierrehumbert and M. Allen, Demonstrating GWP*: a means of reporting warming-equivalent emissions that captures the contrasting impacts of short- and longlived climate pollutants, Environ. Res. Lett. 15 (2020) 044023, https://iopscience.iop.org/article/10.1088/1748-9326/ab6d7e

[25] According to the Lynch study, emissions in CO2 equivalent (E_{CO2eq}) of a pollutant (whether it is a greenhouse gas different from CO2, or contrails) are defined in relation to the real emissions (E) in the following way, for both GWP* and GWP_{100} metrics:

- **GWP_{100}** → $E_{CO2eq} = GWP_{100} * E$
- **GWP*** → $E_{CO2eq} = k * (GWP_{100} * E) + k' * GWP_{100} * (100\ years/\Delta t) * \Delta E$

We recognize, in the computing of CO2 equivalent emissions via the GWP*, the term that takes the emissions in the moment into account in the moment, the GWP_{100} term, that will be lightly weighted by a small k factor (for example 10%), and we discover a new term that takes into account the recent variations of emissions ΔE on a time period Δt shorter than 100 years (reference period for GWP_{100}), weighted by a bigger k' factor (for example 90%).

To illustrate the impact of this change of metrics, here is what Lee finds for the year 2018:

- with GWP_{100}, the effect of cirrus was equivalent to 63% of the CO2 emissions
- with GWP*, the effect of cirrus was equivalent to 1.77 times (177%) the CO2 emissions.

GWP* shows that cirrus have a higher effect than what was anticipated with the GWP_{100}, because of the strong rise in air traffic before the COVID crisis.

In the end, GWP* allows to better represent the short-term/long-term effects of short-lived GES, underestimated and overestimated respectively by the GWP_{100} metrics.

Despite the introduction of these more relevant metrics, it remains that non-CO2 effects are still associated with high levels of uncertainty, and scientists are still making progress in understanding them.

One of the conclusions expressed by Lee et al. in their publication identifies the principles associated with these recommendations: " to halt aviation's contribution to global warming, the aviation sector would need to achieve net-zero CO2 emissions and declining non-CO2 radiative forcing [...]: neither condition is sufficient alone".

It is therefore necessary to **commit to a fast decrease in the intensity of non-CO2 effects, in order to reduce in very little time the immediate contribution of aviation to global warming**. Paths are identified, to this day, leading towards a reduction of the appearance of contrails and induced cirrus[26] (diverting planes towards air corridors or flight altitudes less favourable to the formation of contrails, avoiding evening or night flights when these clouds have a particular warming effect, reducing particle emissions…) or to reduce NOx emissions but these may lead to higher consumption, complications in airspace management and needs for technological maturation.

However, as shown above, even if the non-CO2 effects of aviation were entirely suppressed, it is nevertheless the level of built up CO2 that determines the middle and long-term level of aviation induced global warming. It is therefore crucial **to reduce CO2 emissions of aviation too, as of now in order to slow induced global warming**. It has to be drastic and carried out in the next two to three decades.

In addition, so as to meet the first condition stated above, **any decarbonising measure will have to go together with a verification that either it does result in a reduction of non-CO2 effects or that it does not increase them, based on the most up-to-date science**.

[26] Roger Teoh, Ulrich Schumann, Arnab Majumdar, *et al.*, 2020, Mitigating the Climate Forcing of Aircraft Contrails by Small-Scale Diversions and Technology Adoption, Environ. Sci. Technol. 2020, 54, 5, 2941–2950, https://doi.org/10.1021/acs.est.9b05608

Yet, although scientists regularly make progress in their knowledge of these phenomena, uncertainties on the assessment of climate impacts and on non-CO2 effects mechanisms remain high. **Developing the present research conducted to refine the knowledge of non-CO2 effects**, as well as ensuring the independence of their funding, is therefore a fourth fundamental condition for these verification.

To summarise, here are the key figures and recommendations to remember concerning the contribution of aviation to anthropogenic climate change, for the year 2018.

Emissions of aviation in 2018 (CO2 alone and CO2eq computed with GWP_{100} metrics		
Combustion alone	905 Mt CO2	namely 2.1% of CO2 global emissions, including deforestation and change of land use
Combustion + upstream	1.077 Gt CO2	namely 2.6% of CO2 global emissions, including deforestation and change of land use
Total CO2eq (combustion + upstream)	1.095 Gt CO2eq	counting CO2 equivalent of CH_4 and N_2O emitted during combustion and upstream, computed with GWP_{100} metrics

Nota: since the figures in CO2 equivalent of non-CO2 effects computed with GWP_{100} metrics are not representative, they are not accounted for in the total CO2 equivalent displayed here.

Net radiative forcing due to aviation (CO2 and non-CO2 effects)		
CO2 alone (2018)	34.3 [28 - 40] $mW.m^{-2}$	namely ⅓ of the net effective radiative forcing due to the gradual build-up of CO2 in the atmosphere along the years
Non-CO2 effects (net, 2018)	66.6 [21 - 111] $mW.m^{-2}$	namely ⅔ of net effective radiative forcing of aviation.

		The effective radiative forcing of contrails and induced cirrus is 1.7 times higher than that of CO2. It is only due to the clouds formed on the short-term owing to their short lifetime
Net total (2018)	100.9 [55 - 145] $mW.m^{-2}$	computed from 1940 to 2018

Net contribution of aviation to anthropogenic radiative forcing: this part amounts to 3.5 [3.4 - 4.0] % of effective anthropogenic radiative forcing for the year 2011. It is not possible to compute this contribution for the year 2018 since anthropogenic effective radiative forcing has not been estimated after 2011.

Fundamental principles to reduce the contribution of aviation to global warming
• Reducing right now and in the long run CO2 emissions of aviation in order to slow down induced warming, its magnitude being tied to the CO2 build-up in the atmosphere • Committing to a fast decrease in the intensity of non-CO2 effects, in order to reduce the immediate contribution of aviation to global warming in a very short time • Ensuring that any decarbonising measure **will have to go together with a verification that either it does result in a reduction of non-CO2 effects or that it does not increase them, based on the most up-to-date science** • **Developing the present research conducted to refine knowledge of non-CO2 effects**, as well as ensuring the independence of their funding in order to avoid any conflict of interest.

5.8 Situation of the aerial sector in 2020, impacts of the COVID-19 crisis

Civil airline industry is going through the most serious crisis in its lifetime. The consequences for airlines are especially noticeable. They now spread to all the actors of this industry: aircraft manufacturers, engine manufacturers, equipment manufacturers, maintenance and repair specialists, airport operators and all the subcontractors network. The health crisis due to the first wave of COVID-19, travel restrictions imposed by States and the revival of the pandemic in autumn 2020 have led to an unprecedented drop in global air traffic, with high consequences.

5.8.1 An abrupt stop to air traffic growth

COVID-19 pandemic has caused a strong decrease in air traffic during the year 2020: the main phases of the impact on traffic are reminded below.

From March to May 2020, during the first wave of the pandemic, most airlines in Europe cancelled over 90% of their flights due to the travel restrictions implemented. Around the world, other major domestic markets (Australia, Brasil, China, USA, Japan, Russia) had their traffic drop by 87% compared to april 2019, while international traffic remained close to zero[27].

From May to the end of July 2020, the evolution of the health situation made possible a slow recovery of traffic[28] on domestic markets and some international markets. In France, Orly airport, closed since the end of March, thus re-opened on June 26[29], but with very little traffic (70 flights versus 600 to 650 on a usual basis). In continental Europe (ECAC[30] zone), domestic and international lines progressively re-opened, leading to an increase in the number of flights increasing (-61% compared to July 2019, EUROCONTROL data[31]). On a global scale (IATA data[32]) traffic in July 2020 was a little under 80% lower than in July 2019 (92% decrease in international flights and 57% in domestic flights), with strong disparities from one region to another (-79% in Schengen zone versus -28% in China)

[27] IATA, June 2020, *Air Passenger Market Analysis - April 2020: Air passenger demand comes to a standstill amidst lockdowns*

[28] IATA, Apr. 21st. 2020, *COVID-19 Assessing prospects for domestic markets*

[29] Le Monde, June 26th, 2020. Après trois mois d'arrêt, un premier avion a décollé de l'aéroport d'Orly

[30] ECAC : European Civil Aviation Conference. Intergovernmental authority implemented by ICAO and the Council of Europe, gathering 44 states (41 of them being member states of EUROCONTROL)

[31] EUROCONTROL, July 2020, *EUROCONTROL Comprehensive Assessment for Thursday, 30 July 2020*

[32] IATA, July 2020, Air Passenger Market Analysis - July 2020: Limited recovery continues to be driven by domestic markets and

However, during the month of August 2020, increasingly deteriorating health situation led to slow down this beginning recovery. According to IATA data[33], global traffic was thus steady in September 2020 with a drop of a little under 73% compared to September 2019 (-89% for international flights and -43% for domestic flights), versus a drop a little over 75% (-88% for international flights and -50% for domestic flights) in August 2020 compared to August 2019. Disparities remained important in September 2020 from one large region to the other: -76% in Europe versus -2.8% in China. In number of flights, traffic in Europe (ECAC zone) had dropped by 51% in August and by 54% in September (EUROCONTROL data[34]).

Since the end of September, the appearance of a second epidemic wave in most countries affected by the first wave (except for China) led to another series of travel restrictions during the month of October in many countries, particularly in western Europe. These restrictions, lasting from 4 to 6 weeks, started to be relieved in the beginning of December 2020.

The epidemic resurgence during December 2020 and the propagation of new variants of the virus (United-Kingdom, South Africa, etc.) brought new uncertainty, and many additional restrictions[35]. For example, almost 900 flights were cancelled within some days out of or to the United-Kingdom as of December 20, 2020. Stock exchange quotations of airlines or airline industry companies also dropped at the end of the year. At last, during January 2021, as additional restrictions came into effect, air traffic slowed down, especially international traffic.

On a global level, the IATA measured a 66% traffic decrease in 2020, in comparison to the December 2019 RPK levels (-76% for international flights, -50% for domestic flights)[123], confirming the forecast which was established in November[124]. This volume corresponds to 1999 traffic. Early February 2021, the association published two short-term scenarios for the year, depending on the measures to be taken in reaction to the new Covid variants : annual traffic could increase by a mere 13% instead of the 50% increase presented in the optimistic scenario (in figure 11 below).

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[33] IATA, November 2020, *Air Passenger Monthly Analysis – September 2020 : The recovery in passenger travel slows amid elevated risks*

[34] EUROCONTROL, October 2020, *EUROCONTROL Comprehensive Assessment for Wednesday, 14 October 2020*

[35] Les Echos, Dec. 21st, 2020, Covid : le « lockdown » britannique fait rechuter le transport aérien ; Le Journal de l'Aviation, Dec. 21st, 2020, La liste des pays qui suspendent les arrivées depuis le Royaume-Uni ; IATA, Jan. 29th, 2021, *IATA Economics' Chart of the Week - Travel restrictions rise amidst new COVID variants*

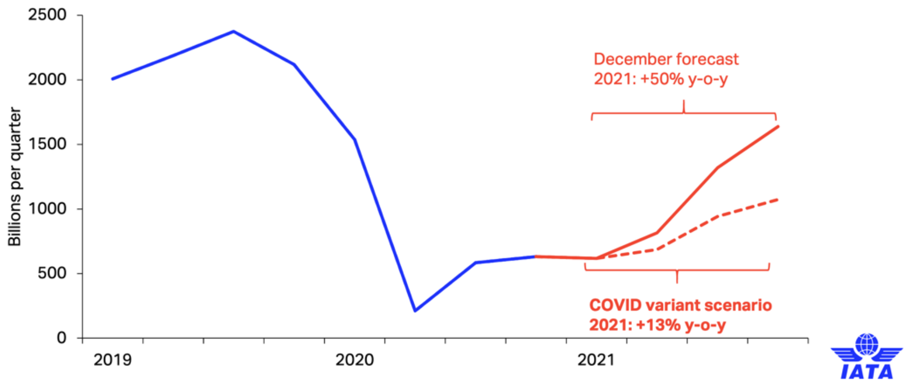

Figure 11 - Monthly evolution of traffic variation in RPK compared to the previous year's month, source IATA

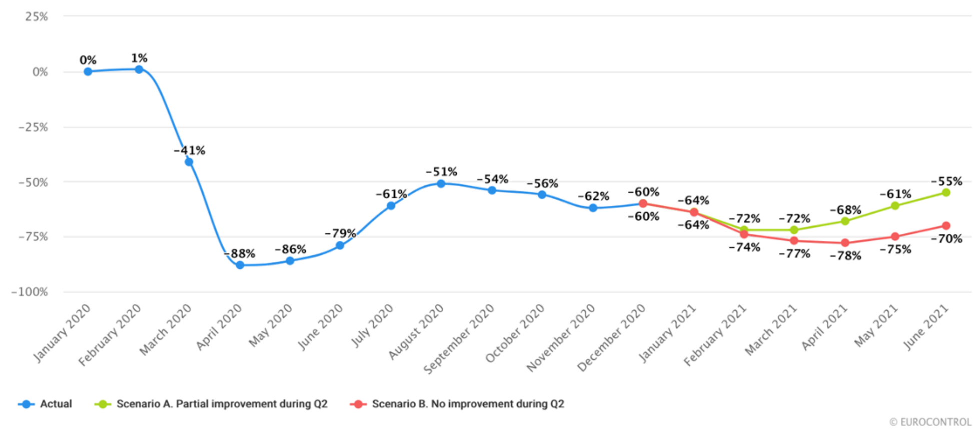

Figure 12 – monthly traffic evolution compared to the corresponding 2019 month and short-term traffic forecast in number of flights, source EUROCONTROL

On a European level, EUROCONTROL measured a 55% decrease in the number of flights in 2020. For the first semester of 2021, the organization built two potential traffic scenarios as presented on Figure 12 above[125]. One is based on an improvement of the situation during Q2, the other on a standstill (respectively, a 55% and 70% decrease in the number of flights in June 2021 compared to June 2019).

This abrupt traffic decrease disrupts the industry forecasts which expected at least a twofold increase between 2017 and 2037 in the annual number of passengers, growing from 3.5 billion to 7 or 9 billion[126]. As of now, the industry hardly counts on a traffic recovery to the 2019 levels within 4 or 5 years onwards.

[123] IATA, February 3rd, 2021, Air Passenger Market Analysis - December 2020, COVID-19 Weak year-end for air travel and outlook is deteriorating

[124] IATA, November 24th 2020, Airline Industry Economic Performance - November Report - 2020

[125] EUROCONTROL, Dec. 17th. 2020, EUROCONTROL Comprehensive Assessment for Thursday, 17 December 2020

[126] IATA, February 2018, IATA Forecast Predicts 8.2 billion Air Travelers in 2037

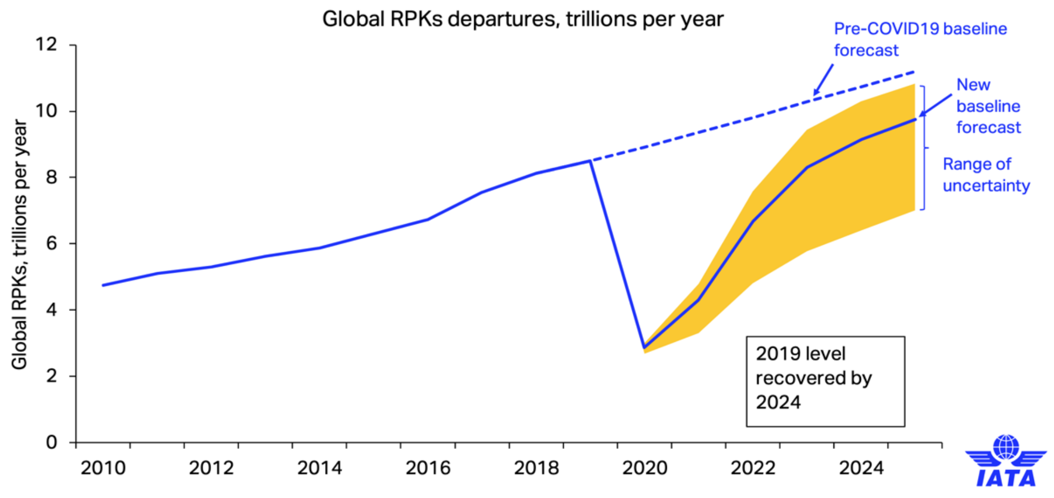

Figure 13 – IATA traffic forecast, November 2020.

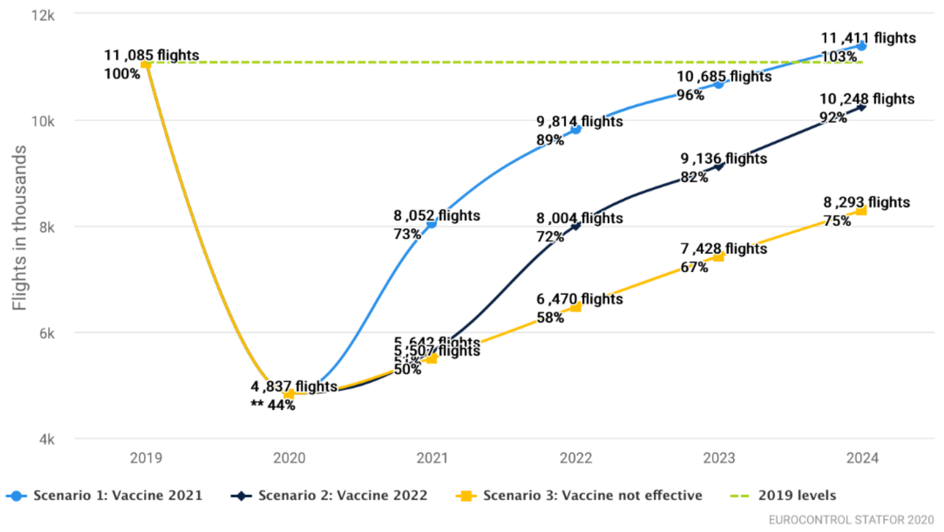

Figure 14 – EUROCONTROL 3 traffic recovery scenarios (in number of flights) for ECAC zone.

The IATA traffic forecast, which was updated in November 2020, indicates that a return to 2019 global traffic levels would not occur before 2024. Traffic should first rise strongly in 2021(4 393 billion RPK, i.e. around 50% of the 2019 traffic), then increase more slowly. However, this forecast bears strong uncertainty until 2024, as shown in Figure 13 above.

Concerning ECAC zone, EUROCONTROL identified 3 recovery scenarios, depending on the availability and efficiency of SARS-COV2 vaccines. They are shown in figure 14 p.52. Scenario 1, which is the most optimistic, with efficient vaccines that would be widely deployed out by mid-2021, indicates at best a traffic recovery (in number of flights) on the ECAC zone by 2024. Scenario 2, considered the most likely by EUROCONTROL at the time of the publication of the forecast, considers an efficient vaccine, widely deployed by mid-2022. It predicts a delayed return of the traffic to the 2019 levels, that is to say in 2026. Lastly, scenario 3 is the most pessimistic, considering an ineffective vaccine in a context of a rampant pandemic. In this case, a return to 2019 level traffic would occur in 2029, that is to say 10 years after the beginning of the health crisis[127].

[127] EUROCONTROL, November 4th, 2020, Five-Year Forecast 2020-2024

5.8.2 A temporary decrease in CO2 emissions related to air transport

Before the health crisis, and since 2009, CO2 emissions related to air transport had been constantly rising due to traffic growth. They amounted to 905 Mt of CO2 in 2018, to 914 million tonnes of CO2 in 2019 (excluding upstream part and non-CO2 effects). In its late 2019 forecast[128], the IATA predicted their reaching 936 Mt of CO2 in 2020.

Both the crisis and the strong decrease in air traffic associated have had conspicuous consequences on the industry's climate impact, with a very strong decrease in emissions in 2020, as shown in the graph below, which presents the evolution of the emissions since 1990.

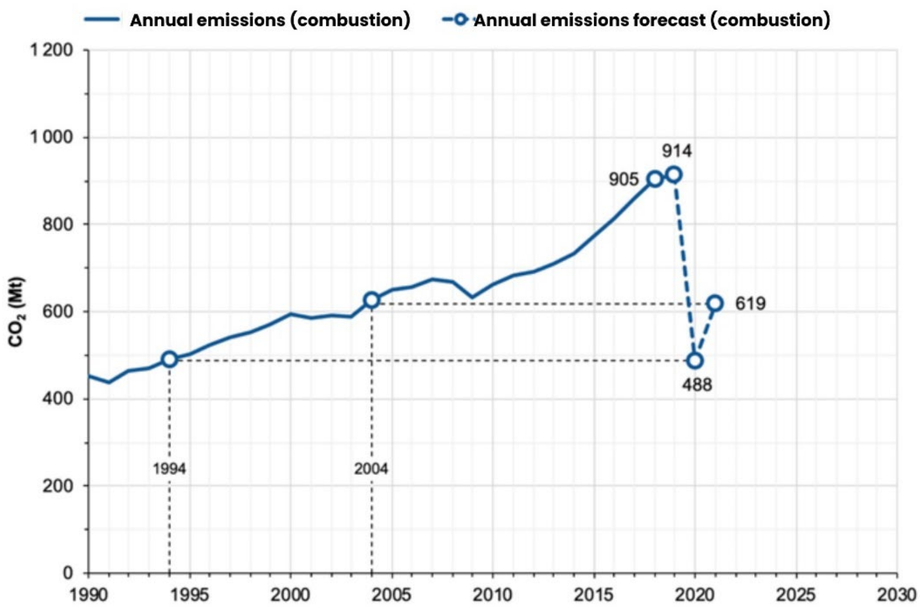

Figure 15 –Evolution of CO2 emission related to global air transport (source IATA)

In its 2020 year-end report[124], the IATA forecasts a strong decrease in the CO2 emitted by air transport, with 488 Mt of CO2 in 2020, which corresponds to the 1994 quantity (a 46% decrease compared to the 2019 level and a 48% decrease compared to the initial 2020 forecast).

Between 2019 and 2020, EUROCONTROL indicates that CO2 emissions on the ECAC zone have decreased by 57%, with significant variations between member states (in Belgium, for instance, the number of flights decreased by 50% compared to 2019 but the CO2 emissions have only decreased by 30% as a result of an increase in cargo traffic)[129]. Moreover, the low traffic level in the area has also made it possible to optimise the flights efficiency, thanks to the lifting of some airspace restrictions. It allowed the concerned airlines to save 26,000 nautical miles for daily flights[130].

The IATA estimates that CO2 emissions should increase again in 2021, to reach 619 megatonnes of CO2, i.e. the 2004 level, remaining 32% below the 2019 CO2 emissions[124]. Due to the observed decrease in traffic and depending on the estimated pace of recovery (see figure 13 p.52), the reduction of the industry's annual CO2 emissions in comparison to the expected levels could therefore continue at least until 2024.

[128] IATA, December 11th 2019, Airline Industry Economic Performance - December 2019 – Report

[129] EUROCONTROL, January 26th 2021, Data Snapshot on CO_2 emissions from flights in 2020

[130] EUROCONTROL, January 1st, 2021, Think Paper #8 - Impact of COVID-19 on European Aviation in 2020 and Outlook 2021

These reductions would nonetheless be temporary because, if air traffic growth rate was to catch up with pre-crisis pace, CO2 emissions would increase threefold within 25 to 30 years[131].

5.8.3 Airlines inservice fleet will not be the same anymore

Airlines have very quickly adapted their offer to the travel restrictions, grounding a large part of their in-service fleets. As the restrictions were lifted, in particular between June and September, the number of in-service aircrafts increased again. However, in its year-end report[124], the IATA forecasts a 58% decrease in available seat capacity, compared to the 2019 levels.

According to the IATA, in November 2020, 22,500 planes were in service globally, while 9 800 were grounded[132], (see Figure 16). EUROCONTROL data[133] show a clear impact of the first wave of the COVID-19 pandemic between mid-March and mid-June 2020, and the consequences of the second wave between mid-September and mid-November 2020 on the air fleets of the ECAC zone airlines.

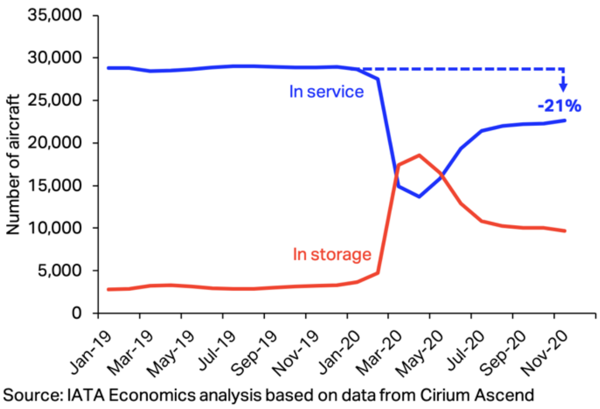

Figure 16 – Global share of in-service and grounded aircrafts (jets and turboprop aircrafts)[132]

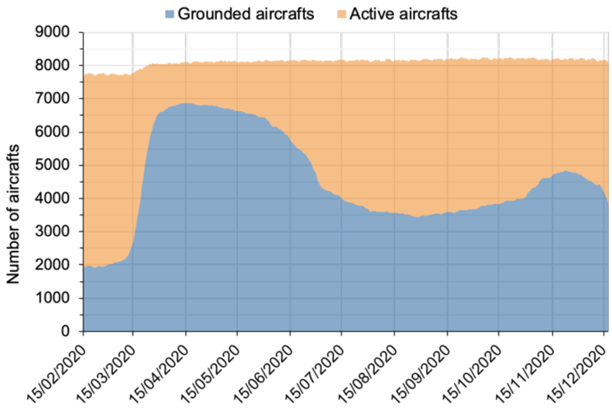

Figure 17 – Evolution of the number of in service planes and grounded planes since February 2020 on the ECAC zone (source EUROCONTROL[133])

For several airlines, the crisis has been an opportunity to permanently stop operating some of their oldest aircrafts among their fleets due to their fuel consumption and higher maintenance costs. Thus, the IATA forecasts that in-service aircrafts will decrease by 17,5% in 2020[124]

Withdrawals from service should continue in 2021 and should concern 8% of the fleets[134]. Some kinds of aircrafts, such as the Boeing 777 are particularly affected[135]. Delta Airlines ended in December 2020 the withdrawal of all the Boeing 777 it owned, replacing them with A350.

Several airlines also anticipated the retirement of some of their biggest carriers, which were harder to make profitable. Air France announced in May 2020 the permanent grounding of its 9 Airbus A380. Lufthansa also decided to anticipate the resale of its six A380[136] . Only a few airlines still operate significant A380 fleets, such as Emirates which owns 115 of them.

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[131] Carbone 4, October 2019, Les émissions de l'aviation internationale pourraient tripler d'ici 2045 et compromettre les objectifs du secteur

[132] IATA, December 16th. 2020, Airlines Financial Monitor-November 2020

[133] EUROCONTROL, COVID-19 - Grounded aircraft in the EUROCONTROL area

[134] IATA, October 27th 2020, Can costs be downsized to make the industry cash positive

[135] Le Journal de l'Aviation, December 1st 2020, Le Triple Sept, prochaine grande victime de la crise

[136] Le Monde, May 21st 2020, Trop cher, trop polluant, pas assez rentable : Air France abandonne l'Airbus A380

British Airways decided, for its part, not to fly its thirty-one Boeing 747s again[137] . Similarly, Virgin Atlantic has retired from service all its Boeing 747s.

Finally, from March 2021 onwards, many airlines have either cancelled orders, or negotiated a postponement of new aircrafts deliveries to curb their cash consumption (as most of the payment of an aircraft occurs upon the delivery). One example is EasyJet, which changed 15 A320neos delivery dates to between 2022 and 2024, and postponed to 2027 and 2028 22 other aircrafts deliveries which were previously expected between 2022 and 2024 in the aim of not having to receive any aircrafts in 2021, without canceling any order[138]. At the end of June 2020, Norwegian canceled the order for 92 Boeing 737 MAX and 5 Boeing 787[139]. According to the IATA, less than half the expected deliveries for early 2020 will have been carried through, which represents 800 planes[132]. The number of deliveries should increase in 2021, to around 1,300 aircrafts, growing back to the 2019 level.

The crisis thus intensifies changes which started a few years ago, with the planned end of quadjets in civil aviation and the surge of twinjets. Aircraft manufacturers have been adapting their catalogue for more than a year to this transformation. Airbus had already announced the cessation of the A380 production in February 2019[140]. Boeing, for its part, had announced in July

2020 that the 747 production would stop in 2022[141]. Within two to three years, long-haul aircrafts sold by manufacturers will therefore be exclusively twinjets, often of a more recent design, less fuel-consuming, such as Airbus A350-900, Boeing 787 and, in a near future, so as to offer more flexibility to airlines, long-range single-aisle aircrafts such as Airbus A321 XLR and the Boeing 737-10[142].

Despite the crisis, Airbus[143] and Boeing[144] still show strong 20-year growth perspectives in their market forecast, which are nevertheless indicative of the changes mentioned above. Both manufacturers announce the acceleration of the fleets renewal in the ten years to come, in contrast to the trend observed in the last ten years, when new aircrafts would essentially add up to existing fleets. Airbus forecasts a global fleet of a little less than 45,000 aircrafts for 2038 (24,000 more than in 2018, requiring around 39,000 deliveries) ; Boeing, for its part, evaluates that the number of in-service aircrafts worldwide will increase by 3.2% per year by 2039, with a need for over 43,000 deliveries.

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[137] Les Echos, July 17th 2020, Le mythique Jumbo Jet de Boeing fait ses derniers tours de piste; Le Journal de l'Aviation, Dec. 14th. 2020, British Airways fait ses adieux à son dernier Boeing 747 ; Air Journal, December 22. 2020, Le dernier 747 de Virgin Atlantic est parti

[138] Le Journal de l'Aviation, Dec 22nd. 2020, Easyjet repousse ses livraisons d'Airbus A320neo de plusieurs années

[139] Le Monde, June 30th 2020, La compagnie Norwegian annule une commande de près d'une centaine d'avions Boeing

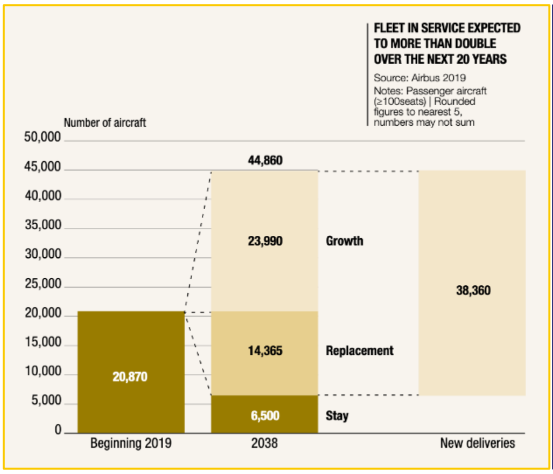
[140] Le Monde, February 14th, 2019, Airbus annonce la fin de l'A380

[141] Les Echos, July 29th 2020, Boeing sonne le glas de son mythique 747

[142] Les Echos, August 21st 2020, Coronavirus : les flottes d'avions ne seront plus les mêmes

[143] Les Echos, October 7th 2020, Airbus juge prématuré de modifier ses prévisions de marché ; Airbus, Sept. 18th 2019, Global Market Forecast

[144] Les Echos, Oct 6th 2020, Malgré la crise, Boeing prévoit toujours le doublement de la flotte mondiale sur 20 ans ; Boeing, November 18th 2020, Commercial Market Outlook 2020–2039



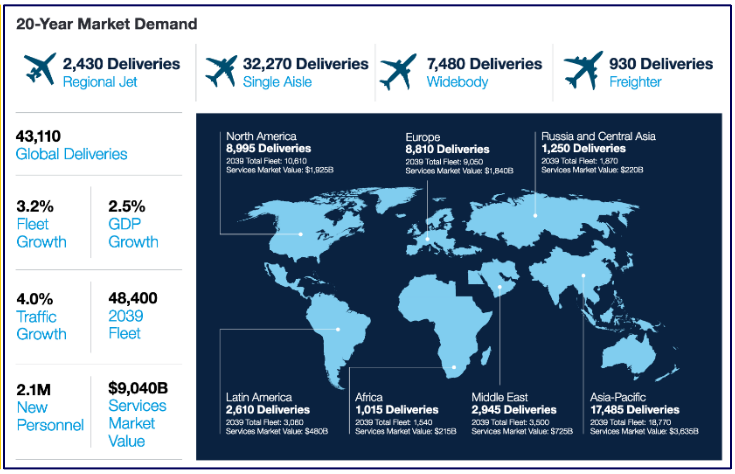


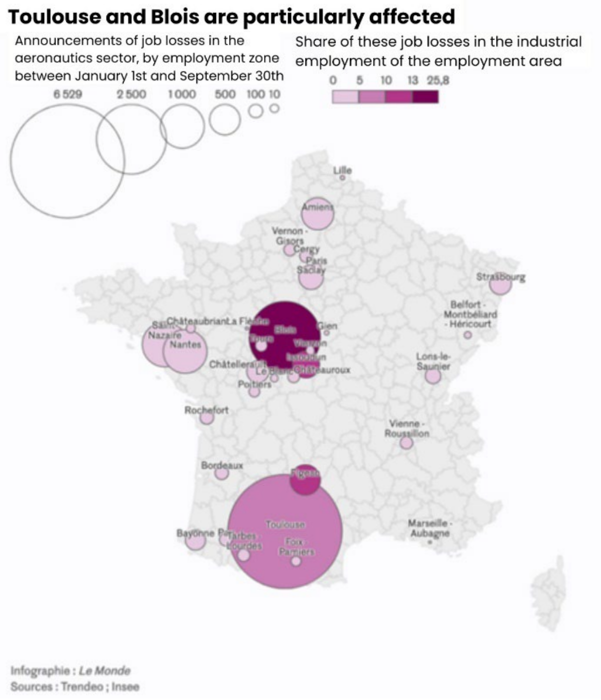
Figure 18 – Airbus 20-year forecast Figure 19 – Boeing 20-year forecast

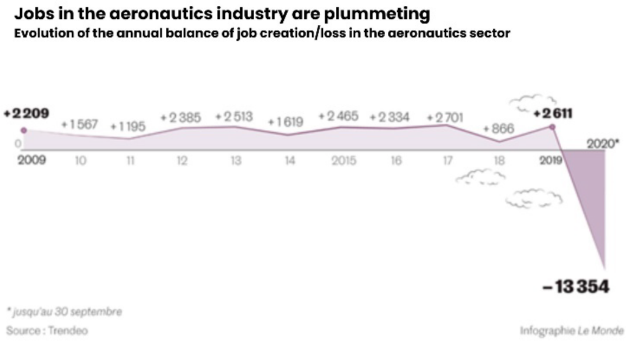
5.8.4 Significant social and economic impacts

Every company in this industry is affected, with the risk of cascading bankruptcies, and jobs and unique know-hows losses. It is estimated that 10 million direct jobs and 65 million indirect jobs are affected globally[145]. The impacts are huge in France: the job and investment monitor Trendeo estimated in early October 2020 that the first semester had wiped off the job increase of the past ten years. It represents more than 13,000 jobs which are cut or being cut, in comparison to a net increase of approximately 12,000 jobs created by mid-March[146]. The adaptation of the PSE (French employment protection scheme) thanks to state aids has somehow enabled a decrease in these numbers.

[145] IATA, April 14th 2020, Remarks of Alexandre de Juniac at the IATA Media Briefing on COVID-19, 14 April 2020

[146] Le Monde, OCt. 5th. 2020, En six mois, le secteur de l'aéronautique a perdu la totalité des postes créés entre 2009 et 2019





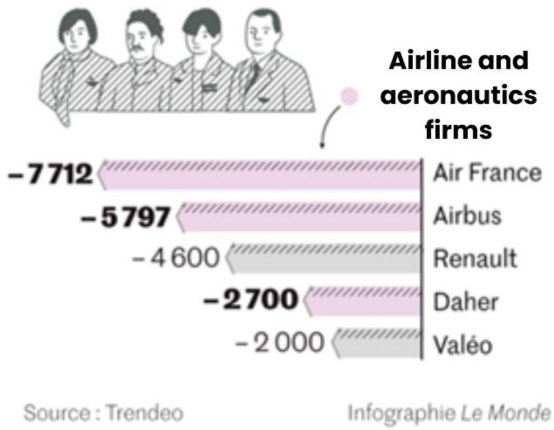


Figure 20 - Infographics showing the impacts on aviation industry jobs in France (source Le Monde[146])

5.8.4.1 Impacts on the airlines

The crisis should reshuffle the cards of the air transport market in the next few years, with total losses of 118.5 billion dollars in 2020 and a loss in annual revenue related to the decrease in air traffic which amounted to 510 billion dollars, according to the IATA[124]. Since March 2020, the airlines have implemented austerity plans (delivery postponement, reduction of the fleet, wage freezes or wage reductions), carried out several waves of job cuts and benefited from public support plans (mainly in the USA and in Europe). At the end of November 2020 the IATA estimated that their cash consumption should persist at least until the 3rd trimester 2021[147], with a likely inversion during the 4th trimester. However, this scenario depends on the evolution of the global health situation and the lifting of travel restrictions. Several airlines worldwide are still facing cash shortfalls on the short-term, which is questioning their long-term viability.

Several bankruptcies, or placement under state supervision have already happened, sometimes to major or historic airlines. Virgin Australia was the first airline to file for insolvency on 21st April 2020[148]. The two main South American airlines, LATAM (Chile, Brasil) and Avianca (Columbia), filed for chapter 11 bankruptcy protection in the USA to restructure[149].

After a year of crisis, major national airlines stay in a difficult position, as their revenues have plummeted, following the almost total absence of international traffic and the loss of their business customers. Major european airlines (among which British Airways, Lufthansa, Air France-KLM and their branches) suffered huge losses in 2020, which could have led them to bankruptcy if they had not obtained financial support from their home countries. On the other hand, on the other side of the Atlantic, Air Canada has not, and like every other canadian airline, benefited from a government aid plan, and its future remains uncertain. Job cuts amount to tens of thousand. These Airlines, often part of the civil aviation history, will certainly have to reinvent themselves after the crisis, perhaps to become “thinner and smaller” as Lufthansa’s CEO was mentioning in January 2021. Those who benefited from government aid plans from the EU, in particular Air France-KLM and Lufthansa, face the risk of having to provide compensation in the form of airport slots, which could weaken them even more[150].

Low-cost carriers which had based their development on transatlantic travel, have, for their part, seen their business model collapse in less than a year and refocused their activity. For instance, the scandinavian company Norwegian is currently under bankruptcy protection law, as well as Virgin Atlantic (for which transatlantic traffic amounted to 70% of its activity) which should be able to get through the year 2021, with the help of fundraising operations.

On the contrary, in the US, the four major airlines (American Airlines, United Airlines, Delta Air Lines and Southwest) still have the investors’ confidence, who “still believe in the future of major airlines”, due to their lower exposure to international and long-haul traffic, their pre-crisis profitability as well as the value of their customer loyalty programmes. Yet, they have recorded a 65% decrease in revenue in 2020, and vast net losses, amounting to 31.5 billion dollars[151]. Their going bankrupt has been avoided thanks to significant aids from the US federal state ($ 25 bn in March 2020, followed by $15 bn in december 2020, with $ 17 bn which could be added in 2021) as well as $ 30 bn of raised funds[152]. The restructuring measures which have been undergone are drastic: the Airlines for America Federation, which represents the US airlines, estimated that 90,000 jobs, i.e. 20% of US air transport staff could be cut[153].

[147] IATA, Nov 27th IATA Economics' Chart of the Week - Vaccines may bring end to cash burn bythe end of 2021

[148] Le Monde, April 21st 2020. Coronavirus : la compagnie aérienne Virgin Australia se déclare en cessation de paiements

[149] Challenges, May 11th 2020. Coronavirus : Ruinée par la crise, la compagnie aérienne Avianca fait faillite ; Ouest France, May 27th 2020. La compagnie aérienne LATAM s'effondre à la Bourse, le Chili étudie un plan de sauvetage

[150] Les Echos, Feb 8th, 2021, Front uni chez Air France-KLM contre les exigences de Bruxelles

In Europe, the low cost carriers RyanAir, EasyJet and Wizz Air have managed to limit the impacts of the crisis and preserve assets in anticipation of a traffic recovery: their business model does not depend on long-haul flights and business-class revenue, and they had a much more significant treasury than their competitors. They also took advantage of the crisis to lead very aggressive policies both on human resources, with more than 8,000 jobs cut and wage decreases of 10 to 14% in average, and on business side (RyanAir has been renegotiating airport fees, procurement and aircraft rentals; Wizz Air is spreading and increasing its network density, see annexes[154]).

5.8.4.2 Impacts on the aviation industry

Pessimistic traffic forecasts as well as delivery postponement and cancelation initiated by airlines (800 actual deliveries versus 2,000 initially planned[132]) (see Figure 21) resulted, since March 2020, in an adaptation of the aircraft manufacturers production rates (Airbus, Boeing, Embraer[155], etc).

This drop in production rates has then passed on to engine and equipment manufacturers (General Electric, Pratt & Whitney, Rolls-Royce[156], Safran, etc.) and subsequently, indirectly to all their subcontractors value chain. The 2020 results plummet compared to 2019 with, for a majority of stakeholders, very significant operating losses followed by cost cutting plans and job cuts.

The two major aircraft manufacturers (Airbus and Boeing) have set up additional measures since March 2020, with the lifting of lines of credit, the use of part-time work schemes and aggressive cost cutting plans.

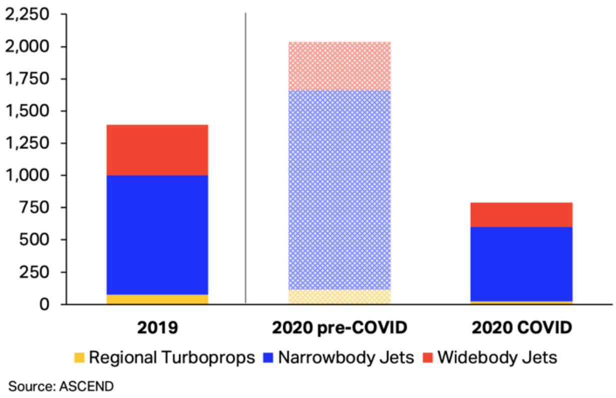


Figure 21 – Comparison of aircraft deliveries in 2019 and 2020 (planned before the COVID crisis and actual) [132]

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[151] 12.4 bn for Delta Air Lines, 8.9 bn for American Airlines, 7.1 bn for United Airlines and 3.1 bn for Southwest. Source : Les Echos, Jan 14th 2021, Delta Air Lines tombe de haut, avec une perte record de 12 milliards de dollars ; Les Echos, Jan. 21st 2021, Avec le Covid, United a perdu 7 milliards de dollars en 2020 ; Les Echos Investir, an. 28th 2021, Lourdes pertes annuelles pour American et Southwest Airlines

[152] Les Echos, March 26th 2020, Les compagnies aériennes américaines obtiennent une aide de 58 milliards de dollars ; L'Usine Nouvelle, December 21st 2020, USA: Le plan de relance prévoit 15 milliards de dollars d'aide à l'aérien ; Les Echos, Jan. 29th 2021, Pour les compagnies aériennes américaines, le Covid-19 est pire que le 11 septembre

[153] Website Airlines for America ; Les Echos, Nov. 13th 2021, Covid-19 : le secteur aérien américain pourrait perdre 90.000 emplois Les Echos, Feb. 4th 2021, Covid : 13.000 salariés d'American Airlines menacés de licenciement

[154] Le Monde, August 6th 2020, La bonne fortune des compagnies aériennes low cost ; Les Echos, Nov. 2nd 2020, Covid : Ryanair continue de survoler la crise

[155] Embraer is the brasilian aircraft manufacturer, making both civil and military aircrafts

[156] Rolls-Royce Holding plc: group composed of aviation, power generation, nuclear and data divisions. It corresponds to the initial Rolls-Royce company's former aviation branch, which has been separated from the Motorcars branch in 1971.

Furthermore, they announced in June 2020 the cutting of around 15,000 jobs for Airbus, and 30,000 for Boeing. The latter, already weakened in 2019 by the 737 MAX flight ban, has recorded 2020 as its worst year ever, with net losses amounting to 11.9 billion dollars and the delivery of only 157 aircrafts. Airbus, for its part, suffered a net loss of almost 3 billion euros over the first 9 months of 2020 and delivered 556 aircrafts.

As for engine and equipment manufacturers, the crisis spread on two sides, impacting the original equipment revenue as well as the revenue related to technical support contracts per flight hour. Airlines cancellations and postponement of deliveries have reduced or delayed incoming cash flows, new engines and equipment being paid at the moment the aircraft is delivered, just like the aircraft manufacturers. The drop in traffic and the grounding of a number of planes have made it difficult to generate revenue as expected from support contracts per flight hour, a growing part of their business model. The british equipment and engine manufacturer Rolls Royce is particularly stricken, due to its focus on high power engines (for long-haul aircrafts) and the large preponderance of per flight hour contracts in its revenue. Since the beginning of the crisis, General Electric, Rolls Royce and Safran, expecting significant losses, have implemented cost-cutting initiatives, including especially the reduction of their raw material purchasing and subcontracting, supply-chain rationalisation and the cutting of around 42,000 jobs. These job cuts, with the risk of losing key competence and expertise, acquired with difficulty in the past, jeopardise the industry's decarbonation, engine and equipment being among the main conveyor of the aircrafts optimisation of energy efficiency. .

The large number of industrial subcontractors of the industry have thus suffered with full force the decrease of the demand, coming from the major purchasers in this industry, translated into an increase in redundancy plans, voluntary separation and the use of part time work[157] [158], in particular in France.

Small and medium enterprises, which are crucial for the industry, such as Latécoère, Figeac Aero, Mécachrome, SKF, Aubert & Duval, supplying aerostructures, interconnection systems, mechanical parts, equipment and sub-assemblies, and high-performance metallurgical materials, had a disastrous year, after years of investment to meet the increase in production rates required by their clients. They have had to adapt their production assets, rationalize their plants, and cut hundreds of jobs in France. These cases exemplify only partly the situation of all French industrial subcontractors in the sector which are for the main part SME or very small enterprises[159]. In Occitanie region (cradle of the aviation industry in France, with Airbus world headquarters and many subcontractors based in this area), 71 companies from the region have thus started a redundancy plan, threatening the survival of 7,000 to 8,000 jobs according to the Union des Industries et Métiers de la Métallurgie. Since mid-2020, the State as well as Regions (local authorities) have implemented measures to foster the industry's consolidation, financially support local companies and assist in the diversification of their activities[157]. Lastly, in december 2020, a complimentary state-guaranteed loans scheme, the "PGE Aéro", was set up with the support of Airbus, targeting the aerospace subcontractors. They will be able to loan up to twice their average stock value during the last two financial years and have their overstock bought back by a porting platform which would sell them back to them incrementally, adjusting to the demand level. These measures could help them overcome the difficulties they are facing. Many firms are now demonstrating their willingness to hold the distance and diversify in the aim of becoming more resilient to crises and hazards[160].

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[157] Le Monde, July 30th 2020, Aéronautique : autour de Toulouse, le feu couve au sein des sous-traitants

[158] Les Echos, Oct. 29th 2020, Les syndicats de l'aéronautique dénoncent un abus des plans sociaux

[159] Le Monde, May 15th 2020, « Soit on s'adapte, soit on meurt » : en Occitanie, les sous-traitants de l'industrie aéronautique résistent ; Le Monde, July 1st 2020, En Occitanie, les sous-traitants de la filière aéronautique retiennent leur souffle ; Le Monde, December 22nd 2020, « La crise nous oblige à nous réinventer » : comment les sous-traitants de l'aéronautique résistent

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French service and engineering companies are then starting to put in place drastic adaptation measures to face the situation (long-term part-time schemes, redundancy plans etc.), in the context of an increasingly uncertain recovery and cost-cutting set up by the industry's purchasers. It is especially the case in the Occitanie Region, where 8 to 10,000 engineers were without a mission in early July 2020 (see in annexes for the cases of Sogeclair Aerospace SAS, Assistance Aéronautique Aérospatiale, Akka Technologies, Expleo Altran and Alten Sud-Ouest). These measures, beyond the direct or indirect consequences on local economies and on a social level, jeopardise future research and development programs by the aircraft and engine manufacturers to decarbonise air transportation. As the chairman of Syntec-Ingénierie mentions "We cannot develop an aircraft without being assisted by engineers, (…) they are part of the production ecosystem"[161], and it will probably be hard to acquire the lost skills again[161].

Lastly, a large number of MRO players have seen their revenue largely decreasing due to the in-depth optimisation of fleet use, as they were already penalised by the traffic slowdown. Both by getting off the market (temporarily or permanently) the oldest planes or those in need of a general renovation in the short term, and by exchanging engines or landing gears between planes to optimise the use time before needing a complete revision, these measures triggered a decrease in the sales of spare parts (often made by engine or equipment manufacturers) as well as a drop in cash inflows linked to maintenance operations (in particular in workshops). The retrofit market for airplane cabins should probably remain largely affected by the consequences of the crisis in the short run, with an expected 50% drop in investments from airlines between 2021 and 2025[162].

5.8.4.3 Impacts on airport operators

The crisis unsettled the financing mechanisms of airports (in France among other countries[163]), as well as the local economy[164] and employment situation. According to the European Airport Association, nearly 200 airports could go bankrupt[165]. Airports and their interrelated firms (layover management companies, security, services, hospitality, stores, and so on) are also facing a sharp drop in resources, mainly caused by the lack of airport usage fees and by the decrease in traffic and thus activity. The poor number of transiting passengers impacts stores in airports terminals, which face a drop in their revenues and a decreasing attractivity of commercial infrastructures. Yet, this source of revenue is important for airport management[166].

Large investments to increase airport capacity have been delayed for at least two to three years or even cancelled, reinforcing the local economic impacts or the spread to other sectors. The project to build a new terminal 4 in Roissy Charles de Gaulle airport is now judged "obsolete" and incompatible with the environmental approach of the French government. The project in its current format was officially abandoned in the beginning of February 2021[167].

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[160] Les Echos, Dec. 23rd 2020, Covid : nouvelles aides pour les sous-traitants de l'aéronautique ; Ministère de l'Economie, des Finances et de la Relance, Dec. 23rd 2020, Bruno Le Maire annonce le lancement des PGE «Aéro», et la conclusion d'un premier financement d'envergure, soutenu par Airbus, au bénéfice des fournisseurs de la filière aéronautique ; Le Journal de l'Aviation, Dec. 23rd 2020, Avec le lancement des PGE « Aéro », l'État renforce son aide aux fournisseurs de la filière aéronautique

[161] Le Monde, July 4th 2020, Les ingénieurs, victimes collatérales de l'aéronautique en crise

[162] Le Journal de l'Aviation, October 8th 2020, Le marché du rétrofit de cabine pourrait être réduit de moitié jusqu'en 2026

[163] Les Echos, Sept. 2nd 2020, Aérien : la crise remet en cause le modèle des aéroports français

[164] Le Journal de l'Aviation, Dec. 31st 2020, Aéroport de Roissy-Charles-de-Gaulle : la crainte d'une « catastrophe sociale »

[165] Les Echos, Dec 31st 2020, Deux cents aéroports européens au bord de la faillite

[166] Les Echos, Dec. 1st 2020, A Orly et Roissy, le Covid plombe les commerces de luxe des aéroports

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5.9 Which CO2 emission forecast for this industry?

5.9.1 Industry's target for international traffic

As early as 2009, the airline industry, through the ATAG, set the aim of reducing 50% of the CO2 emissions generated by international flights in 2050, compared to the 2005 level. This objective is to be met thanks to :

- the continuous improvement in energy performance, from 1.5% to 2% per year.
- Carbon offset should allow to stabilise emissions from 2020 onwards. These figures have been revised in 2019, due to the COVID crisis
- The rising use of alternative fuel

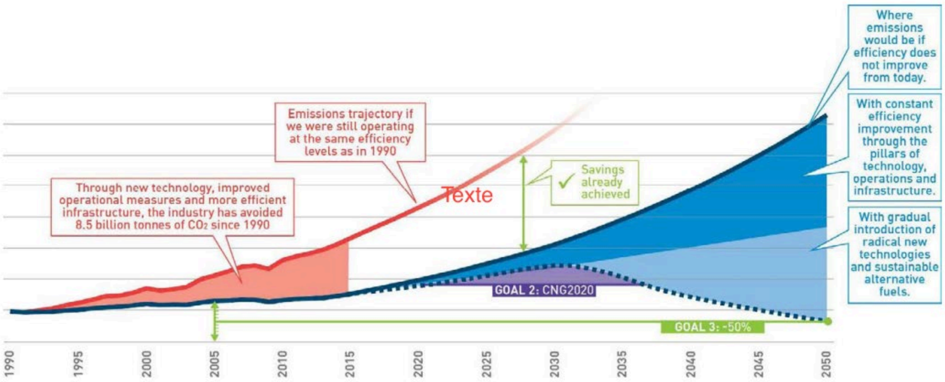

Figure 22 - Graph taken from the « 2019 Environmental Report » by ICAO (p174)[168], illustrating the industry's pledge

This objective is remarkable as few other sectors made such commitments globally. It is also very ambitious but how compatible is it with a +2°C carbon budget?

Between 2005 and 2019, the energy performance surpassed the initial target, in particular with the launch of the latest generation of aircrafts: A320 NEO family, A330 NEO, A350, B737 MAX and B787.

However the growth in traffic has been such that CO2 emissions significantly increased. Between 2000 and 2018, the number of passenger-kilometer-carried increased by 62% in France, while CO2 emissions relative to air transport grew by 21%, despite the decrease in CO2 emission per unit (kg of CO2 per PKM). Between 2017 and 2018, CO2 emissions of the airline industry in France grew by 3.8%, reaching 27 Mt of CO2, including upstream emissions.

The airline industry acknowledged these trends. In 2019, the ICAO forecast that the international flights emissions would multiply by 2.5 to 4 before 2050, if not for a major reduction scheme. The ICAO revised the energy performance down to 1.37% (if no major technological breakthrough is found) allocated between plane performance improvement (0.98% per year) and air and ground operations improvement (0.39% per year). The ICAO (through the CAEP) has then revised the projected trend as shown below:

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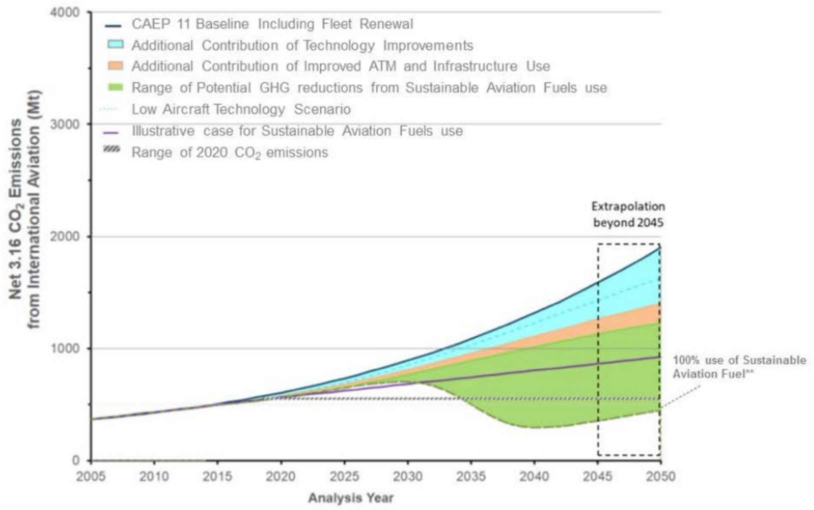
[167] Les Echos, Feb. 11th 2021, Le gouvernement enterre le projet d'extension de Roissy, devenu « obsolète »

[168] https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf



Note: Reductions in atmospheric carbon from sustainable aviation fuel use occur from feedstock production and fuel conversion and not from fuel combustion.

Figure 2. Net 3.16 CO_2 Emissions from International Aviation, 2005 to 2050, including Sustainable Aviation Fuels Life Cycle CO_2 Emissions Reductions

Figure 23 – CAEP expected trend, extract from the 2019 ICAO Executive committee minutes[169]

This trend differs from the 2009 ATAG trend. Its outcome shows that in spite of the expected technological evolutions and the full use of SAF (sustainable aviation fuel) in 2050, CO2 emissions in 2050 should be equal to the 2005 level, not half of it. Considering those hypotheses, the ATAG target would not be met. On the other hand, we can also see that the CORSIA offset would be effective only between 2020 and 2034. Afterwards, CO2 emissions will go below the 2020 level thanks to alternative fuel.

- Global emissions in 2005 amounted to around 650 MtCO2eq[170](combustion alone), that is to say around 644 MtCO2eq without upstream emissions. They would be in the range of 322 megatonnes in 2050 if we halve them. However, if we consider a 905 MtCO2 hypothesis (combustion alone, no upstream emissions) in 2018 (cf. §5.7.1), decreasing by 3,39%(cf. §4.2.3) per year, the outcome in 2050 will be around 300 MtCO2 emitted. The ATAG target is therefore above this objective.

- Moreover, the objectives are not expressed in terms of CO2 budget, although it is the key indicator to describe the CO2 impact on climate. It is thus very difficult to confirm or deny an alignment with a climate objective such as those presented by the IPCC. In any case, the curve is obviously above a 3.39% per year decrease curve. Total accumulated emissions (the "integral of the curve") would therefore exceed the carbon budget if they were computed.

However, the ATAG reaffirmed in september 2020 that this objective was aligned with the Paris Agreement, if not exceeding the expectations. It justifies this claim by referring to the 2050 target from the 2DS scenarios ("2 degrees scenario" and B2DS "Beyond 2 degrees scenario"), developed by the IEA in its 2017 ETP report. This reasoning is flawed for two reasons:

[169] https://www.icao.int/Meetings/a40/Documents/WP/wp_054_fr.pdf

[170] ATAG Waypoint 2050 report p27 (https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/)

[171] Way Point 2050, https://aviationbenefits.org/media/167116/w2050_full.pdf

[172] Energy Technology Perspectives 2017 https://www.iea.org/reports/energy-technology-perspectives-2017

- 2DS and B2DS scenarios have been put forward by the IEA in 2017. They suggest a global strategy which aims at limiting global warming at "+2°C" and "+1,75°C" with a 50% probability. As of now, they cannot be said to be "aligned with the Paris agreement" as they could then be. The IEA has since put forward a new scenario, the SDS "Sustainable Development scenario", which aims at limiting global warming to "+1.8°C" with a 66% probability, which is considered "in line with the Paris Agreement". 2DS and B2DS should not be considered as up-to-date references;
- Not only does the IEA report present emissions targets for 2050, but it also describes the way to meet them and the related accumulated emissions in relation to a carbon budget. In fact, the ATAG paper proposes an expected trajectory associated with an (pre)allocated carbon budget for a time period, but does not evaluate the corresponding cumulative emissions on that same period. This situation makes it impossible to conclude anything concerning the air transportation emissions.

Thus, even if these objectives are noteworthy for they are ambitious and consolidated in the whole industry and globally, they are not in line with climate forecast such as those put forward by the IPCC in terms of carbon budget. At this point, we cannot define a robust climate/physical framework through which we could consider the likely global evolution of air transport, either from a technological, use cases, traffic perspectives or employment angle.

5.9.2 Adopted approach to account for emissions[173]

On the basis of observations from §5.9.1, we choose to reconstruct target and trend-based scenarios on which we will apply :

- improvement levels intended by the sector ("Sector" scenario)
- improvements brought by measures we propose

173 see Calculations note for details on calculations in this paragraph

Intrinsically, air transport finds its place, usage and customers in an international context. While today's public authorities act in majority on the scale of countries (or economic unions of countries), aircraft and engine manufacturers are naturally positioned on the global market. Hence, for Europe and particularly for France, which has a major part of its international aviation industry on its territory, the questions of decarbonisation, innovation development, the future of air transport, the sector's economic growth and social impacts need to be addressed on a global scale. Furthermore, the majority of Airbus' clients are not french and until now, perspectives for growth are more present in Asia, Africa, the Middle-East or even the United-States than in Europe. A study on a worldwide scale is therefore essential (cf. 8). However, at the local scale, the problem has its territorial, organisational and energy specificities, which, taken into account, allow for more precise and relevant proposals on decarbonising solutions. Provided competitive equilibrium is preserved in the measures' formulation and application, the latter should be taken at a national scale, at the level of industrial players, operators or legislators. Hence, the study on the french territorial scale (cf. 7) tries to inform national policies and evaluate impacts on national employment in the air sector (airlines, airports …). Either way, acting on both national and international levels is not incompatible and is essential to achieve the global objective.

Despite the latest advance on the "non-CO2" effects described in 5.7.2, it seems like there is still great uncertainty on the quantification of these effects. **In this report, we choose to focus exclusively on emissions linked to kerosene combustion and to the upstream portion, without adding in the CO2 equivalent of "non-CO2" effects** (as defined in chapter 1.1.3). As indicated in chapter 5.7.2, estimating the CO2 equivalent of these effects by multiplying only combustion related CO2 emissions by 0.7 (Lee et al.'s method) is representative of neither their immediate impact on climate (underestimation) nor their long term impact (overestimation).

However, despite uncertainties concerning their quantification, **not accounting for non-CO2 effects should not obscure their important contribution to immediate climate change** induced by aviation. It is therefore fundamental to apply the principles identified in chapter 5.7.4, using most up-to-date knowledge, and make sure all decarbonising measures implemented by the air sector reduce or at least do not increase the non-CO2 effects.

The first step is to precisely define the references, metrics and scope of study.

The scope of study corresponds to commercial aviation activities, in France or worldwide (passenger, cargo or courier flights). The french perimeter comprises domestic flights (including metropolitan-overseas flights and overseas-overseas flights) and international flights from or to the French territory.

Emissions linked to infrastructure building and maintenance, operation of air companies and aircrafts' complete life cycle (from construction to recycling) are not taken into account. As a matter of fact, these emissions are treated inside the scope[174] of the construction and manufacturing industries, not transport. If it is deemed necessary to take them into account for a complete carbon audit to evaluate an airport building or extension project, in comparison with other options, we consider here that transportation functions with "iso-infrastructures", meaning it utilises the capacities offered by existing infrastructures. Finally, emissions linked to building and recycling aircrafts are marginal compared to transport emissions[175], which is why it is relevant, when decarbonisation is taken as the goal, to encourage the renewal of the fleet with less polluting latest-generation aircrafts.

Emission values are evaluated in terms of CO2 only (excluding any other effect contributing to radiative forcing). The emission factors for kerosene are taken from the BaseCarbone® ADEME9 (kerosene Jet A1 or A): they are used to calculate emissions from the upstream portion (as a reminder, extraction, refining and transporting kerosene to the aircraft's reservoir), based on flight emissions.

For the global scope, emissions from 2018 are evaluated at 1.07 GtCO2 (only CO2), upstream part included (cf. 5.7.1).

For the french scope, air transport emissions (upstream part excluded) are taken from the French Civil Aviation Authority (DGAC)[176] data for 2018, which we limit to CO2 emissions only (effects of methane, nitrous oxide, etc. produced during combustion and present in the DGAC data are excluded). For international flights, only CO2 emissions from LTO[177] phases and from operating APUs[178] in and around french airports, as well as half cruising phases are attributed to France, the rest being attributed to the country of departure or arrival.

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[174] According to categories identified by the High Council on Climate, as stated for example in the general public version of the report 2020 Redresser le Cap, Relancer la Transition

[175] Around 0.5% maximum, according to interpreted data from figure 10 page 12 of report: https://www.fzt.hawhamburg.de/pers/Scholz/Airport2030/Airport2030_PUB_DLRK_13-09-10.pdf

[176] Ministry of Ecological Transition, Les émissions Gazeuses Liées au Trafic Aérien en France en 2018

[177] Landing & Take Off : includes landing, take-off, descent, climbing and rolling phases, but not cruising.

[178] Auxiliary Power Unit : auxiliary motor used on the ground for air conditioning and other power needs.

Within the framework of this report, emissions from the upstream part are accounted for and added to the data provided by DGAC. This is necessary to evaluate the potential of alternative fuels - biofuels, power-to-liquids (PTL), hydrogen - in reducing CO2 emissions. Alternative fuels, one of the major levers for decarbonisation put forward by players in the sector, do have an impact on CO2 emissions during their fabrication, especially biofuels and PTL.

Hence, inside the DGAC perimeter, including upstream parts related to kerosene production and transport and excluding any non-CO2 GHS, emissions are estimated at **26.7 MtCO2** for 2018. This value will be the reference for building carbon budgets, trend-based trajectories and for evaluating the efficiency of decarbonising measures proposed in this report.

5.9.3 Global and french carbon budget for air transport[179]

A sector's contribution to global warming is determined by its contribution to radiative forcing. Fixing a global carbon budget allows us to anticipate, with a certain degree of uncertainty, an evolutive trajectory for radiative forcing linked to CO2 emissions (or CO2 equivalent when possible). As seen in §4.2.3, the Paris Agreement did not lead to the definition of a carbon budget, either at a country or a sector's level. Nevertheless, as negotiation makes it possible to define different levels of commitment according to each country's specificities (emission level, GDP,...), it would be possible and even beneficial to define a cross-industry arbitration concerning carbon budgets. This arbitration would take into consideration the technical difficulty to decarbonise, the dependence level on fossil fuels, the actual contribution to emissions, the criticality of the sector in the future, the number of people working in the industry, etc. Unfortunately, if such an arbitration exists on a national level in France with the SNBC, it does not at the international scale. As the SNBC excludes emissions from international transport from its perimeter, and international flights account for 80% of emissions in 2018 according to DGAC, we cannot rely on its baseline carbon budget. Besides, this exclusion shows how the climate question as presented by the IPCC is still not apprehended on a global scale by public authorities and businesses (and not only the air industry).

The IEA proposed a sectorial approach in its scenarios, in particular in the SDS scenario updated in ETP 2020[180]. Regarding transport, figure 3.16 of the report shows that in the SDS scenario, the main emission reduction effort is on road transport (passenger and freight transport, cars and trucks) with a zero dependence on fossil fuels in 2070 for passenger transport, 2050 for trains and 2040 for 2 and 3-wheels vehicles. For aviation, the scenario proposes a constant but weaker reduction, amounting to around 0.3 GtCO2 in 2070, a level higher than the target formulated by the ATAG, but 85% lower than the emission target of the STEPS scenario taken as the baseline (« Stated Policies Scenario », namely the scenario accounting for measures already undertaken until now). This reduction is essentially achieved with technological, energy-based measures and alternative fuels, as well as a 10 to 12% traffic decrease compared to the STEPS scenario which assumes a high air traffic growth rate post-COVID, up to 6% per year in Africa. Note that the SDS scenario does not include compensatory measures in the calculation of emissions. It is therefore difficult to compare SDS with trajectories put forward by the air industry, which account for the CORSIA offset and do not stipulate reduced traffic growth.

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[179] see Calculations note for details on calculations in the this paragraph

[180] Energy Technology Perspectives 2020 - https://www.iea.org/reports/energy-technology-perspectives-2020

The IEA's criteria for distribution of efforts depend on an assessment of the dependence on fossil fuels and the difficulty to decarbonise, estimated to be significantly higher for aviation and sea transport than for other means. These criteria are technical ones which allow to set up an energy-based trajectory compatible with climate change challenges. They do not take into consideration problems of usage, societal transformation, social acceptability or political choices. While the IEA's SDS scenario is indeed compatible with the IPCC's RCP 2.6 scenario in its globality and provides the advantage of proposing a cross-sector distribution of efforts, the impact on populations of such a distribution should be discussed and the final distribution rendered legitimate by a democratic governance body.

Therefore, we assume the three following hypotheses to define a budget and a baseline trajectory for the french and international aviation sector :

1. As seen in §4.2.3, the global carbon budget defined by the IPCC, available from 2018 to 2100 and necessary to limit temperature increase to below +2°C from pre-industrial levels with 67% chance and below +1.5°C with less than 20% chance, is considered to be the maximum allowed to abide by the Paris Agreement. This budget, 1,170 GtCO2 available globally between 2018 and 2100, is compatible with the IPCC's RCP 2.6 scenario and will be used as the baseline.

2. As seen in §5.7.1, CO2 emissions (only) from the global air industry, upstream parts included, represent 1,077 GtCO2, being 2.56% of the world's emissions in 2018. We then allocate 2.56% of the carbon budget available from 2018 onward to the global air industry, that is ~29.9 GtCO2. Without bias in favor of or against the air industry, this method allows taking into account certain realities specific to air transport use and technological performance as opposed to other industries.

3. As seen in §5.9.2, emissions in the french perimeter of our study amount to 26.8 MtCO2 in 2018, being 2.48% of global emissions. Therefore we allocate 2.48% of the global air carbon budget to the french air industry, being ~744 MtCO2 available from 2018 to 2100.

This 744 MtCO2 budget corresponds to cumulated emissions resulting from a reduction scenario of 3.39% each year from 2018 to 2100. It means that, under this assumption, the air sector makes a reduction effort similar to this scenario's average, starting from the reality of its emissions in 2018 (the share of which in the global economy has increased for the last 10 years, due to increasing air traffic).

In this report, we look at trajectories until 2050. If the budget is not surpassed but totally depleted in 2050, it would mean that from 2051 onward, emissions must be zero and that the average annual reduction level must be more than 3.39% before 2050. These two hypotheses are not realistic and very risky, which is why we allocate for this period a budget corresponding to a 3.39% yearly reduction path from 2018 to 2050 (and not 2100), that being 536 MtCO2. Then there is 207 MtCO2 left available from 2051 to 2100, which is 28% of the global budget compatible with achieving carbon neutrality in 2100.

In the summary table below, we evaluate budgets corresponding to the 84%, 67%, 50% and 33% scenarios described in §4.2.3, in order to establish other baselines to calibrate ulterior trajectories.

Climate targets	CO2 budget available from 2018 to 2050 (MtCO2)			Total CO2 budget available from 2018 on (MtCO2)	Corresponding annual reduction rate
	World	World aviation (upstream included)	French aviation (DGAC perimeter, upstream included)	French aviation (DGAC perimeter, upstream included)	
84% chance below 2°C, RCP 2.6 compatible	726 264	18 586	462	575	4.55%
67% chance below 2°C	843 954	21 598	536	744	3.39%
50% chance below 2°C	944 374	24 167	600	946	2.57%
33% chance below 2°C	1 100 572	28 165	699	1272	1.51%

Table 4 - CO2 budgets for all sectors / air sector from 2018 to achieve climate targets

Recall that these budgets suppose:

- The reduction effort of the air industry is similar to the average cross-sector effort needed to achieve climate goals. It is the responsibility of public authorities and/or international instances to consider revising upward or downward adjustments of these budgets, depending on economic and societal priorities and each sector's own decarbonisation constraints.

- In the French perimeter for this carbon budget, "half-trips" from other countries to France are also accounted for. France being one of the first tourist destinations in the world, flights for tourism purposes are much more frequent than business flights and these "half-trips" constitute a significant part of the budget.

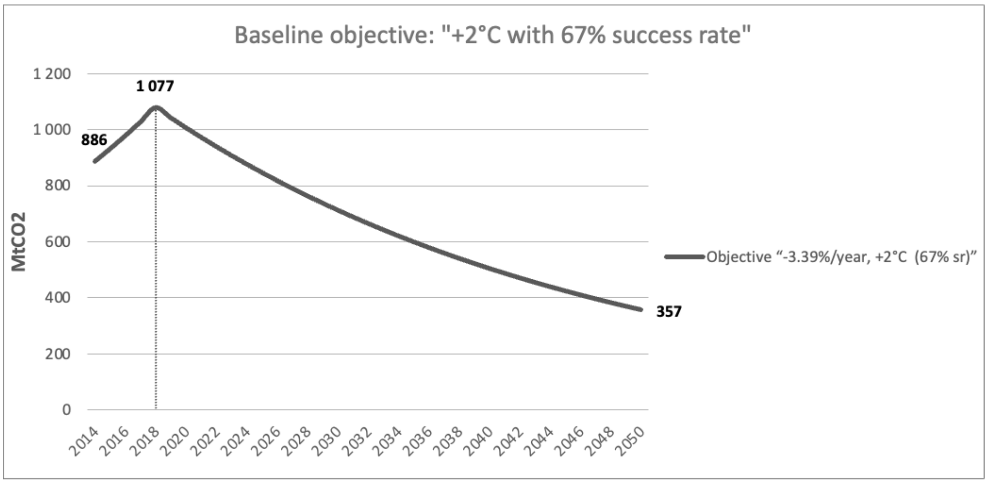

Figure 24 - Baseline trajectory - World

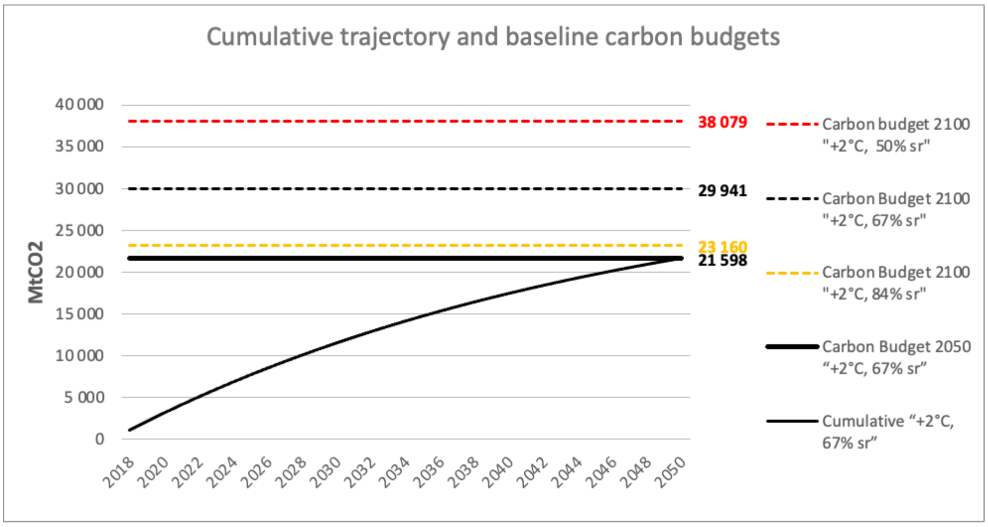

Figure 25 - Cumulative trajectory and baseline carbon budgets - World

5.9.4 Establishing a global trend-based baseline trajectory[181]

The working hypothesis of air traffic growth, outside of COVID periods, is the one most regularly formulated by the air industry : 4%/year[182]. This rate might be high, though it is still lower than the french growth rate of 4.54% between 2015 and 2019[183]. This is a fundamental hypothesis to determine the air industry's capacity to achieve decarbonisation targets. However, this study aims to look at conditions to stay below a given carbon budget, and to ultimately adjust this hypothesis accordingly. In that sense, the reference value used here is not a structuring one and could be modified if necessary.

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[181] See details of the hypotheses, estimations and references used in this paragraph in the calculations note

[182] In its 2019-2039 projection, the IATA forecast a global growth rate between 3.2% and 5.3% per year.

https://www.iata.org/contentassets/e938e150c0f547449c1093239597cc18/pax-forecast-infographic-2020-final.pdf

[183] 352.3 billion PKT in 2015 and 420,8 billion PKT in 2019, according to DGAC's tendanCiels indicators: https://www.ecologie.gouv.fr/statistiques-du-trafic-aerien

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The COVID crisis' impacts have been evaluated based on IATA and Eurocontrol previsions, assuming a return to the 2019 traffic level in 2024. This traffic recovery assumption will also be adjusted to evaluate its sensitivity. For now it helps to build the first draft of a plausible trajectory.

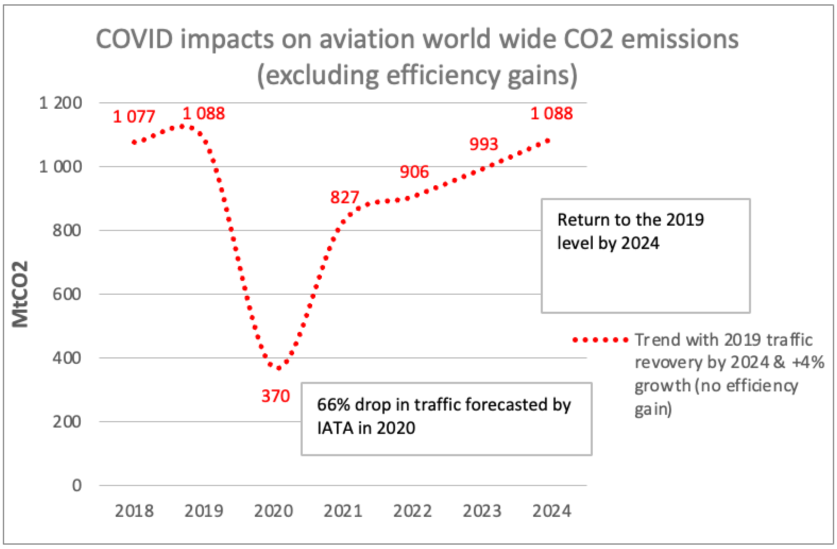

Figure 26- Forecast for COVID crisis' impact on global emissions (excluding any improvement in energy performance) (see details in the calculations note)

Therefore, we obtain a baseline trajectory for emissions which directly follows the traffic's evolution (without any improvement in performance), considering a full recovery in 2024.

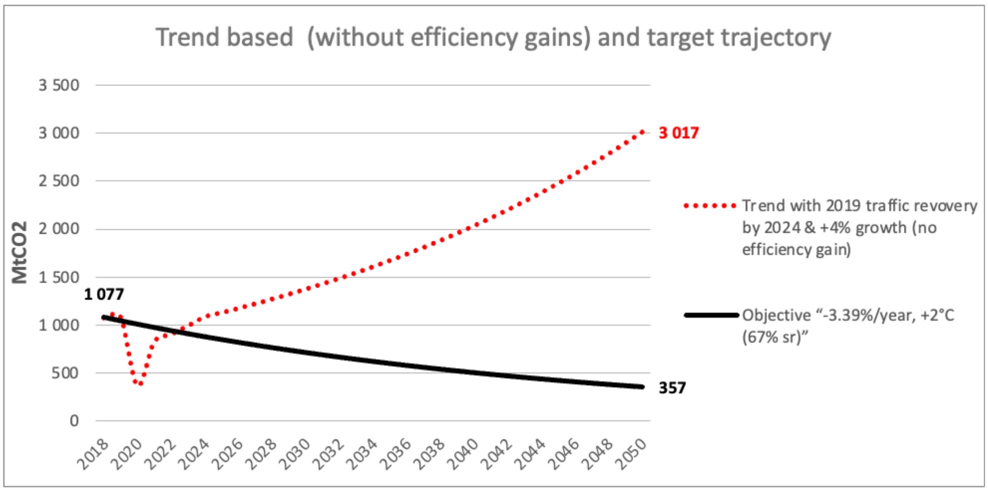

Figure 27 - Trend-based and target trajectories - World

With COVID effects included, the average growth rate is 3.5%.

5.9.5 "Sector" trajectories

Here we include in the model the effect of improvements predicted by the industry by 2050. We call them "Sector". These improvements are of two different natures: performance improvement (airplanes and operations) and alternative fuel usage.

5.9.5.1 Predictions of performance improvements

For the "Sector" trajectory we assume a performance improvement of 2% each year from 2018 onward, which is the most optimistic hypothesis put forward by the industry to date.

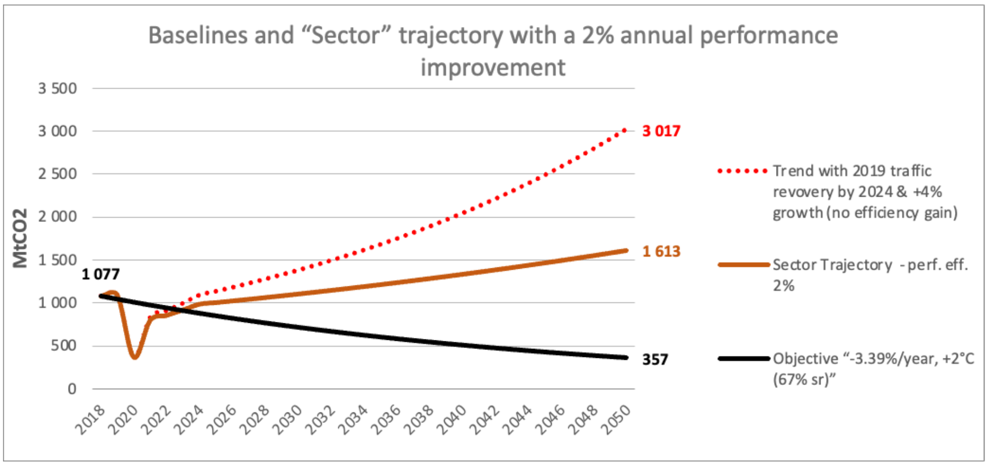

Figure 28 - "Sector" trajectory with a 2% annual performance improvement

The "Sector - 2% perf" trajectory from Figure 28 shows the impact of performance improvement on emissions.

- 5.9.5.2 The increasing importance of alternative fuels

The OACI predicts that in 2050, the global air fleet will operate with 100% of alternative fuels. Even though this claim seems extremely optimistic, especially with regard to production externalities of such fuel quantities, the aim here is not to dismiss this hypothesis, but to look at such an assumption's impact on emission trajectories and carbon budgets. The last generation operational airplanes (A3XX NEO, B737 Max, B787, A350) are certified for an alternative fuel mix of 50% (meaning they can operate with 50% of alternative fuels maximum). However, little alternative fuel is presently used because of non-availability. To reach 100%, new engines and certification processes should be considered. We take the assumption that this evolution will arrive by 2035. Alternative fuels taken in this study are of three types (biofuels, PTL, hydrogen) (see details in §7.2.2.3).

We assume the following:

- Alternative fuels are composed of 50% of 2nd generation biofuels (from green waste) and 50% of PTL produced with CO2 capture (half from the air and half from industrial plants) and hydrogen from water electrolysis (from wind power)[184].

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184 See details of assumptions and references used to calculate emissions in the calculations note.

- SAF production will amount to 6Mt in 2025 (see McKinsey and OACI estimations in §8.1) and should reach 100% in 2050 with a geometric progression, which corresponds to a production trajectory above actual projections.
- Despite recent announcements (from Airbus, particularly), a development of hydrogen technology by 2050 is regarded with caution by the industry. For example, the OACI trajectory published in 2019 (figure 23) does not include technological breakthroughs such as "Hydrogen airplanes". The ATAG's WayPoint 2050 report (published in 2020) indicates that "By 2050, it is expected that electric and hydrogen-powered propulsion have the potential to serve regional, short-haul and perhaps medium-haul markets"[185]. At this stage, we align ourselves with the no-hydrogen hypothesis, or rather one of "not enough hydrogen fueled planes to significantly curb emissions". In the next sections of the report we consider impacts of hydrogen technologies in more voluntary scenarios. Note that the "50% PTL" assumption mentioned above could be changed to "25% PTL and 25% hydrogen" without a major impact on emission trajectories.

This leads us to the following trajectory:

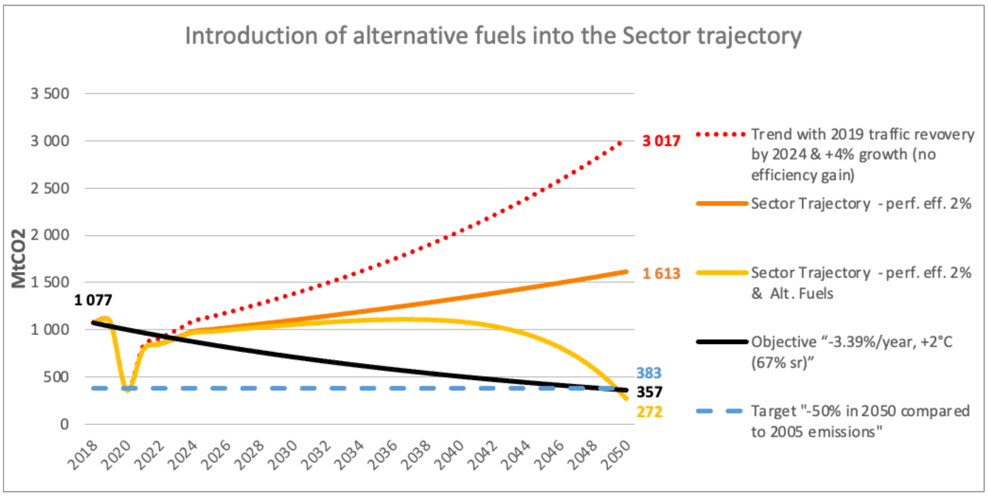

Figure 29 - Impacts of progressive alternative fuel introduction (50% biofuels, 50% PTL) to reach 100% in 2050

This trajectory is better than the ones predicted by the air industry (upstream emissions included)[186]. Under extremely favourable hypotheses (whose energy externalities are not studied here), we rebuild a trajectory which eventually leads to a target below ATAG's one ("Reducing by half the emissions of 2005 in 2050"), and even below the target of our baseline trajectory. However, this trajectory's carbon impact does not depend on the achieved target in 2050, but on accumulated emissions released in the atmosphere between 2018 and 2050, to be compared with the baseline carbon budget.

[185] https://aviationbenefits.org/media/167116/w2050_full.pdf

[186] see Calculations note: 650 MtCO2eq upstream excluded gives 766 MtCO2 with upstream parts in 2005, that is a 383 MtCO2 target in 2050

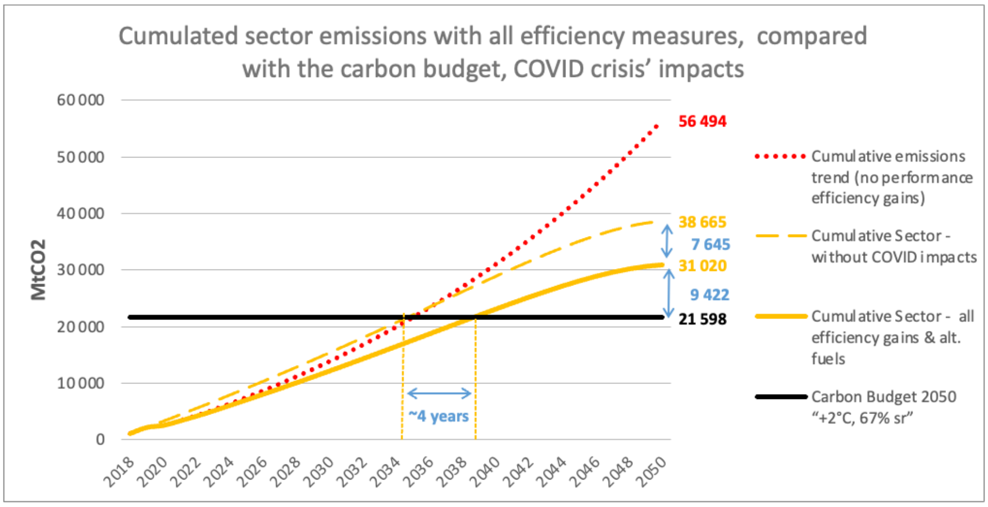

Figure 30 - Cumulated sector emissions with all efficiency measures, compared with the carbon budget and COVID crisis' impacts.

In this perspective, we see that the carbon budget will be depleted around 2039 and it is necessary to further reduce emissions by around 9.5 GtCO2 to be within the budget, that is an additional effort of about 30% of total cumulative emissions (see figure 30).

Comparing this curve with the "no COVID crisis" curve, other hypotheses remaining the same, we see that the crisis delays the time the budget is reached by 4 years and represents a 45% contribution to reduction efforts needed to stay within the budget.

These estimations are to be taken with caution, given the number of predictive assumptions made by the industry itself. However, they allow us to identify the problem and the approximate extent of the efforts to be made.

5.9.5.3 CORSIA's impact and "Final sectors" trajectories

As detailed in §5.6.2, CORSIA's capacity to ensure carbon neutral growth of global air transport from 2021 relies on compensated air routes, and thus on national participation in the program. As a matter of fact, the principle is to yearly offset emissions exceeding the average 2019-2020 level (eventually taken to be the 2019 level because of the COVID crisis) of the routes in question (ie. between participating countries). The more countries participate, the broader the route network, and the more important CORSIA's coverage of global aviation's CO2 emissions.

If we assume all countries responsible for global air transport participate in the program, the entirety of CO2 emissions would be covered. Provided all targeted airlines follow the program's offset requirements, it would theoretically be possible to ensure a "carbon neutral" growth, when offset is considered.

Nevertheless, given the rules adopted by the OACI, participating countries will commit for the whole period from 2021 to 2035[187]. Not covered routes would not be subjected to offsetting and their growth would not be limited. A 2016 report from CE Delft[188] revealed how only 76% of total

CO2 emissions from the international air industry in the 2021-2035 period would be covered by CORSIA, the remaining 24% being emissions from international routes not covered by the program. According to that same study only 28% of emissions covered by the program would be offset by air companies within the 2021-2035 period. **CORSIA then offsets around 20% of the air sector's emissions from 2021 to 2035**.

[187] Participation is in fact only voluntary in the period from 2021 to 2026. From 2027 on participation is optional for countries with reduced air transport or less developed or developing island countries

[188] https://www.cedelft.eu/en/publications/download/2286

To evaluate the maximal trend-based effect of the CORSIA program, we considered a fictional **CORSIA*** program where 100% of emissions above the 2019 level (domestic emissions outside of the CORSIA scope included) were offset in 2021 and offset was equivalent to an immediate and total decrease in emissions. **It is important to note that these two assumptions largely maximise the real effect of CORSIA on reducing emissions.**

We obtain the following results:

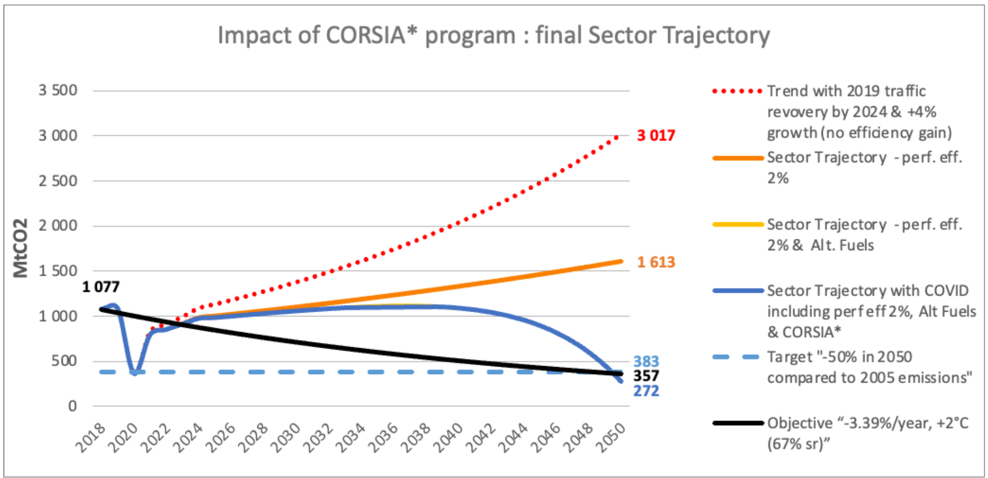

Figure 31 - Impact of CORSIA* program on Sector emission trajectories

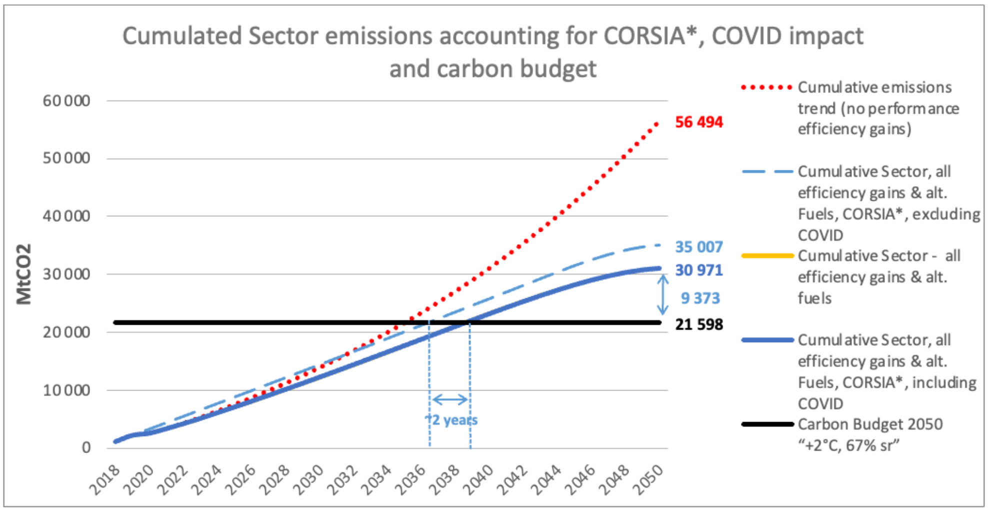

Figure 32 - Cumulated Sector emissions accounting for CORSIA*, COVID impact and carbon budget

- Given the impact of the COVID crisis, coupled with annual performance improvement and alternative fuel growth assumptions, CORSIA* offset would be effective only between 2034 and 2038, and its impact would be marginal: ~50 MtCO2, that is ~0,16% of cumulated emissions in 2050.
- Given that the CORSIA offset only applies to combustion emissions (the upstream parts are not included), a slight increase in emissions persists after 2034.
- The date at which the carbon budget is depleted remains almost unchanged (2039) and the remaining efforts would still be around 9 GtCO2, that is approximately a 30% decrease in total emissions.
- The COVID crisis' effect on emissions is less important as a result of CORSIA. As a matter of fact, if traffic had continued to increase after 2019, short-term emissions would have increased considerably above the 2019 level, and CORSIA would have allowed to offset a larger emission volume compared with today. For airlines, costs linked to the CORSIA offset are mechanically removed during the crisis, which is a lesser evil given the economic struggles caused by a brutal traffic decrease.

Therefore, the fictional CORSIA* program, that is CORSIA applied with very optimistic assumptions, does not allow to move towards a "2°C" trajectory for air transport, because its ambition is to stabilise emission levels with offsetting, not to reduce them. Furthermore, if the air industry managed to stabilise its emissions to slightly below the 2019 level (for example the 2018 level), the CORSIA program would yield no effect, at least in its actual definition, whereas "2°C" carbon budgets would still be largely exceeded in this case. Finally, CORSIA only offsets CO2 emissions (the only ones under study in this report) but completely ignores non-CO2 effects which would increase with traffic growth, without being offset.

That being said, because of its mechanism and existing uncertainties around future predictions, CORSIA is a concrete incentive for airlinesto reduce emissions, provided that the carbon price is aligned with the market price, and to move more quickly towards solutions to limit emission. It also has the double advantage of existing at the international level and being managed by an organisation recognized by the air industry: the OACI. These two elements make it more easily acceptable for air transport professionals. Therefore we do not oppose CORSIA but are fully aware of its extent and possible impacts.

Methodically speaking, CORSIA offset should be applied to emission trajectories which have already been technically optimised, in order to evaluate the offset level, that is CORSIA's provisional impact for the 2018-2050 period. We proceed that way in the next sections, even though we know, as seen earlier, that either we can sufficiently reduce emissions and CORSIA would have no effect, or we can't, in which case CORSIA won't allow us to stay within the budget.

5.10 The French government economic recovery plan presented in June 2020

In response to the covid-19 crisis and its disastrous consequences for the aeronautical industry, the French government presented in June 2020 a 15 Billion euros recovery plan made up of subsidies, investments, loans and guarantees intended for the sector's companies.

This plan is structured into 3 axes:

1) Respond to the emergency by supporting companies in difficulty and protecting their workforce
2) Invest into SMB to stimulate the industry's transformation
3) Invest to engineer and produce tomorrow's aircrafts in France

Although the 3rd axis is of prime interest to us here, as it deals with one of the decarbonisation levers that we study and quantify in section 7.2.2.2 of this report, the first two axes deserve a few words . The plan does not specify the assumptions made about the crisis duration or the air traffic growth expected by 2050, even though these elements structure the way we apprehend the trajectories of skills' innovation, protection and transformation.

Despite the recovery plan and even though the industry was the first to receive state aid, the traffic ban decision taken to slow down the virus propagation translated into significant layoffs, which is symptomatic of the industry's lack of diversity and resilience when confronted with this type of crisis. In the future, energy supply tensions and climate change impacts will undeniably increase the probability of crises with similar consequences, and against which the industry must prepare.. Therefore, we provide a few ideas for the industry's diversification in section 9.4

Regarding the third axis of the recovery plan, we understand that the government:

- Bets that technological breakthroughs will happen by 2030 / 2035, with a "zero CO2 emission" plane in mind both for regional and mid/long range haul (A320 successor), and technological demonstrators ready between 2026 and 2028.

- Relies heavily on the use of hydrogen and biofuels to succeed
- In return for state aid, requests Air France - KLM :
    - to shut its metropolitan lines as long as a train alternative of less than two and a half hours exists
    - to cut down CO2 emissions by half for all metropolitan flights leaving from Orly airport or connecting two metropolitan regions by the end of 2024
    - not to slow down the mid and long haul fleet modernisation

Investing into a mid/long haul programme to significantly reduce fossil fuel consumption is obviously to be fostered, as part of the necessary decarbonation of the sector. We also support the modal switch from planes to trains on metropolitan journeys. Moreover, the recent government announcements suggesting that airlines would no longer be allowed to take over the flight routes abandoned by Air France, in order to prevent unfair competition, seem to go in the right direction.

However, the recovery plan does not quantify the GHG emission reduction trajectories it would enable, no more than the SNBC defines objectives for the international air traffic. The plan does not propose any action to immediately reduce emissions and the lack of quantification raises the challenge of its steerability. Gambling everything on future technological breakthroughs entails technological and industrial risks, and therefore choices and arbitration to be made at the appropriate time. How to undertake such arbitration without a clear trajectory? Who will do it, and based on what criteria?

The government indicates that this plan was designed with the help of the GIFAS and specifies that the latter will also be in charge of the monitoring. This is a questionable choice. If the techno-industrial expertise of the GIFAS is not to be denied, it is also a lobbying structure defending, first and foremost, its own vision of the aeronautical industry and air transport's best interests . Therefore, it is likely that it will naturally avoid running a deep transformation given the oligopolistic attribute of the market, which incentivises actors to adopt cautious and conservative behaviours. Hence, we deem preferable that the implementation and monitoring of the recovery plan be taken care of by the state, supported by multiple organisations including climate scientists and energy specialists on top of air industry representatives.

Finally, the recovery plan mentions the advent of a "zero CO2 emissions" plane, based on hydrogen technologies. If we also discuss, based on quantitative data, the decarbonisation possibilities offered by this type of fuel in sections 7.2.2.3 and 7.2.3 of this report, it is worth recalling that "zero emissions" does not exist. Regardless of the fuel considered, the climate impact of grey energy as well as the availability of energy and chemical resources necessary for its production must be taken into account. Reviewing and making potential arbitrations about resources, energy and land consumptions in favor of air transport or another sector will also be required. It applies to hydrogen but also to biofuel and other synthetic fuels. Prior to claiming that a plane is "low-carbon" (without considering the "compensation" mechanisms), one has to go beyond the simple aviation perimeter and consider the whole life cycle. This is the reason why we reintegrate in this report the upstream emissions (oil extraction and refining as well as kerosene transportation).

5.11 Conclusion

At this stage of the analysis, we can draw the following conclusions:

- Given the consequences on life conditions on earth, human societies and the economy, remaining below the "+2°C" threshold, in line with the Paris Agreement spirit, constitutes a non-negotiable physical and climate framework, within which we can still act. This is a vital priority , of utmost importance.
- According to current scientific knowledge, **remaining below the "+2°C" ceiling imposes a significant reduction in anthropogenic GHG emissions** in order to comply with the RCP 2.6 GIEC scenario.
- **This reduction trajectory involves deep and fast transformations** of our ways of producing, conveying, consuming, hence of our lifestyles. The more we delay these changes, the more we will have to accelerate the trajectory and the transformation shock will be important.
- **Air transport contributed up to 2,56% of the world's CO2 emissions in 2018 and to 3,5% of the global radiative forcing measured in 2011** considering the current best estimates of non CO2 induced effects.
- The COVID-19 crisis has and will have devastating impacts on the aerospace industry and air transportation, notably in terms of employment . **The air traffic should not recover its 2019 level before 2024.** This crisis, the worst the industry ever went through, naturally affects the air traffic's GHG emissions.
- However, the air traffic growth paths considered by **IATA or OACI anticipate a significant growth in the air transport's contribution to global warming.**
- **There is no international governance allowing to define a GHG emission reduction trajectory for air transport** stemming from a global arbitration between sectors of activity and guaranteeing the overall achievement of the objective.
- Therefore, we set, by default, the GHG reduction effort incumbent upon the aviation sector and the associated carbon budget at the level of the global effort to stay below 2°C in 2100 with a probability of 67%. Any other trade-off, upwards or downwards, requires a public debate and a political decision.
- In order to assess the decarbonising potential of alternative fuel-based solutions, whose low-carbon feature only makes sense when considering the entire life cycle, **it is necessary to include the upstream sector** (research, extraction, refining and kerosene transport) in the calculation of emissions and the associated carbon budget.
- **At the global level and including the upstream phases, the carbon budget of the aviation sector is 21.6 GtCO2 between 2018 and 2050.** This budget is obtained by maintaining the relative share of air transport in global emissions, considering that each country makes the same "relative effort" (without demographic considerations).
- Since its inception, the aviation industry has constantly improved the energy efficiency of aircrafts for economic reasons, performance and democratisation of use. Nevertheless, these improvements have so far mainly contributed to the increase in air traffic and travelled distances, hence to the increase in GHG emissions. While aviation carries out missions that are essential to the current global balance, **it also increasingly contributes to global warming.**

- Taking into account a performance improvement of 2% per year -the most optimistic put forward by the aviation sector - a ramp-up of the use of alternative fuels to 100% in 2050 as well as the maximum and immediate application of the ICAO CORSIA offset program, **the carbon budget will be reached around 2039 and the total cumulative emissions in 2050 will exceed the budget by 43%** (see Figure 33), and this is without considering "non-CO2" effects.
- This trajectory even exceeds the total budget allowed (by 2100) for the climate to stay below +2°C with a probability of 67% around 2048. To stay within this budget, no more CO2 emissions would be allowed from that date onwards. This trajectory would probably arrive closer to the "+2°C with a 50% chance" budget in 2100 (see Figure 33). If this level was commonly defined as "in line with the Paris Agreement" in the past, it is now accepted that the reference is the IPCC RCP 2.6 scenario within which the "-3.39%/year and 67% chance of staying below +2°C" trajectory is taken as the baseline.

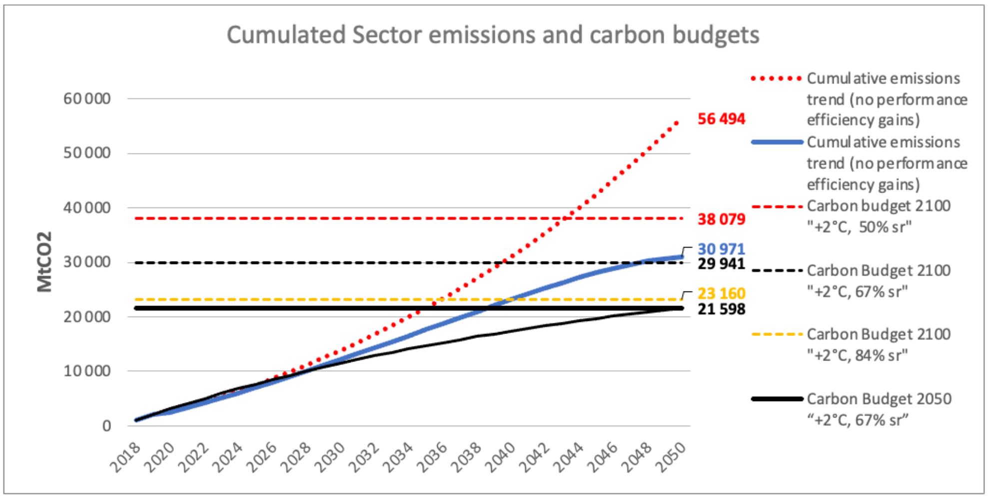

Figure 33 - Sector trajectory and carbon budgets

- **The two major axis of additional GHG emission reduction presented by the sector to date are:**
  - **Gambling on breakthroughs in decarbonising technologies**, in particular hydrogen (see the government's plan).
  - **Accelerating the use of alternative fuels** (biofuels, synthetic fuels, hydrogen), which may or may not be coupled with aircrafts in technological disruption (as for hydrogen).
- **These two proposals cannot be pushed to their maximum potential without considering the following risks:**
  - It is very unlikely that a state-of-the-art aircraft, such as a "hydrogen aircraft", will arrive before 2035 (as a reminder, Airbus announces the release of such an aircraft in 2035, subject to massive state support and extensive international collaboration). But in 2039, if nothing else is done, the carbon budget will be exceeded. There will be only 4 years left to renew the world fleet and deploy hydrogen production and distribution infrastructures on a large scale.

    - The use of alternative fuels generates externalities (in terms of energy required, land coverage with wind turbines or solar panels). This option, which necessitates very strong trade-offs in favour of air transport to the detriment of other sectors, must be studied more globally, in as much as it imposes a physical limit of a different nature.
- **In this perspective, air transport must be embedded in a more general public debate on the use of resources, lands and financing.** Once the physical framework is established, the reflection regarding the priority usage and missions of air transport will have to start and must prepare the sector to adapt to the carbon constraint in a socially acceptable way and offer transport services that will be deemed essential.

Based on these observations, this report proposes to evaluate, or re-evaluate, in detail a set of technical and operational improvements in the short, medium and long term, to measure their impact in France and worldwide, to evaluate the remaining effort to stay within the carbon budget and to anticipate the effect of the sobriety shift on employment and on the French aeronautics industrial base.

- **In our view, both the French and global perimeters deserve to be studied in as much detail as possible:**

    - The French perimeter is under the responsibility of the French State, which has a strong legitimacy of action according to current citizen and democratic modalities, while taking into account international competitive risks as well as economic and social risks. Each country has its own specificities that must be considered for purposes of efficiency, relevance of the possible alternatives, and social acceptability of the proposed measures. We can mention, for example: the carbon intensity of the electricity mix, the existence, deployment and potential of a low-carbon domestic mobility network, the country size and the existence or not of overseas territory, tourism activity and air travel use… Thus, the France perimeter has been studied in detail while bearing in mind these parameters and the possibilities for local action.

    - The world perimeter is the most relevant to evaluate the real contribution of air transport -which by nature holds an international dimension - to climate change. Albeit a synchronised action at the global level would be much more effective, it is clear that the legitimacy of action is less important than at the national level and that the decision-making process is longer and less effective, with the defense of local interests often taking precedence in negotiations. International and national actions must be carried out in parallel. Finally, the aerospace industry market is structured at a global level. In a country like France, where the aeronautics industry plays an important role in both national economic performance and employment, studying global scale trajectories is essential to assessing the impact on activity, including national, to draw conclusions and to organise a possible transformation of the sector.

6. Steering total air transport emissions at the national and international level

The steering of total emissions from air transport is an issue that requires strong national and international coordination with the essential objective of controlling carbon trajectories.

Proposal n°0: Define a carbon-eq budget and a GHG reduction trajectory for national and international air transport, taking into account the full reality of the climate impact of air transport. The carbon-eq budget for international aviation could be defined by ICAO. It should be part of a global emissions budget compatible with a 2°C trajectory (currently IPCC RCP 2.6 scenario).

In France, include these targets in the carbon budget of the SNBC and in the next revision of France's Contributions au Niveau National (CDN, National Level Contribution), which are revised periodically within the framework of the Paris Agreement.

Identify an official body responsible for overseeing the reduction of emissions. Promote a project for the complementarity of regional ETS systems with CORSIA to the European Commission.

6.1 Define an emissions measurement indicator that takes into account the full reality of the climate impact of air transport

In order to measure and project the emissions attributable to France in national and international air transport, we propose that these emissions be quantified in the framework of the SNBC on the perimeter used by the DGAC: LTO, APU and half-cruise for international flights.

We also propose that the DGAC integrate the measurement of "non-CO2" effects and thus produce a complete emissions indicator in MtCO2eq, based on the best scientific evaluations and depending on the propulsion technologies in use (turbojet, turboprop, hydrogen aircraft, etc.).

Last but not least, we propose that the upstream emissions of fuels (research, extraction, refining of fossil fuels, transportation, carbon capture and synthesis for the others) be encompassed in this indicator, so that the decarbonising effect of alternative fuels is taken into account at its true value, over the whole life cycle.

Ideally, this indicator should be defined at the international level (by the ICAO, for example) and adopted by all countries. But there is nothing preventing France from doing so immediately, proposing it and using it within its own perimeter, while preserving the indicators currently shared within the framework of the Paris Agreement, which allow comparing decarbonation trajectories with other countries.

6.2 Defining a carbon budget and a trajectory to be included, at the national level, in the SNBC

This measure aims at keeping the carbon footprint of the aviation sector within a limit that ensures compliance with French and global climate objectives. The first necessary step is therefore to define the aforementioned limit.

The carbon budget for international air transport could be defined by the ICAO, ensuring that it is part of a global budget compatible with a "+2°C" trajectory. The breakdown by country will probably be the subject of bitter negotiations, with no guarantee of success, which is why each country can/must act without delay. In the absence of such a definition, the inter-sectoral equity rule proposed in chapter 5.9.3 applies.

At present, France equipped itself with a tool, the National Low-Carbon Strategy (SNBC), which does not include emissions from international transportation. However, the current measurement of CO2 emissions by the DGAC is immediately available and, therefore, can be technically integrated into the SNBC. This proposal is in line with recommendation n°7 of the 2019 High Council for the Climate report regarding the notion of carbon footprint in relation to the objective of neutrality. In a second phase, we propose to integrate into the SNBC a MtCO2eq measure based on the scientific consensus advocating for the inclusion of non-CO2 effects.

The provisional version of the Reference Scenario for Energy and Climate (SNBC-PPE) indicates that while international transports are taken into account in the energy balance and decarbonised at half of its energy consumption in 2050, it remains outside of the national greenhouse gas inventories to date. This is all the more regrettable since the principle of imputing half of the emissions from international transport to France is both replicable and virtuous: it can be adopted by all other countries without the risk of double counting emissions, and it encourages international cooperation in the implementation of decarbonising strategies.

While this report focuses on aviation, this measure should also be applied to the entire international transport sector, first and foremost the maritime sector. It is France and Europe's duty to promote this transnational vision, especially with the signatories of the Paris Agreement. Even if the adoption by the signatories of this counting method for international transport at the Conference of the Parties (COP) will take time, this point should not be allowed to limit national lucidity regarding France's contribution to global radiative forcing, nor should it slow down its efficient trajectory of transformation.

Once this measure is adopted and integrated, the definition of a carbon budget and a trajectory is typically a decision of the public authorities. At the global level, we have seen that the targets set by international governance are insufficient, which means that, if they were maintained, other sectors would have to make an additional effort to stay within the overall "+2°C" carbon budget (approximately 990 GtCO2eq). Regardless of the level of governance, once the global budget is set, the sectors must share the pie, knowing that there will not be a second service. Thus, the carbon budget of the SNBC is set at 5.4 GtCO2eq between 2018 and 2033, divided between different sectors of activity.

What would be air transport's piece of the pie? The neutral vision, which we have followed in this report, would be to add the 27.5 MtCO2 of air transport for 2018 (including upstream parts and revised later with the measurement in MtCO2eq) and decrease this budget by 3.39% per year. If we consider that aviation should not decrease that much, then the other sectors (agriculture, housing, …) must make a greater effort. Is this acceptable? In our opinion, the debate deserves to be opened clearly, factually and publicly.

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189 The same recommendation applies to the inclusion of international air and sea transport emissions attributed to France in national carbon budgets. The proposition was not reconducted in year 2020, because these emissions are « to some extent » considered by the Loi énergie-climat from November 2019, which in its article 2 and 3 opted for the inclusion of international transport under an indicative ceiling from Jan 1st 2022 onward, outside of any carbon budget. Article L.222-1 B of the Environment Code is thus modified as follows : "for each period mentioned in the same article L. 222-1 A, an indicative ceiling is defined for GHG emissions generated by connections from or to France and not counted in the carbon budgets mentioned in article L. 222-1 A, called 'carbon budget specific to international transport'". However this law has not yet come into effect, as most recent decrees regarding the SNBC (in which carbon budgets are defined) made no mention, as of February 2021, of such regulations.

190 https://www.ecologie.gouv.fr/sites/default/files/Synth%C3%A8se%20provisoire%20des%20hypoth%C3%A8ses%20et%20r%C3%A9sultats%20pour%20les%20exercices%202018-2019.pdf

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6.3 Identifying an official national body to oversee the emissions reduction

Once these targets have been established, a body must be able to objectively and independently monitor and steer the reduction of emissions from the aviation sector and ensure compliance with the decarbonisation trajectory. In particular, it is necessary to:

- Obtain a reliable assessment, year after year, of the sector's actual emissions, carried out by itself or by another body; airlines operating in Europe are already required to report their CO_2 emissions, but without taking into account non-CO_2 effects; it will be necessary to develop this accounting.
- Assess the evolution trend of these emissions in the coming years within the existing regulatory framework and the existing societal context.

Two control strategies are applicable.

Monitoring strategy
The monitoring body simply applies the constraint set by the SNBC to the sector as a legal obligation. It is not concerned with finding out how the sector will adapt to meet this constraint, but it must be able to sanction any failure. This strategy is simple to implement and leaves it up to the industry to decide which uses and air links will be retained.

This strategy is only applicable if its implementation does not distort competition.

In other words, a regulatory constraint on the sector's overall emissions must ultimately be translated into a constraint for each company. We identify three possible approaches:

1. A distribution decided by the steering body, which may ultimately be imposed on companies, potentially after lengthy negotiations.
2. A distribution decided collegially by the sector itself and its representative bodies. Here again, the risks of non-convergence are significant in such a highly competitive context.
3. An allocation in the form of an auction or an exchange of emission quotas.

If this strategy is adopted, it would probably mean durably reintegrating aviation into the European carbon market (EU ETS) while ensuring good complementarity with the offset mechanism already put in place by the sector (CORSIA). This proposal is detailed below.

Planning strategy
In this strategy, the steering body compares the emission figures projected for the coming years with the trajectory set by the SNBC in order to propose regulatory changes ensuring alignment with the set decarbonisation trajectory. In the event of a need for sobriety, uses and flights considered to be the lowest priority will first be called into question, while guaranteeing social and societal criteria of equity and acceptability. The choice will be made by the steering body which, to achieve its objectives, will have to possess the appropriate legislative, fiscal and operational tools.

Beyond the potential feeling of interference by the steering body in the air transport sector, this strategy is more difficult to implement on a transnational scale, as it assumes a convergence of views on prioritisation of uses. A democratic and pan-European consultation on this subject (for example via representative citizens' committees in each country (Note 192)) could be the first concrete step toward implementing this strategy.

Who should be entrusted with this steering mission?
The DGAC is one option. However, this body plays the roles of regulatory authority and service provider, and is currently financed by air traffic, thus threatening to create conflicts of interest. The DGEC (Directorate General for Energy and Climate) is an interesting alternative, since it has a department for the fight against greenhouse effect.

6.4 Defending a harmonisation project between CORSIA and the regional ETS?

The establishment of CORSIA as a global offset scheme interferes with the operation of other regional regulatory systems such as EU-ETS, which acts both on international air traffic between EU states and on domestic traffic. Abandoning the EU-ETS in favour of CORSIA would free the domestic traffic from all constraints, since it is not covered. However, in 2018, global air activity (in RTK, Revenue Ton Kilometers: passenger and cargo capacity in metric tons multiplied by the distance flown) comprised 69.4% of international traffic against 30.6% of domestic traffic. The Airbus report on traffic forecasts for the period 2019-2038 also suggests a scenario of compound annual growth rate for domestic flights of 4.4% (compared to 3.9% for international flights). This figure, reflecting mainly the significant growth in domestic traffic in China and India, exhorts us to be cautious about the decarbonising potential of CORSIA.

It should be remembered that CORSIA was defined by the industry players themselves. In order to avoid double emissions counting with EU-ETS, they even suggested to the ICAO that CORSIA replace all other regional carbon measures or legislation, justifying the need for a different treatment with the international nature of their activity. Despite its international scope, this initiative seems regrettable to us in more than one respect.

On the one hand, we have shown in section 5.9.5.3 that CORSIA was an insufficient response to the challenges of the sector's decarbonisation, since the mechanism allows us to hope at best for a stabilisation of emissions at the level of 2019, solely through offsetting, and not a decrease. Moreover, even if the principle is mathematically valid, the use of offsetting does not have the same effect as a controlled reduction. By investing in "green" projects, offsetting adds intermediaries to the implementation of decarbonisation, thus increasing the level of risk. Furthermore, the immediate nature of the GHG reduction induced by these projects is not guaranteed, while time is against us in the fight against global warming.

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192 Like the Citizens Convention for Climate in France or the Committee on Climate Change in the UK

193 This is typically the case of reforestation projects, in which today's carbon emissions are exchanged for tomorrow's carbon capture, since trees take time to grow.

194 This explains why today the cost of carbon credits purchasing only takes up less than 1% of the total ticket price. See https://theshiftproject.org/wp-content/uploads/2019/06/2019-05-31_Avion-climat-et-fiscalit%C3%A9-Petit-manuel-dauto-

d%C3%A9fense-intellectuelle_V3.pdf

195 Council of the European Union, 2017. Non-ETS (ESR): WPE 2 March – Commission presentation on 2030 GHG emission reduction target (WK 2310/2017 INIT). Brussels, 01 March 2017.

On the other hand, it is important to remember that the air transport sector has a privileged position within the EU-ETS. If in general 45.5% of ETS credits (called EUA - European Union Allowances) were allocated free of charge in 2018 across all sectors, the aviation sector is an exception, since it was entitled to free allocations of up to 85% of its needs. While the European decarbonisation strategy foresees a level of CO_2 emissions in 2030 that is 40% lower than in 1990, which for the aviation sector would mean a target emission level of 50 $MtCO_2$ in 2030, the European Commission has raised this to 111 $MtCO_2$, arguing that the issue of its decarbonisation is practically difficult. As a result, the EU has made an implicit trade-off in favour of the aviation sector and thus relied on a greater effort from other sectors to achieve its emissions reduction target.

It is regrettable that this "favour" did not convince the sector.

All existing ETS systems (including the EU-ETS) are by nature multi-sector and multi-industry and are intended to be "linked" in the sense that credits are in principle tradable. Aviation was integrated into the European system (EU-ETS) in 2010 to include international aviation and also domestic flights (departure and arrival in the same country of the Union). As an example, the Swiss ETS (non-EU) launched in 2019 also includes international and domestic (intra-Swiss) flights. The two systems are "linked", allowing aircraft operators to avoid double charging (a flight is never subject to both systems but to one or the other) and to acquire credits in both compensation systems which are interoperable ("one stop shop"). The solution that has been implemented consists for operators to identify and account for flights and associated CO_2 from Switzerland and intra Switzerland to the Swiss ETS on the one hand, and flights and associated CO_2 from the EU region to Switzerland to the EU-ETS on the other hand. One way to summarise this separation is that "all flights departing from a region/country with its own Aviation ETS are associated with the ETS of the region/country of departure". This system avoids double counting of flights and market distortion, since all operators are subject to the same identification and compensation rules. This successful experience could serve as an example for a composite EU-ETS / CORSIA solution, which we detail below.

CORSIA or EU-ETS: What to choose?

Despite the international dimension that it gives to the sector's carbon markets, the total abandonment of EU-ETS in favour of CORSIA by the air transportation sector raises a fundamental question: why should air transport be entitled to a different carbon price than the rest of the economy? Letting CORSIA replace part of the legislation would be a terrible admission of a lack of ecological ambition from the EU, since it would leave the aviation sector with complete autonomy to set up an incentive system to reduce emissions, even though the EU set up a system which by nature is multi-sectoral. In addition, it is important to underline that domestic flights from Europe (and from any other country such as the USA, China or India) would not be counted. In fact, according to a study by CE Delft, CORSIA alone would at best offset about

20% of global emissions from the aviation sector over 2021-2035, and according to our calculations, it would only offset a very small part of French emissions over 2021-2050. In addition, in the case of zero or negative emissions growth compared to 2019, CORSIA will have no effect. These considerations are unlikely to encourage innovation in low-carbon aeronautics even though massive public funding is being provided.

The opposite proposal - to exclude CORSIA from the European space in favour of the EU-ETS - has the advantage of not posing the problems noted above: an increase in the price of EUAs (European Union Allowances, which are the credits of the EU-ETS system), solid credits whose free allocation is freely defined and controlled by the EU, would force the industry as a whole to change and adapt. The price signal would best reflect the negative environmental externalities generated by air travel. However, this path poses a political problem: CORSIA's ambition is to cover the whole world, including areas where the implementation of an ETS is unlikely, even in the long term. If Europe completely dissociates itself from the project, the question of the survival of the CORSIA program arises. It should also be noted that such a scenario, even if it is much more ambitious than CORSIA, is nonetheless insufficient in practice with regard to the requirements set out in the Paris agreement. Indeed, aviation has a privileged position in the European EU ETS: while in general 45.5% of ETS credits were allocated free of charge in 2018 for all sectors, aviation was entitled to free allocations up to 85% of its needs, and is once again an exception. Thus, unlike the other sectors now integrated into the EU-ETS, which have seen their emissions decrease in 2019, those of the aviation sector have increased by 1.5%.

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196 https://cedelft.eu/en/publications/1924/a-comparison-between-corsia-and-the-eu-ets-for-aviation

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Towards a composite CORSIA and EU-ETS solution.

This path is more complex but seems to be the most pragmatic response to climate issues. Several systems can be considered. The alternative presented here is a "50/50" mix that would see all flights departing from the EEA+ (European Economic Area) subject to the EU-ETS, while flights from outside the EEA+ would be subject to CORSIA. "50/50" thus reflects the idea that the traffic flow leaving Europe and the one entering Europe would therefore be assigned respectively to the ETS and to CORSIA, as a kind of complement to the current ETS which already covers intra-European flights.

Such a scenario, similar to the one set up between the European Union's ETS and Switzerland's ETS in its principle (separation of the reported flows), would see domestic and intra-EU emissions entirely covered by the EU-ETS system, without any overlap with CORSIA. Flights between an EU country and a non-EU country would thus be covered up to 50% by the EU-ETS (flights from the

EU to third countries) and 50% by CORSIA (flights from third countries to the EU). This scenario would transfer 62% of the sector's emissions initially covered by the "full scope" to the ETS. A major advantage of including flights departing from Europe in the EU-ETS would be the possible inclusion in the future of local NOx pollutants which are mainly related to take-off, and even non-CO2 effects.

The application of such a solution is nevertheless incompatible with the objective of keeping global warming below 1.5-2°C. Limiting emissions to the 2019 cap is largely insufficient and the vast majority of carbon credits allocated to the aviation sector are currently free of charge. CORSIA as well as the EU-ETS must therefore evolve if they want to allow for a real decrease in the sector's emissions. France must make its voice heard so that the European carbon market can as quickly as possible ensure decarbonisation of the economy by reducing the number of allowances issued free of charge. The total number of allowances auctioned each year must also be gradually reduced to reach a decrease trajectory compatible with a 2°C scenario, i.e. -3.39% per year starting in 2018 assuming alignment with the global target. This decrease is currently 2.2%, which is largely insufficient given that barely more than half of European economic activity participates in the carbon market. France must also lobby international bodies to ensure that the ICAO regularly lowers the emission thresholds in CORSIA.

Stabilising a sector's emissions level is indeed incompatible in a not too distant future with the decarbonisation of the world economy, and the other sectors will not be able to sustainably compensate for an effort that aviation will not have made.

The 50/50 mix is thus the best scenario at the European level, in terms of environmental performance and sustainability. It is difficult to apply it to France alone. This scenario requires strong coordination within the European Union in order to promote this position in a united way at the ICAO level. The other States of the EUR-ICAO region (wider than the EEA) not directly involved in the ETS could also advocate this solution, thus creating a regional ICAO position. In the absence of a regional common approach, the EEA states could apply CORSIA while issuing national waivers to the CORSIA SARPs (Standard And Recommended Practices) exempting from annual reporting and CORSIA compensation all flights departing from their own territories (because covered by the ETS), such a national derogation procedure being allowed in principle at the ICAO level. The implementation of this well-defined legislative framework mixing ETS and CORSIA will enable the arrival of the technical solutions addressed in this report in the most efficient way possible.

7 Proposing and assessing decarbonation measures in France perimeter

7.1 Introduction

The aeronautic and air transportation industries are already familiar with most of the following proposals. The objective is to shed light on the content of these proposals from the viewpoint of the technique, operations, practicalities, sectorial constraints and obstacles to their implementation, externalities created (notably in terms of energetic resources, usage, economic activity, concurrence and employment) and, finally, to assess the associated carbon impact.

It is worth noting at this stage that if the axes presented and quantified hereunder reveal inadequate to comply with the carbon budget allocated to the sector, at fixed carbon budget, sobriety of use will be the only way to reduce the remaining carbon emissions. Hence, the reader is free to assess positively or negatively each proposal, or to imagine how to limit their scope. However, the reader should also understand that reductions not achieved through the proposals will necessarily translate into additional sobriety.

Besides, of all the proposals put forward in this report, the most promising in terms of emission reductions are also the most unpredictable, given that they present risks at many levels (technical, industrial, financial, regulatory, market) and require robust international coordination. Full and immediate implementation of the simplest measures is thus a strategic choice: it would save time for the implementation of more complex measures and prepare the potential transformation of the sector's backdrop. Subsequently, any 'restraint' in the adoption of the short-term measures will result in the implementation of proposals presenting higher risk levels and earlier than necessary; less prepared, said measures will either underperform in terms of GHGs' reduction, or be more socio-economically disruptive.

The reference trajectories at France's level are elaborated in accordance with the same principles as the World's trajectories presented in 5.9.4, based on France's carbon budget presented in 5.9.3 and the "DGAC" perimeter presented in 5.9.2.

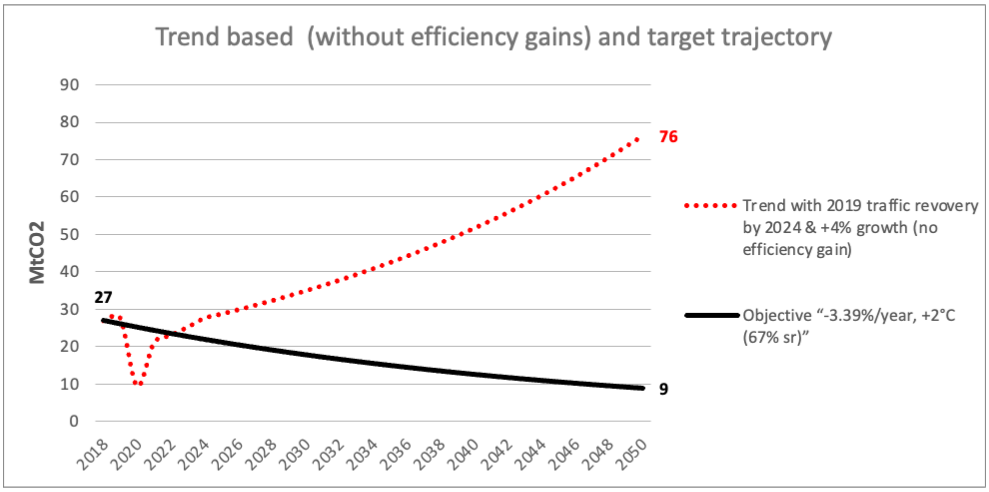


Figure 34 - Trend and target trajectories – France

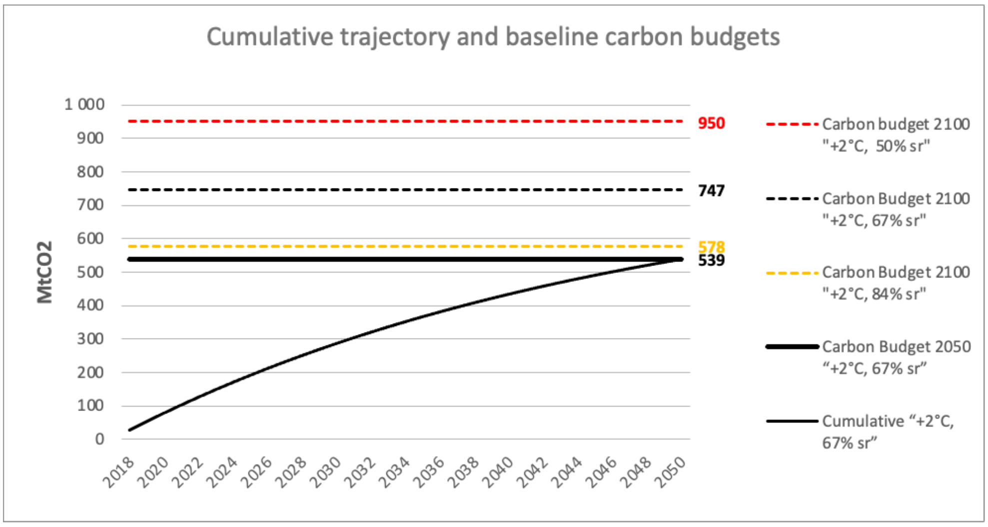


Figure 35 - Cumulative trajectory and reference carbon budgets - France

Assuming that growth is similar for France and the World is debatable, as the global air traffic grows essentially outside France and Europe. Nonetheless, this working hypothesis is meant to be adjusted depending on whether the decarbonation objective is reached or not (see 5.9.4).

7.2 Improving the energetic and emissive efficiency of air transport

7.2.1 Efficiency axis in the short term (5-year prospect)

7.2.1.1 Decarbonation of ground operations

Axis n°1: Decarbonation of ground operations	
Nature	Regulatory; investment (from airports)
Application perimeter (targets)	Single-Engine Taxi-In or Taxi-Out (SETI/SETO): Aircraft Dispatch Towing System: airlines and airports (mutualization and electrification of the stock of light vehicle assistants and others)
Lever used	Sobriety, exploitation measures, technical progress

Context	Ground operations encompass all the activities realized while the aircraft does not fly, that is, the "parking" and "taxi" phases (aircraft's movement on the ground before take-off and after landing). These activities entail a significant consumption of kerosene, and thus carry weight in the CO2 emissions. Airlines understand this and incentivise to limit the consumption of kerosene during these operations. Among the levers available to reduce these emissions, one can retain the two main ones: · stop resorting to Auxiliary Power Unit (APU) during the parking phase. · Reducing the use of aircraft's motors while moving on the ground (Taxi-in and Taxi-out). Lever n°1: Substituting the use of the APU when the aircraft is static (parking phase). The APU is an auxiliary generator (generally a turbine-type generator) used to produce energy on board of aircrafts to supply the different aeroplane systems and, in flight, ensure the continuity of the supply to these systems in case of engine problem: · Function n°1: electricity supply (400 Hz and 28 VDC) to embedded systems · Function n°2: starting the engines during the departure and in case of breakdown during the flight · Function n°3: providing the necessary pneumatic power to control the temperature in the cockpit and the cabin. APUs are generally positioned at the rear of the airplane – in the tail's cone – and supplied by the aircraft's kerosene tanks. Resorting to the APU is the prominent source of CO2 emissions while the aircraft is static and accounts for 0.4 MtCO2 for all the flights operated on the French territory (1.7% of all air transport's emissions)[1]. While function n°1 is generally carried out by an external electricity supply and function n°2 is transitory, maintaining a controlled temperature (function n°3) in the cabin represents the main use of the APU on the ground. The predominant source of reduction thus lies in function n°3.

For Air France's fleet, the annual consumption of fuel linked to the use of the APU is estimated at 45 000 tons of kerosene and the associated emission of CO2 at 0.17MtC02 (2019 data, taking into account the upstream sector). In order to air-condition the cabin while on the ground, two alternatives exist to the use of the APU. The one used most often, the ACU or mobile air-conditioner unit, does not constitute a decarbonating solution as it substitutes to the APU a diesel engine on floating chase. The second consists in using an electric ground power unit (often integrated underground near the boarding gate) and possesses an important decarbonation potential for countries with a decarbonated electricity mix like France (reduction of a factor 1000 of the CO2 emissions compared with the APU, per kW of cold produced). This solution remains underused given the significant investment required to equip airport facilities[2]. Moreover, in some airports which already possess them, these equipment may fail to air-condition the cabin in case of strong sunshine – which incentivizes the use of APUs. It is worth noting that the airports CDG (Roissy Charles de Gaulle) and ORY (Orly) as well as TLS (Toulouse Blagnac) impose a maximum time limit to the use of the APU at the departure and arrival (respectively 10 and 5 minutes) – other airports have less restrictive measures. An axis of progress would be to align all airports with these measures, even though the savings entailed are not measurable due to the diversity of the situations forcing the use of the APU.

Lever n°2: Reducing the use of the aircraft's engines[3] during ground movements (Taxi-in and Taxi-out)

The haulage phases before take-off (taxi-out) and after landing (taxi-in) are phases during which aircrafts use up to 4% of their fuel to propel themselves with the help of their engines[4]. These activities entail CO2 emissions of about 1 MtCO2/year[5] during the haulage phases on French ground, and without the upstream sector.

To diminish this fuel consumption, the first possibility consists in using only one engine. The thrust generated by one engine in slow-motion is often enough to ensure the haulage propulsion, notably for the most recent models (for example: the engines of the LEAP family of which the A320neo or B737max are equipped). This is called the "Single Engine Taxi-In" (SETI) or "Single Engine Taxi-Out (SETO).

Several airlines (50% according to experts) already apply the SETI. On the other hand, the SETO is less used[6] (20% according to experts). Certain constraints regarding security (risk of discovering an ignition incident at the runway threshold and returning to the ground facilities) and operations (less easy manoeuvres) detailed in Annex 2 (see 13.2) may partially explain the difficulties of implementing these practices.

An alternative would consist in resorting to an aircraft towing system during haulage (sometimes known as the name of the most prominent brand Taxibot). It consists of a semi-robotised towing tractor system conducted directly by the pilot, which picks the aircraft and brings it to the runway threshold. Such a system would allow keeping both engines off during the haulage phases. Although this towing system runs on diesel, the consumption is much less (of about -75%[7]) than the one of turbojet engines.

Furthermore, these towing tractors might soon be powered by electricity. In both cases, the implementation of this towing system requires some aircraft modifications and training for the pilots – feasible in one year through continuous training.

In addition, airports are organized by hubs which entails that aircrafts may take-off and land during the same time slot – although peaks of activity may vary significantly from a hub to another. Covering all the departures and arrivals would require a very important quantity of towing systems. A rate of 30% use is an ambitious value but feasible within 5 years, with a preferential use during the Taxi-Out phases – for which the SETO is seldom applied, see aforementioned.

Detailed description	Lever n°1 Replacing the APU with power ground units in Paris-Charles de Gaulle and Orly airports at every parking space within 5 years. Lever n°2 · Generalising the use of Single Engine Taxi-In (SETI) · Generalising the use of Single Engine Taxi-Out (SETO), depending on the duration of the haulage and except for the first flight during daylight in accordance with the constraints relating to maintaining flights' security (see Annex 1). · Implementing, within five years and in each French airport, a service of electrical towing system for aircrafts' haulage and imposing such a system to all airlines during the haulage phases. · Including the mastery of towing systems in pilots' training programme · Counting the number of aircrafts equipped with the electrical towing system among all airlines operating in France.

CO2 impact	· Lever n°1 Replacing the APU with ground power unit in Paris-Charles de Gaulle and Orly airports would allow reducing the fuel consumption by 44 000 tons of kerosene per year and reducing the associated CO_2 emissions by 0.13 $MtCO_2$/year – upstream sector excluded – based on 2019 air traffic. This estimate concerns all the traffic operating from and to CDG and ORY. · With the objective of generalizing the use of ground power units by 2030 in all French airports, a reduction of 0.30 $MtCO_2$/year could be reached – upstream sector excluded (based on 2019 air traffic, to be corrected according to the traffic increase). · Lever n°2 Keeping in mind that, nowadays, the SETI is implemented in 50% of the flights, and that the SETO is implemented in 30% of the flights, and that our objective is to reach respectively 90% and 75% (taking into account the constraints of use), the immediate reduction in CO_2 emissions relating to the generalisation of the SETI and SETO will be: o -0.02 $MtCO_2$/year for SETI's implementation alone o -0.09 MtC02/year for SETO's implementation alone based on the air traffic in 2019 and excluding the upstream sector. · Assuming that the electrical towing system is generalized in all French airports within 5 years, and with a reasonable usage objective of 30% of the flights during the Taxi Out phase (the remaining flights implementing the SETI/SETO), the reduction of CO_2 emissions might reach 0.15 $MtCO_2$/year in 2025, upstream sector excluded (based on the air traffic in 2019, to be corrected according to the traffic increase).

Externalities produced	Impacts on employment · No employment loss caused by the implementation of the SETI/SETO or the use of ground power unit in replacement of the APU – which will still be necessary on board in case of electric set outage; · The creation of a new market regarding the service of electrical towing systems will result in new employments. The electric generator industry should also benefit from it. Value creation may take place on the national territory: the industry responsible for the conception and production of electrical tractors is already implanted in France (for example 3 plants belonging to TLD corporation are located in the Centre-Ouest region[8]). Impact on airlines and airports · Evolution of the piloting and control procedures to implement (see annex for more details). · No competitivity loss or concurrence distortion as the proposed compensations concern all airlines operating in French airports. · Reduction of noise annoyance and NOx pollutions in the airports' areas. · The generalised use of the electric set or the electrical towing system represents a source of income for the airports able to sell this service to airlines (value creation on the French territory). The latters would make substantial savings in fuel. · The implementation cost of the electrical towing system could be financed through the airport service charge, or through the optimized mutualization of the equipment by the handlers and/or the companies – similarly to the financing of the push-back nowadays[9]. · The ground traffic plan could also be impacted.

Proposal to deal with the externalities	Beware the impacts on punctuality relating to the dependency on towing systems. A delay at take-off may induce an acceleration during the flight, and thus an increased consumption. For instance, a departure on time using thermic towing could be chosen if the ecological cost of the acceleration is superior to the gain induced by the electrical towing.

[1] NOTE 197 See calculation note

[2] NOTE 198 Service tarification by airports to companies/assistants is a difficult topic. Considering the level of investment, the tariff associated is hardly acceptable by the users who will rather resort to the APU (more flexibility, notably between contact points equipped with PCA and remote points non-equipped). Hence Orly airport never decided to invest in PCA due to the absence of tariff alignment with companies. A tariff mechanism with sufficient incentive for the users remains to be invented to modulate, undoubtedly, depending on the time of use, the type of aircraft and the stand used (contact or remote). Maybe the airport should also consent a reduced ROCE on this type of "green" equipment, fundable via green bond (and so, passing on the weak cost on the tariff).

[3] NOTE 199 This report does not study the limitation of thrust reverser during landing

[4] NOTE 200 https://www.safran-landing-systems.com/fr/systemes/roulage-electrique

[5] 201 See calculation note

[6] 202 EasyJet applies the single engine taxi out (SETO), coordinating particularly with the ATC which oversees that everything goes as planned when the second engine starts.

[7] 203 See calculation note

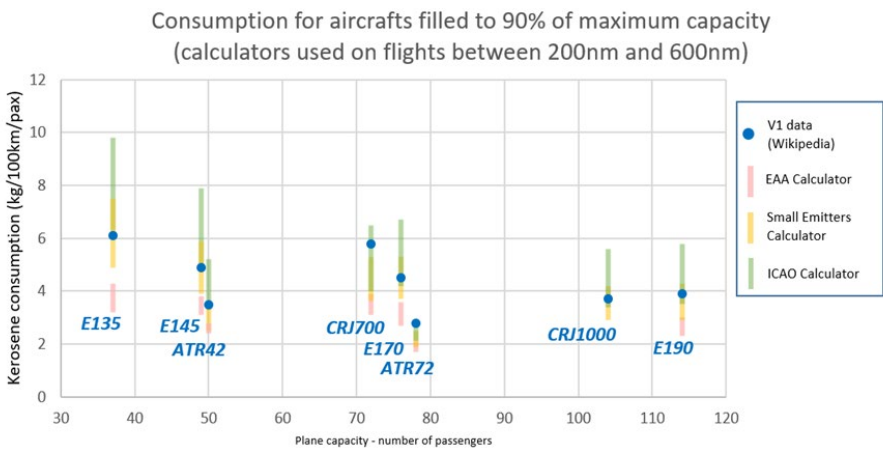
[8] https://www.tld-group.com/fr/le-groupe/capacite-industrielle/

[9] NOTE 205 Airport authorities would incentivise handlers and companies to further mutualise this stock. This is not an easy task because assistants think they will lose flexibility. However, this is a win-win scheme: less parking surface is necessary on the apron and less competition between assistants to reach first the position. One solution would be to organise it like a rental cooperation of assistance machines, which would also allow creating a better rate structure. Result: fewer vehicles, less congestion, a slight diminution of site coverage and less emissions. The airport needs to be the orchestrator of such a project through strong incitation measures, making them even mandatory. This is the role of a responsible Airport Authority.

7.2.1.2 Replacement of the turbo-engine aircrafts of small capacity with propeller airplanes

Axis n°2: Replacement of the turbojet aircrafts of small capacity with propeller airplanes	
Nature	Regulatory requirement regarding technologies
Implementation perimeter (targets)	Flights operated by small turbojets
Lever activated	Technological (energy efficiency)

Detailed description	Commercial turbojets of less than 105 seats (CRJ700/1000 and Embraer 135, 145 and 170) are forbidden from interior flights as of 2023, to the advantage of aircrafts using turboprop engines. This is explained by the fact that current commercial turbojets are less efficient in terms of fuel consumption per passenger – future technological evolutions might lead to reviewing this proposal. They would be replaced, in fact, by turboprop engines (aircrafts using propellers) which consume less fuel (typically the ATR 72 or 42). When the air traffic allows it (minimal frequency and sufficient passenger flow), small and medium haul aircraft of new generation should be preferred. · Turboprop engines consume significantly less than turbojets of similar capacity and generation, as evidenced by the graph in the annex. For example, the replacement of a turbojet CRJ700 (consuming between 3.2L and 6.4L/ seat.100km) with an ATR72 of same capacity (consuming between 1.8L and 2.7L/seat.100km) represent a consumption saving of 40-45% (for distances ranging from 200 to 600 NM). · The reduction in fuel consumption aside, this solution has the advantage of diminishing significantly the climatic effects – excluding CO2 – generated by turbojets while at their cruising altitude[1]. On the other hand, turboprop engines have a slower cruising speed (of about 550km/h against 850km/h for turbojets). The increase of the duration of the journey caused by this change is negligible for domestic flights, which duration seldom exceeds an hour and a half. A one-hour flight would last about 20 more minutes. Part of the increase in flight duration is also due to airports' layout which is sometimes favourable to jets. For that matter, this additional flight duration often makes turboprop aircrafts less competitive economically than regional airplanes using turbojet engines – the cost reduction relating to fuel being largely offset by the increase of other charges (employment of flight personnel notably).

CO_2 impact	The impact was calculated for the “Hop !” company. Of all the French airlines, this company possesses around 50% of the jetliners of less than 105 seats and, more importantly, 85% of the turbojets of less than 105 seats[2] [3]. · The consumptions of the different aircrafts of the ‘Hop!’ company and the ATR42 and ATR72 come from the public calculators EEA, Eurocontrol – Small Emitters tool and OACI: NOTE 209 210 211[4] **[5] [6]**. · The annual consumption of fuel was calculated assuming that air traffic (pax.km) was proportional to the aircraft’s capacity. · The different cases considered are: o The company’s traffic: identical to the traffic in 2017 (2.54e9 pax.km[7]) or reduced traffic taking into account a modal shift toward trains (see. 7.3.3). o New fleet: replacement of the turbojets which capacity is inferior to 105 seats by turboprop engines, or replacement of turbojets which capacity is inferior to 120 seats[8]. Details of the Kerosene consumptions per aircraft types depending on the capacity in number of passengers:  · The estimations of CO_2 emissions in the different cases with minimal and maximal hypotheses can be found in the tables hereunder (details of the calculation in the calculation note):

Minimum gain estimation				
CO2 Emissions (kt)	2019 Hop! Traffic		2019 Hop! traffic after modal shift	
Current Hop! fleet	124	/	69	/
Replacement turbojets < 105 seats by turboprop engines	77	-38%	50	-28%
Replacement turbojets < 120 seats by turboprop engines	64	-48%	46	-33%

Maximum gain estimation				
CO2 Emissions (kt)	2019 Hop! Traffic		2019 Hop! traffic after modal shift	
Current Hop! fleet	269	/	150	/
Replacement turbojet	139	-48%	95	-37%

s < 105 seats by turboprop engines				
Replacement turbojets < 120 seats by turboprop engines	106	-60%	76	-50%

· Notwithstanding the modal shift, the saving in the case of the replacement of turbojets of less than 105 seats ranges from 46 to 129 kt of CO_2 (median value at 88kt), i.e. a reduction of about 40-45% compared with current emissions – taking into account uncertainties about the fleet's consumption. After considering the modal shift, the savings amount to 39 kt of C02 (median value), i.e. close to 35% of the company's emissions after the modal shift.

· Extrapolating to other French companies, the total savings could be of 45 ktCO_2, after the modal shift.

· The savings could be even more significant if this measure is applied to all airlines (French or not) operating on the French territory.

If emissions relating to the upstream sector are re-integrated, the saving in CO_2 would be 58 ktCO_2, i.e. 0.21% of all emissions in 2019. Assuming a progressive replacement between 2021 and 2025 (optimistic scenario) and forecasting on 2026-2050 (which implies that the ratio of regional flights remains constant over this period), we can hope for a diminution of 2.8 MtCO_2 compared with the baseline scenario (cf. §7.1).

Note:

· These calculations were realized based on public calculators with minimal and maximal hypotheses. This model might be refined airway by airway, looking at long distance airways for which the performance comparison (consumption and journey times) between turbojets and turboprop engines might be less favourable.

· Moreover, these calculations were realized on hypotheses of fleet replacement on the basis of an existing fleet. On the basis of private data (Flight Radar or OAG kind), it would be possible to look at the CO2 savings airway by airway through replacing aircrafts directly by those having a lower consumption.

· This study does not consider the flights performed in the DOM/TOM and operated by other French companies because the staggering majority of them are already done by aircrafts using turboprop engines.

Non-CO2 impacts	Turboprop engines fly at lower altitudes than turbojets engines (7.6 km threshold, against 12.5km for turbojets). Yet, the altitude at which emissions (excluding CO2: water, particulates, condensation trail…) are emitted may impact the radiative forcing they generate, according to Marquart and al[9]. · It seems that radiative forcing of emissions excluding CO2 tends to diminish when the altitude of emission decreases, but this is relative to each pollutant and also depends on altitude[10]. · Radiative forcing of non-CO2 emissions may increase significantly if they are emitted in the stratosphere. This is due to water, which remains there longer instead of joining the water cycle as it normally does when emitted at lower altitude[11]. · It was demonstrated that altitude modification of a few hundreds of feet may limit the creation of condensation trails[12] which is responsible for particularly important radiative forcing[13]. Nevertheless, this modification depends on local parameters and meteorological conditions. However, these effects need to be studied more in depth to quantify their global impact.

Externalities generated	**Service Quality** · Journey times: Flight times are slightly increased (less than 30 minutes for Paris-Toulouse[14]). Additional lengthening is due to the fact that passengers of turboprop aircrafts often disembark in the most remote terminals, notably in big airports – this practice could be reviewed if the measure is adopted. · “Standing”: the “standing” of propeller aircraft may be perceived as inferior. Bias of a lower safety whereas it is equivalent. · Comfort: The external noise of turboprop aircrafts is lower than the one of regional jets (10-15 dB less for an ATR compared with a jet of similar size)[15]. Internal noise is similar (around 79dB). **Economic externalities** · Aircrafts’ replacement cost (to interpret in light of public aids to AF) · Turboprop engines’ higher maintenance costs (machine operator) · Air crew costs – the slight lengthening of flight times entails an increase in flight personnel · Turboprop engines’ economic rentability is strongly linked to the price of kerosene. · Parking on remote spaces or in false contact (contact point without use of the footbridge) is economically advantageous for non accostable regional flights – the remote tariff or false-contact being widely inferior to contact tariff with footbridge. **Externalities on employments** · The slight lengthening of flights’ duration has the advantage of slightly increasing the employment of flight personnel, proportional to the number of flights. · Income deficit for regional jets’ constructors (Canadian and Brazilian aircraft manufacturers). · Increased activity for the manufacturers of turboprop aircrafts (ATR – European). · Impact on employment is globally positive (acceleration of the natural replacement of the fleets).

	Risk of bypassing or counterproductive consequence · Bypassing the rule by flying the biggest turbojets, which will remain authorised and may generate a development and increase of the traffic.

Proposal to deal with the externalities	**Service quality** · "Standing" and impression of safety: the image of the propeller aircrafts needs to be reworked. Propeller aircraft could become an asset for the airlines which accept to replace their jets. At the time of low-carbon mobility, airlines could communicate on their efficiency – which would also present an educational interest for the passengers/citizens. · Journey times: Dedicating a specific space to turboprops in big airports to facilitate the general traffic/boarding? · Comfort: equivalent or inferior noise, no action needed. **Economic externalities** · Airlines' maintenance costs: bonus/malus system helps companies to offset the maintenance costs · Possibility of green financing (green bonds) for any aircraft which consumption is at least 30% less than the one of the aircraft decommissioned. · No action on externalities affecting aircrafts manufacturers. **Employment externalities:** positive assessment, no action needed. **Avoiding risks of bypassing** · Risk of flying bigger turbojets: making administrative authorisations to exploit an air route dependent on a minimum occupancy rate, without which the authorisation is withdrawn.

[1] NOTE 206: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012JD018204

[2] NOTE 20: https://www.airfleets.fr/home/

[3] NOTE 20: https://www.flightradar24.com/

[4] NOTE 209: https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1-annex5/view

[5] NOTE 210: https://www.eurocontrol.int/publication/small-emitters-tool-set-2019

[6] NOTE 211: https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v11-2018.pdf

[7] NOTE 212: https://www.ecologie.gouv.fr/sites/default/files/Bulletin_Stat_trafic_aerien_2017.pdf

[8] NOTE 213: Air France has made the opposite strategic choice of retiring all its ATRs by 2021 and "rationalising" its fleet with CRJ 700/1000 and ERJ 145/170/190

[9] NOTE 214: Marquart, S., M.Ponater, F.Mager, and R.Sausen, 2003: Future development of contrail cover, optical depth, and radiative forcing: Impacts of increasing air traffic and climate change. J. Climate, 16, 2890–2904.

[10] NOTE 215: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012JD018204 see also Marquart and al.

[11] NOTE 216: https://archive.ipcc.ch/pdf/special-reports/spm/av-fr.pdf

[12] NOTE 217: https://www.carbone4.com/trainees-de-condensation-impact-climat/

[13] NOTE 218: https://www.nature.com/articles/s41467-018-04068-0

[14] NOTE 219: https://www.flightradar24.com/

[15] NOTE 220: http://noisedb.stac.aviation-civile.gouv.fr/bdd

7.2.1.3 Limiting the Fuel Tankering

Area n°3: Limiting the Fuel Tankering	
Stakeholders	Airlines
Context	
So-called Fuel Tankering i.e., loading more fuel than necessary for the flight to avoid or limit refuelling at the arrival airport, is a common practice for airlines. The additional fuel loaded for the return flight is an extra mass leading to overconsumption: on a medium-haul flight, about 5% of the additional fuel will be used up to allow the transportation of the remaining 95%; On a long-haul flight and depending on the flight's length, this ratio is of the order of 30%. According to Eurocontrol and within Europe, fuel tankering is practiced 221: • At about 10% for operational reasons (supply difficulty at the arrival airport, shortages, delay, short rotation);	

• At about 90% for economic reasons: the overconsumption cost is compensated by the difference of fuel price between the two airports. Within Europe, this practice saves 265M€/year to airlines and leads to a rejection of 0.9MtCO_2/year for the entire European air space (source Eurocontrol).

221: https://www.eurocontrol.int/publication/fuel-tankering-european-skies-economic-benefits-and-environmental-impact

The use of this leverage is variable and depends on the airlines, but is frequently used by medium-haul airlines in Europe 222. For long-haul flights, the flights practicing this leverage are flying mainly to African destinations; In this case, the carbon cost versus saving ratio is particularly unfavourable.
Detailed description of the measure
Forbid (or discourage, cancel the savings through taxation, or encouraging good fuel management) this practice to all the airlines operating flights to and from France, except, by way of derogation, in case of actual operational reasons or when the savings, in terms of tons of CO2, is above the tutelary cost of carbon (about 500€) 223.
CO_2 impact
As estimated by Eurocontrol, the impact of fuel tankering is 0.9MtCO2 per year. By forbidding this practice, between 0.07 and 0.17MtCO2 could be avoided on the flights handled by DGAC in 2018, excluding upstream costs. For conservatism, the lower value is used in the following. By projecting this gain of 0.3% per year with respect to the reference scenario (cf § 7.1), a gain of 3.7MtCO2 can be estimated over the 2018-2050 period for this measure.
Involved externalities
Impact on employment is low: the measure is barely an inconvenience when the flight considered can also be done by an airline operating from outside of France. However, for most long-haul flights under consideration, Air France is usually without significant concurrency. Furthermore, and in some cases (intercontinental flights from cities in the French provinces), foreign airlines will be, on average, more affected than Air France by this constraint.

Without global regulation of airport charges, Air France would be penalized of about 10 to 20 M€ per year.
Proposal of externality management
The irresponsible nature of fuel tankering is so obvious that the interdiction in one country would presumably spread quickly to others.

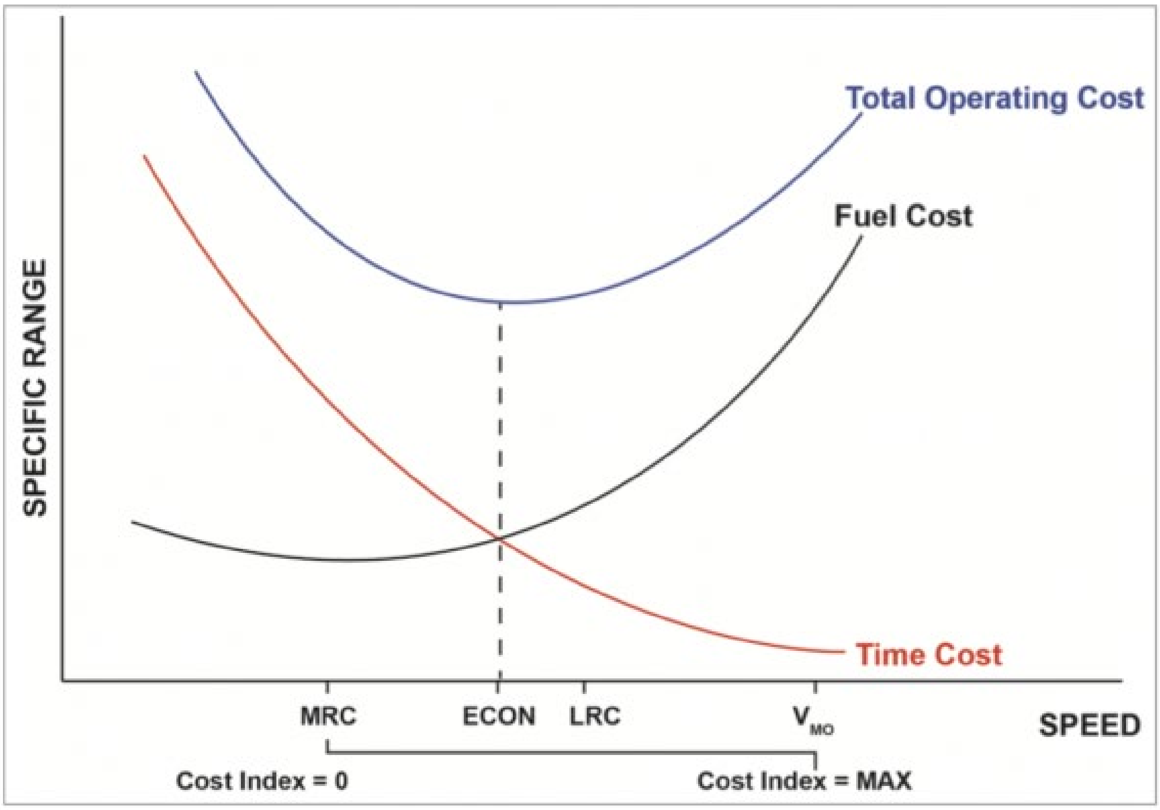
222: feedbacks from pilots of various airlines

223: https://www.strategie.gouv.fr/publications/de-laction-climat

7.2.1.4 Reduce the cost-index of flights to 0

Area n°4: Reduce the cost-index of flights to 0	
Stakeholders	Airlines
Context	
The aviation industry is very competitive. Airlines seek reduction of exploitation cost. The cost of an airway depends on multiple factors, among them: • The cost of fuel (CF) in €/L • The cost of "time" (CT) in €/h, including for example the hourly wage of workers and maintenance, but also the additional cost of delays (penalties, connections etc.) These factors are not independent: fuel consumption increases beyond the optimal speed of the aircraft while the spending on wages and maintenance are directly proportional to the number of flight hours, hence decreasing with the speed. Reducing the speed below the optimal speed is unfavourable for both factors, hence is seldom used except to comply with external constraints (air traffic, etc.). During flight preparation, airlines define flight plans which include flight level and speed. These two values are defined by the choice of the indicator called Cost Index (CI) and lead to the kerosene usage of the aircraft.	

Among other things, this parameter is used in flight management systems to select the speed in order to increase the gains of the airline either by fuel savings (low CI) or charges reduction (high CI).



(https://mediawiki.ivao.aero/index.php?title=Cost_Index)

A CI of zero means that the flight is optimised in terms of fuel usage and allows the aircraft to reach its maximum flight range. When CI = 0, the fuel cost takes precedence over everything else; when the CI increases, both speed and consumption are increased at the expense of fuel cost which becomes less important. The optimum of exploitation cost is CI ECON.

For a given aircraft, the airline defines to the crew a recommended CI, based on its strategy and the various costs. In 2019 (pre-COVID), recommended CI encouraged flying relatively close to the optimal speed for Airlines such as Air France, as well for most airlines.

Therefore, the expected gains are theoretically low. However, the Cost Index remains an interesting topic for the following reasons:

Fuel cost:

The CI, corresponding to the financial optimum for the airline, may evolve depending on the values of the various costs (fuel, hourly maintenance costs, crews, etc.). For example, airlines may be tempted to increase the CI when the fuel cost decreases in order to reduce the overall operating costs, at the expense of CO_2 emissions. Typically, as the fuel cost is relatively low during the post-covid recovery, the CI must be monitored.

Constraints linked to control and air traffic

Near airports areas, air control must regulate the traffic to avoid blockages. This regulation is achieved by requesting aircrafts to slow down or speed up, moving away from the optimal speed. The impact of such measures are limited in time and insignificant in long-haul flights compared to the total flight duration. However, this is not the case for short-haul flights spent mainly in the vicinity of airport areas. Nevertheless, for a constant number of flights and aircrafts, the current solution is better than having aircrafts coming in bulk near an airport, which would lead them to a holding pattern, emitting more CO_2.

An opportunity to reduce these speed deviations is to unblock airport areas to reduce traffic constraints, which is only possible by reducing the number of flights, hence is directly linked to the measure 13 "Passenger reduction". In major airways such as the North Atlantic Tracks (NAT), aircrafts are constrained to fly at similar speeds imposed by air control to ensure a given separation distance during the entire flight. Because various aircraft have various optimal speeds (between Mach 0.82 and 0.85), this unique speed leads to a suboptimal average performance for these airways. As new aircrafts tend to fly faster, this constraint is already limited with aircrafts of various generations. This constraint could become even more disadvantageous if the aircrafts of the following generation fly at new speeds.

Constraints linked to operational hazards:

The last specific case for which aircrafts may fly at a speed far from CI=0 is the management of operational unknowns. For example, an aircraft taking off with a 30 minutes delay will have to fly faster to catch up its delay and avoid missed connections at arrival. In case of a significant delay leading to missed connections, passengers are deferred to the following flight, if the occupancy rate allows it, or to a later flight with additional fees for the airline (meal, hotel…). Connecting time could be increased, but this would lead to a reduced number of flights within a day for an aircraft, therefore a loss of profitability for the airline 224.

Therefore, there is an interdependency between the risk of flight speed increase and:

- Duration of connections (managed by the airline)
- Occupancy rate of the aircrafts
- Frequency of rotations

Detailed description of the measure

The measure consists in:

- **Encouraging airlines to choose the flight speed with respect to the optimum Mach (in terms of consumption/emission of CO2)** for every aircraft and for their entire fleet. This monitoring could be done by the airline or with the external support of the aircraft manufacturer or by a service provider with dedicated software.
- Based on this monitoring, adapt operations and constraints to target a majority of flights with a CI = 0 (for example 90 % of the flights at a speed leading to an increased consumption/emission < 0.2%). The main optimization leverages of flight speeds and consumption/emissions are:
    - **Collaboration with air control to optimize flight conditions in constrained air spaces** to avoid suboptimizing the aircrafts' speed.
    - **Optimize the whole operations by finding the optimum for the various CI parameters**, connection duration and occupancy rate in order to minimize the global CO2 impact for the entire fleet (metric = average CO2 per passenger per year)

CO_2 impact

It is hard to estimate precisely the average CI used by the airlines today, particularly taking into account the air traffic and operational constraints (delay, connections etc.). Based on the opinion on the current situation of pilots and air controllers, we make the following assumption:

224: The linking of flights from an airport with a curfew (for example Orly), is another example of a delay-triggered mismanagement. Even if the CDM coordination between ADP/NAV and airlines to obtain derogations for flights exceeding the curfew of less than 5 minutes is rather fluid, there are multiple examples in which several evening flights are diverted to CDG for a few minutes delay only. The consequence is disastrous for passengers (transported by bus overnight from CDG to Orly) and for the environment because the aircraft flies empty (empty leg) early in the morning to come back to Orly from CDG. This policy backfires: an overshoot of a few minutes of the curfew is refused to limit noise disturbance to Orly's residents, leading to an empty 50km-long trip of with lots of unnecessary emissions. Unfortunately to date, residents' associations refuse to hear this argument.

- 10% of the flights are completed at a speed leading to an overconsumption of 1%, corresponding to an overspeed, limited by the LRC speed, well-known by the pilots.
- 5% of the flights are completed at a speed close to the maximal aircraft speed to catch up important delays. This overspeed leads to an overconsumption of about 4%. [225]
- The remaining 85% flights are completed with a speed close to CI = 0 and an overconsumption close to 0.

With these assumptions, the recommendations of flight speed monitoring would lead to a gain of 0.2% of the 2018 22.6Mt CO_2 air traffic emission (DGAC perimeter), or 0.05MtCO_2 per year.

If all the flights are completed close to CI = 0 (very optimistic), the gain would be 0,3%, or 0.07MtCO_2 per year.

By projecting a gain of 0.2% per year with respect to the reference scenario (cf § 7.1), we can estimate a gain of 3.0MtCO_2 over the 2018-2050 period for this measure.

Involved externalities

Due to the constraints linked to the potential delays, speed flight management is closely related to:

- The duration of the connections (managed by the airline), which must be sufficiently long to minimize the need to speed up in case of a reasonable delay.
- The aircraft occupancy rate: this occupancy rate must be increased to reduce the emissions per passenger, but on the other hand, a limited occupancy rate is an opportunity to replace passengers [226] if another flight misses its connection, and brings operational flexibility to avoid having to speed up.
- Similarly to the occupancy rate, the rotation frequency is an opportunity for passenger replacement.

Because these parameters cannot be optimised separately, the objective is to look for the best compromise in terms of global CO2 emission.

225: Edwards, H, Dixon-Hardy, DW and Wadud, Z. Optimisation of aircraft cost indices to Reduce Fuel Use. 94th Annual Meeting: Compendium of Papers. January 2015

226: Even if this is not the classical management strategy, usually targeting overbooking. The calibration of the algorithms is not based on potential delays of other flights within the network.

7.2.1.5: Overview of the efficiency of the short-term measures

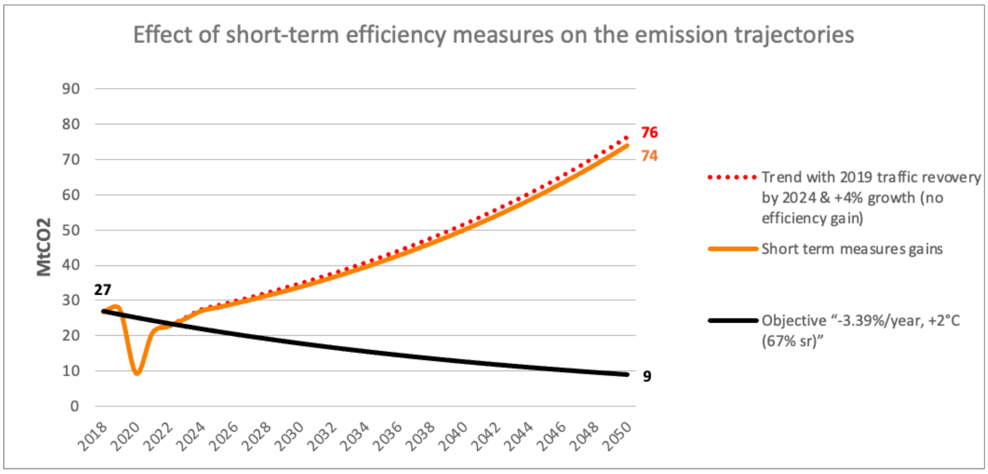


Figure 36: Effect of short-term efficiency measures on the emission trajectories - France

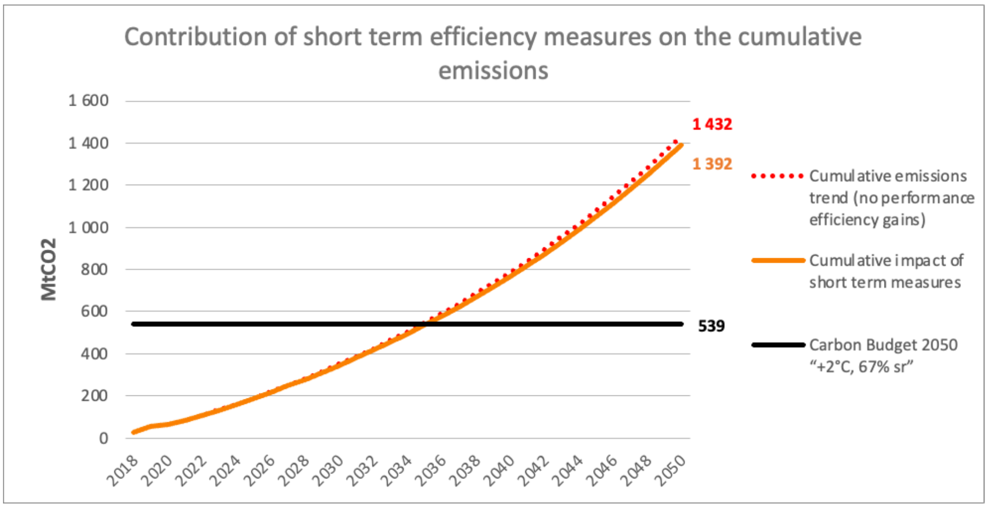


Figure 37: Contribution of short-term efficiency measures on the cumulative emissions - France

Short-term efficiency measures appear largely insufficient to both reach the target or to stall. Other short-term measures linked to usage sobriety are possible. Indeed, this is the combination of short-term measures which significantly contributes to the target (cf 7.3).

7.2.2 mid-long term (from 2025)

The scope of these areas can be evaluated for the world or for France. They are studied once here and will be evaluated twice depending on the perimeter under study.

7.2.2.1 Optimisation of inflight operations

Area n°5: Optimise inflight operations	
Stakeholders	Airlines, regulators

Context
Optimisation of routes and trajectories is one of the fuel savings leverages. Some hopes rely on the Single European Sky (SES) initiative, with the main objective to overcome borders to optimize air traffic. However, in this context, projects targeting the improvement of the operations of large air spaces 227 are facing many limits. For example, modification of military zones requires long negotiations, an air control service provider would not always have interest in optimising the traffic, mainly for security reasons, and finally an excessively transformative project may be abandoned if it does

not meet the acceptance of all the stakeholders. Thus, many European-wide air network optimisation projects are delayed or even abandoned.

The SESAR (Single European Sky ATM Research) project coordinates research and development activities linked to the ATM for the European Union. The project aims at developing the future European air traffic management system, contributing to the Single European Sky (SES). Particularly, the objectives of the project are to bring security solutions, operation efficiency and environmental impact optimisation. On this last point, the ambition of the SESAR and SES projects is to reduce CO_2 emissions by 10% 228.

In parallel of the SESAR project, member states of the OACI are progressively setting up packages of measures from the OACI environmental report. This is the "green aviation" project, made of ATM and system measures, called the ASBU.

Detailed description

Routes and trajectories optimisation

Several solutions are considered to reach this objective, for example:

- continuous descent approach (CDA)
- 4D trajectory management (3D geographic + time parameter), in order to minimise the deviations from the optimal trajectories (ex: waiting time at arrival)
- Free route airspace (FRA) to reduce traffic constraints leading to a longer trajectory than strictly necessary.
- XMAN, sequencing consisting in reducing the aircrafts' speed long before a busy airport in order to reduce waiting time.

The development of these initiatives is definitely positive in terms of reduction of emissions, and must be supported. However, the global gain of these solutions is, to this day, hard to evaluate precisely compared to the targeted 10% emission reduction.

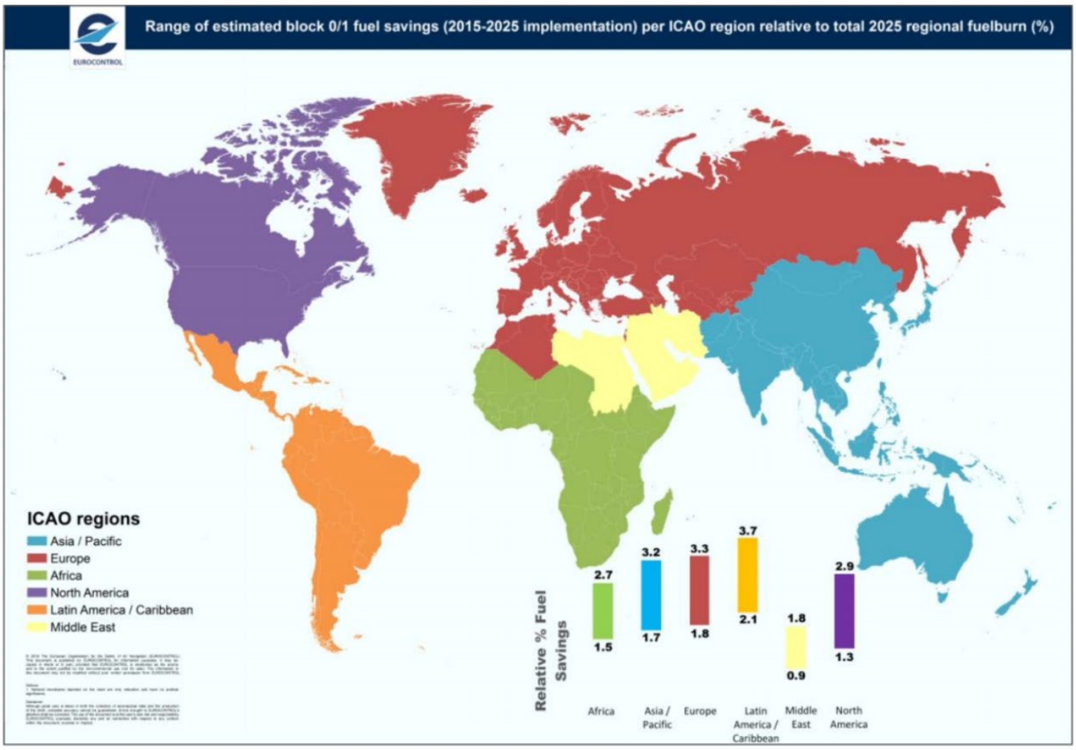
227: The most important is FABEC, a air space centred on France and Germany

228: https://ec.europa.eu/research/press/jti/factsheet_sesar-web.pdf

The "Horizontal flight efficiency – KEA" indicator, measuring the gap between real and ideal trajectories, does not diminish significantly anymore 229, and the (realistic) ambitions shown by Eurocontrol state that it will be difficult to do much better in the coming years. The OACI report "2019 environmental report – aviation and environment" 230 also explains that operational trajectories efficiency is about 96% within Europe today, leaving limited room for improvement. This is explained by several reasons: real aircraft trajectories are already optimised; the large airports saturation often requires to modify in-flight trajectories in order to optimize arrival traffic on the runway; conflicts (Ukraine, Syria…) impose to circumvent closed air spaces; Traffic regulation (in case of bad weather conditions or strikes for example) which generates delays, encourages companies to plan new fly routes not crossing through the impacted control areas, even if it lengthen the flight; etc. The sustained traffic growth imposes to find more complex solutions that must be deployed at large scale in a denser and denser air spaces.

Based on the OACI report "2019 Environmental report – AVIATION AND ENVIRONMENT" (cf. picture below), the estimation of the gains due to the ATM optimisations and trajectories is of the order of 3% for the European zone.

Figure 38: Geographical distribution of expected consumption gains (OACI)



229 https://www.eurocontrol.int/sites/default/files/2019-07/ernip-airac-1905.pdf, https://www.sciencedirect.com/science/article/pii/S1361920917309987, or https://pubs.acs.org/doi/abs/10.1021/acs.est.9b05608

230 https://www.icao.int/environmental-protection/Pages/envrep2019.aspx#:~:text=The%20ICAO%20Environmental%20Report%202019

Therefore, airway optimisation is possible but difficult, and the gain remains to be shown. However, traffic moderation and stronger national wills would allow the stabilisation of air traffic density, increase its predictability and be a step towards a better use of the European air space. This outlook on air control is the one supported by the National Union of Civil Aviation Engineers and Executives (SNICAC) within DGAC.

Flight data exploitation and the use of software such as Openairline/Skybreathe is another way for SESAR to optimise trajectories. This point is not studied here, but the pledge is to reduce fuel consumption by 2 to 5%.

Formation flying

Airbus also studies the possibility to flight in formation 231. Similar to migratory birds, it would allow to slightly reduce the consumption of two long-haul aircrafts. Anticipated savings are from 5 to 10% for the following aircraft, hence from 2.5 to 5% for both aircrafts together. Setting up formation flying would be associated with significant flight security challenges, air control and airline business models, but this point is not detailed here.

Reduce the condensation trails

Studies explore the possibility to modify flight plans in order to reduce condensation trails while limiting the simultaneous increase of fuel consumption 232. The idea is to fly the aircrafts at slightly different altitudes, at which the humidity rate would not favour trails creation. Because airways are chosen to optimise flight duration (hence kerosene consumption and flight cost) and airlines are often reluctant to change the trajectories of their aircrafts, scientists estimate that less than 2% of the flights, which create the most persisting trails, could be diverted of +/- 2000 feet in order to limit about 60% of the condensation trails in the area. According to them, these deviations would lead to a fuel overconsumption of 0,014%, therefore a large total benefit 233.

Unfortunately, at this stage we have too few studies of this type, exploiting local data (for example Japan air space), and for which potential gains are simulation results that would require experimental validation. Furthermore, many questions on operational feasibility remain: is it possible, before take-off, to estimate the 2% flights of interest and to compute the appropriate flying altitude? Would airlines and air control agree to deviate some flights for an ecological reason? This would bring an additional constraint and a new complexity level, to an already complex exercise due to the traffic density.

We note that this proposal is promising, but requires additional studies and a better understanding of physicochemical phenomena responsible for high altitude clouds. Finally, note that its applicability for a decarbonation strategy is possible only when considering the whole radiation forcing (CO_2 effect and beyond CO_2) within the perimeter of emissions to reduce.

231: https://www.airbus.com/newsroom/press-releases/en/2019/11/airbus-inspired-by-nature-to-boost-aircraft-environmental-performance.html

232: See for example https://www.sciencedirect.com/science/article/pii/S1361920917309987 or https://pubs.acs.org/doi/abs/10.1021/acs.est.9b05608

233: See for example https://www.sciencedirect.com/science/article/pii/S1361920917309987 or https://pubs.acs.org/doi/abs/10.1021/acs.est.9b05608

CO2 impact
For this measure, mid- or long-term accurate modelling of the CO2 emission gains is hard. Thus, our estimation relies on existing studies and avenues for research. Possible optimisations: - ATM and trajectory (vertical and horizontal) optimisation: Potential maximum of 3% according to OACI. - Other innovating technologies: formation flying, which would represent 2,5 to 5% for long-haul flights. For France, the long-haul flights being responsible for 56,6% of the emission, we estimate a reduction of 1,4 to 2,8% if this practice was generalised. Therefore, we anticipate a gain of 4 to 6% for flight operations by 2050. By adding the short-term measures "Decarbonate ground operations" (2,4%) and "Reduce the cost-index of flights" (0,25%), we reach an operational gain up to 6 to 9%. SESAR's objective being 10%, we optimistically choose to assume a reduction of 10% by 2050 over the whole operations, or 7,35% for flight operations over the mid-long term. This number is an estimation to reach the order of magnitude of 10% for the whole operation, and is not the result of a detailed study on the deployment of specific solutions.

7.2.2.2 Technological innovation and aircraft roadmap 2025-2050

Measure 6: Make the technological innovation serve the stakes and constraints of climate change	
Stakeholders	Aeronautic industry, public authority
Context	
The implementation of new ambitious aeronautical development programs directed towards the stakes and constraints of climate change is a new opportunity to revitalise	

the innovation, a distinctive trait of the aeronautic industry, and to reconnect with the slowing aircraft energy improvement.

Such large-scale programs have marked aeronautics' history: The Concorde program or the A380 program are good examples and show that development is achievable when provided with the political will and ambition. They also show that, unfortunately, mobility in an international context (energy cost, growth…) is a first order commercial and industrial stake.

We can estimate that, excluding the upstream R&T, 10 years are necessary for a new program development, certification and production of the first aircrafts.

This is a huge challenge and future aircrafts must meet the following constraints:

- **The reduction of the total environmental impact per passenger.km**: Reduction of the fuel consumption (energy efficiency) and reduction of effects beyond CO2 (Cf 5.7.2), being as compatible as possible with alternative energies (Cf 7.2.2.3), and dramatic improvement of the energy efficiency with respect to the most recent commercial turbojet engine.
- **Climate evolution**: In a warming atmosphere with increasing absolute humidity, everything else being equal, the thrust and lift of the motors tend to decrease. Similarly, the atmosphere layer in which shear drag is maximum (creation of turbulences), tends to increase in altitude. It will likely be necessary to anticipate this effect to define flight altitude and cruise Mach.

The role of the state and the European partners is central. While the industry is under the choc of the COVID-19 crisis, such programs would not see the light of day without a strong political impulse and public guarantee, particularly for the industrial risks. The aeronautic support plan of the French government and the European Green Deal through Clean Sky, its research and development project, show encouraging signs of the political will to tackle this challenge.

Detailed description

<u>Technological improvement avenues</u>

From the technological point of view, energetic and "climate" performance improvement rely on the following avenues:

- **Engines**

Engineers agree that the most recent turbojet engine architecture (LEAP from Safran and GE, geared turbofan from Pratt & Whitney, etc.) has reached a technologic-industrial asymptote 234, which will likely be topped only on the long-term with significant efforts on architectural aircraft and motor improvement (we detailed some solutions later in this report). At best, a few percent will be obtained in the coming years

235. Moreover, even if an energy efficiency improvement would be possible, it would not necessarily lead to an improvement of the environmental footprint: one of the improvement avenues is to increase the thermal efficiency, but a higher thermal efficiency leads to the production of more fine particles favouring condensation trails, releasing more nitrogen oxide, producing ozone, a strong greenhouse gas. However, these two effects may be attenuated thanks to technological improvement of the combustion chamber, which is the case between the LEAP and the CFM56 236, from the consortium CFM international made of Safran and General Electric.

234: see this report from the NLR, Dutch's aerospace centre

235: Particularly in long-haul flights, if for example the industrialisation of the "UltraFan" by Rolls Royce succeed. However, this is a not a short-term perspective: at least a decade for industrialisation and another decade for diffusion before such motors and significantly common.

Another optimisation path is the improvement of propulsion efficiency, leaning towards higher dilution rates, or even coming back to turboprop (propeller engine), which would lead to high gains on fuel consumption. Aircraft would then fly more slowly at much lower altitudes, which would cancel the vast majority of non CO2 climatic effects. Such aircrafts already exist, at least for some operational range 237, and most of them are French. Unfortunately, the reduced speed makes this solution prohibitive in the current economical setting (except for short flights), because it leads to higher costs 238 compared to fuel savings. This proposal for short-haul flights is studied and quantified in paragraph 7.2.1.2. The technology being available, it can theoretically be quickly implemented.

The Open Rotor technology, co-developed by Safran, combining the advantages of both turboprop and turbojet with a high thermal and propulsive yields, would bring a gain of about 15% for the flights which could benefit from this technology. However, its deployment is not guaranteed due to the intrinsic challenges of technological breakthroughs 239. Because the open rotor design has consequences on the entire aircraft architecture, it requires specifically-designed aircrafts. Airlines could also be reluctant to adopt this technology, due to both the changes in terms of maintenance operations and passenger opinion. The reluctance of the certifying authorities (EASA, FAA etc.) could also be anticipated for two reasons:

- Unlike with classic turbojets, the absence of fan cowl does not guarantee the containment of an ejected fan blade.
- There is a significant risk of increased noise nuisances for residents. 240

Finally, even if the open rotor is deployed on mid-haul flights, its use in long-haul flights is slightly harder: This technology leads to a speed decrease 241 of about -10%, and the cost of the longer flights could be considered prohibitive compared to the fuel saving in a context of relatively low oil price.

The difficulty to accept the losses in terms of speed, passenger perception, and cost associated with the turboprop or at the Open-Rotor technology, shows that using the technology with a main priority to reduce environmental impact compared to other goals, is not straightforward.

236: it can be checked easily with the OACI database: Despites a better thermal yield, the LEAP emits fewer fine particles (lower Smoke Number) and NOx compared to the CFM56.

237: https://www.latribune.fr/entreprises-finance/industrie/aeronautique-defense/20120218trib000683764/atr-ou-l-incroyable-resurrection-d-un-constructeur-d-avions-a-helices.html

238: Among others: hourly cost of flight crews, number of flights per aircraft per day. https://www.latribune.fr/entreprises-finance/industrie/aeronautique-defense/aviation-sans-co2-oublions-l-avion-electrique-la-solution-est-ailleurs-dit-safran-834909.html

239: Even if Safran tested a prototype on an engine pylone in 2017, a previous version already achieved this in 1985, was tested in flight in 1986, but was never deployed in commercial aircrafts. In this case, the risk associated to the technological change was stronger than the fuel consumption gains. In order to promote its product, Safran is constrained to remind a few unpleasing truths regarding the perspective of electric aircrafts, which is very revealing of the uncertainties on to the future of the Open Rotor : https://www.latribune.fr/entreprises-finance/industrie/aeronautique-defense/aviation-sans-co2-oublions-l-avion-electrique-la-solution-est-ailleurs-dit-safran-834909.html

240: see https://www.easa.europa.eu/eaer/system/files/usr_uploaded/219473_EASA_EAER_2019_WEB_HI-RES_190311.pdf, page 31

241: More precisely, the maximal propulsion efficiency of the Open Rotor is achieved for speeds between 0.7 and 0.8, while the reference speed for the mid-haul flight is 0.78 and 0.85 for the long-haul flights. https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SPM_brochure_fr.pdf

- Structure and mass

Designing lighter airplanes is a possible track for improvement. Unfortunately the status for this topic is almost the same as for the engines: further progress on what has already been done is more and more difficult. As a matter of fact, mass is already an optimisation target in the aircraft conception in order to reduce fuel consumption (economic interest for the airlines). This optimisation must be balanced with the need for robustness, reliability and security, but some new technological elements could enable further progress.

Another way to approach this problem would be to increase the number of passengers carried in each plane with measures such as cabin densification, or occupancy rate optimisation (cf. 7.3.2).

- Air flow

Currently, perspectives on frictional drag reduction target air flow laminarity. It means keeping the plane's air flow pattern as laminar as possible, and delay the transition to a turbulent air flow. As a matter of fact, a laminar flow generates a 90% weaker frictional drag than a turbulent one.

Distinction is usually done between natural laminarity (Natural Laminar Flow, NLF) and Controlled laminarity, by active or passive systems (Laminar Flow Control, LFC)242.

For example, those technologies are applied on the Boeing 787, with its Laminar Flow Nacelles and hybrid laminar flow control on the vertical stabilisers, as well as some private jets.

The exploitation of natural laminarity on the wings of a future short-medium-haul plane is estimated to save about 4-5% fuel. This concept imposes a cruise speed reduction, around 0,75 Mach243, as the sweep of the wing (its angulation to the back) must be reduced to decrease the three-dimensional effects destabilising the flow244. On a long-haul plane, this concept would induce a substantial cruise speed reduction, similar to the one of the Open Rotor.

Concepts such as Hybrid Laminar Flow Control (HLFC) or Laminar Flow Control (LFC) are on much lower maturity levels.

- New Architectures

New architectures are promoted on a regular basis, like the flying wing which could potentially lead to significant improvements on fuel consumption, but remain to be quantified. But these are long-term perspectives, implying strong changes in all areas245, thus do not respond to the necessity of reducing the emissions of the Airline industry in the next decades.

- Breakthrough alternative energies aircraft : electric hybridisation.

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242 Cf. Overview of Laminar Flow, NASA-TP/19980232017 and Review of hybrid laminar flow control systems, K.S.G. Krishnan, O. Bertram, O. Seibel.

243 Like the « Blade »demonstrator , part of the european research program Clean Sky :

https://www.cleansky.eu/news/clean-sky-blade-laminar-flow-demonstrator-makes-first-flight.

244 https://www.aerospacetestinginternational.com/videos/airbus-tests-laminar-flow-wing.html

245 Even including modification of the airports, for such wide planes.

The electric hybridisation of thermal engines is identified by the sector as a major opportunity to reduce aircraft' CO_2 emissions. However, those improvements would only apply to small sized aircrafts, like business jets and regional transport. In addition, the weight is a crucial factor in the airline industry, and what could be gained with hybridisation must be balanced by the additional weight (meaning overconsumption) of the extra engine.

Several distributed electrical power architectures are possible : gas turbines with electric hybridization (partial or complete / in series or parallel) , turbo-electric (partial or complete), and even in the long run, 100% electric motors.

Different hybridisation levels and various primary energy sources (ex-gas turbine and eventually fuel cell) will have to be tested. At the same time, integration technologies for the airframes will also have to be developed and rendered certifiable.

Those applications will allow the development and validation of technologies which will then be applicable to short and medium haul aircraft, and later to long haul with increasing capacity of generation, transmission, and storage of electric power.

Nevertheless, the growing demand of rare-earth elements required to produce electric engines and batteries for the airline industry will compete with the automobile industry, with a decarbonation strategy also relying on hybridisation and full-electric power. Furthermore, the weight consideration being crucial, hybridisation technology (with two engines instead of one) could reachan efficiency limit leading to distinct technological choices for the short to long haul.

o Breakthrough alternative energies aircraft : Hydrogen

Before Airbus went public on the pre-project « ZEROe »246 in September 2020, with the objective of launching a hydrogen-powered short-medium haul and/or a regional plane in 2035, the sector was cautious on this technology.

While hydrogen (or, more precisely, dihydrogen named H_2) is indeed commonly used in the aerospace industry, and while it has the strong advantage of producing only water during its combustion with oxygen, using it as a fuel for a decarbonised commercial flight is a fascinating challenge, complex in several aspects :

- Building a hydrogen-powered aircraft means inventing an entirely new plane, a technological breakthrough from its predecessors, with new equipment (storage, coolers), new engines, which require a new plane's architecture.

Consequently, it is a large scale industrial project, carrying its batch of risks.

Hydrogen is not a natural gas, it has to be manufactured. As of today, almost all of the hydrogen produced worldwide for industrial processes, for example in refineries, is done by steam reforming of hydrocarbons247, producing CO_2. The total emission balance of an aircraft powered with hydrogen produced this way would not be better, if not worse, than an existing turboreactor. It must use a low carbon manufacturing process (as electrolyse or CSC248), using low carbon electricity.

246 https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html

247 https://www.ifpenergiesnouvelles.fr/enjeux-et-prospective/decryptages/energies-renouvelables/tout-savoir-lhydrogene

248 Capture and Storage of Carbon.

This process must be developed ata scale matching industry needs, involving significant and dedicated efforts synchronised with the aeronautic roadmap of the energy industry, generating production externalities, and controlling the supply chain risks (see Externalities and details in 7.2.2.3)

Airport infrastructures must be adapted as soon as it is launched, as part of a synchronised international collaboration enabling the new planes to cover international flights.

- In particular, storage at airports as well as in the planes themselves is a totally new challenge: for the same energy delivered, liquified hydrogen requires 3 times more space than kerosene, at best .

Hydrogen is a volatile and inflammable gas. If gasified hydrogen meets air in a closed space, it can ignite at a lower temperature than kerosene (which is the expected reaction for thrust). Tank positioning is consequently crucial.

Unlike kerosene, it should not be stored in the wings, but in tanks inside the plane to be more protected in case of a crash, or the loss of a fan-blade.

The small molecule size (H_2) makes it easily leaky and forces the revision of the circuit impermeability.

Loading hydrogen on planes implies new constraints to maintain security levels required in the Airline Industry, and leads to a certification issue, although in principle fully manageable by the industry.

While the non-CO_2 effects of high altitude kerosene combustion are yet to be totally mastered (cf.5.7.2), they are even less understood when hydrogen combustion happens inside an aircraft reactor, which produces by nature much more steam. They are said to be lower (its combustion being “cleaner” than kerosene’s), but it will be necessary to analyse all the emissions to evaluate its global contribution to the FR (CO_2, NOx from the atmosphere’s nitrogen, particles, others).

The hydrogen-propelled aircraft challenges are less about technical realisation strictly speaking, than getting a long enough range to maximise the replacement of the existing fleet (regional, short haul, medium haul ?), the supply chain management for low carbon hydrogen, or the synchronized upgrade of airport infrastructures. Of course it will have to find its market, in particular when competing with newer kerosene-propelled aircrafts, much less risky in the short term for an airline. It carries a real opportunity, but also a real industrial risk with multiple dimensions, which means an important risk for the emission trajectory which must quickly decline.

Which aircraft roadmap to 2050 ?

The future aircraft program tackling the climate stakes and constraints will have to combine those different technological leads, while adapting to the needs for mobility and to atmospheric changes induced by climate evolution. Aircraft decarbonation will not happen everywhere at the same time : the evolution of the certification authorities’ regulations will have to adapt to the new energy on board (as hydrogen, synthesis fuels, or batteries), to onboard energy management (high tension, strong current), and to the new propelling units (e.g. open rotor, turbojet with high bypass ratio)

The roadmap showed in the European SRIA’s tender (Strategic Research and Innovation Agenda) “The proposed European Partnership for Clean Aviation” in the context “Horizon 2020” specifies : “Low-emission Clean Aviation technologies will allow energetic efficiency gains from 30 to 50% in 2050, compared to the actual fleet. Furthermore, this partnership will allow the plane, the engines, and equipment, to use the full potential of low-carbon, even zero-carbon fuels, potentially including some breakthrough innovations such as hydrogen. Those improvements will speed up the transition to carbon neutrality.”

An aircraft roadmap means a schedule for the launches of new planes with technologies, capacities, and given performance levels that match precise mobility needs. Planning such a roadmap must be done by aircraft category.

2 kinds of innovative aircraft stand out from the experts’ analyses, and are expected to be launched between 2030 and 2035 in the strengthened roadmap of the European project Horizon 2020 / Cleansky (see SRIA The proposed European Partnership for Clean Aviation), and by Airbus as well (Zero emission concept Presentation on 21st September 2020):

- Regional transport plane (from 20 to 80 passengers, range from 500 to 1000km), with an ultra-optimised infrastructure to integrate a/some gas turbine(s) (jet prop engine) “100% drop-in fuels” or hydrogen injection, electrically hybridised, allowing a 50% fuel consumption reduction in 2035 compared to 2020 equivalent aircraft and respecting the OACI noise nuisance limitations.

- Short-Medium haul (short and medium range aircraft : SMR, from 80 to 250 passengers, range from 1000 to 7000km) ultraefficient (e.g. natural laminarity…), with breakthrough technologies (e.g. turbojet with high bypass ratio), able to use alternative fuels (SAF) and/or dihydrogen, allowing a 30% fuel consumption reduction in 2035 compared to 2020 equivalent aircraft.

2 other kinds of aircraft could also benefit from the above technological innovations developed for regional planes and/or short-medium haul :

- Long haul planes (LHP, more than 250 passengers and range superior to 7000km) integrating aerodynamic improvements and mass reduction to blending rates of "drop in" alternative fuels (SAF), which should allow a 30% fuel consumption reduction in 2035 compared to 2020 equivalent aircraft.
- Very short haul planes (Commuters, less than 19 passengers and range less than 500km), electric hybrid, on battery or fuel cell, which could fly in 2030 without thermal propulsion. Those very short haul planes would only have a minimal influence in the climate impact reduction, as their share in traffic is low. However, commuters will be useful as development platforms allowing the manufacturers to gain experience and validate new technologies (CleanSky 2 Hydrogen Powered Aviation, Clean Aviation SRIA).

On this basis, we built an aircraft roadmap, called "INDUS", based on the schedule announced by the industry, with the most optimistic assumptions

Year	Type	Feature	Energetic performance (1)	Incorp. ratio SAF (2)	Incorp. Ratio H_2	Reference
2018 (3)	SMR	Last generation of turbojet	80%	50%	0%	A3XX NEO, B737 Max
	LHP	Last generation of turbojet	75%	50%	0%	A350, B787
2025	Commuter	Liquid fuel (excluding H_2)/ electric hybrid propulsion	50% (4)	25%	0%	SRIA Clean Aviation (optimistic).
	Regional	Last generation of turbo propellers	90%	50%	0%	Assumption
2027	SMR	Last generation of turbo propellers	75%	50%	0%	Assumption(Aircraft like Boeing NMA/MoM)

2030	Commuter	Hydrogen propulsion	85% (-15%) (5)	0%	100%	Assumption
	Regional	Liquid fuel (excluding H_2)/ electric hybrid propulsion	50% (4)	25%	0%	SRIA Clean Aviation
2035	Regional	Ultraefficient configuration, Hydrogen propulsion	85% (-15%)(5)	0%	100%	SRIA Clean Aviation (optimistic) and Airbus (ZEROe)
	SMR	Ultraefficient configuration, gas turbine, turbojet with high bypass ratio, H_2 propulsion, liquid H_2	63,8% (-15%) (5)	0%	100%	SRIA Clean Aviation (optimistic) and Airbus (ZEROe)
	LHP	Ultraefficient configuration, gas turbine using SAF fuel, (APU) hybrid (6)	56,3% (-25%)	100%	0%	SRIA Clean Aviation (optimistic)

Table 5 - aircraft roadmap optimistic "INDUS"

(1) The energetic performance is the needed percentage of energy, compared to the best plane existing in 2018, regardless of the fuel, to complete the same mission.

(2) SAF incorporation ratio here means the maximum quantity of biofuel or PTL the plane can carry to produce 100% of the energy required.

(3) In 2018, the fleets are not entirely renewed with the last generation of available aircraft, so we take them into account in our model.

(4) The energetic performance here includes the emission reductions resulting from the electricity used in propulsion. The real aircraft performance is inferior. Here only (for modeling purposes), energetic performance is merged with emission performance, and emissions from the necessary electricity production are not taken into account here because of its negligible volumes.

(5) Target nominal energetic gain of 25% from one aircraft generation to the next, lowered to 15% for the hydrogen transition because of the additional weight of onboard equipment and the necessary volume of H_2.

(6) Hydrogen-propelled long haul assumption seems really unrealistic as of today. In fact, if it seems technically possible, the low density of hydrogen would imply a far too big tank to be carried around for a long haul. The main lead considered to decarbonise long haul travel is the use of SAF.

Next, we will look into the impacts of a roadmap "INDUS+5" with the safer hypothesis of a 5 years shift in the launch schedule of those aircraft.

Matching those ambitious objectives also imply :

- Thinking about the technical and commercial aspects of these programs, from the beginning with principles of eco-conception, such as :
  - Controlling emissions other than CO_2 in order to not degrade the energy and fuel performance
  - Facilitating recycling at the end of the service life
- Applying the co-conception to the entire life-cycle by making the engine and aircraft manufacturer collaborate in the pre-project phase (improving integration of the motor function)
- Applying the co-conception with the airlines to prepare the public for potentially different aircraft shapes with respect to the traditional ones.
- Making use of new knowledge and technologies (e.g. bearing and non-bearing laminar aeras; lengthening of the wings to reduce the implied drag forced; optimal cruise Mach potentially inferior to the actual ones; noise control during take-off and landing phases)
- Considering technologies not used yet for economic reasons (e.g. Open Rotor) or to adapt existing technologies (e.g. turbo-jet);
- Reducing the carbon cost of the ground operations and maneuvers, for example by including from the conception an electric engine in the front landing gear to ensure autonomous taxi, which could harvest energy back during the landing.
- Stimulating airlines (by regulation mechanisms, by establishing ambitious and clear objectives, by bonus/malus system of license fee, etc…) to quickly renew their fleet favoring those new more economical aircraft.
- Guaranteeing enough supply in alternative energy (SAF, PTL, H_2) made by low-carbon industrial processes, from the commissioning of the aircraft. Today, the new planes are certified for an incorporation ratio of 50% of SAF, but its availability is insufficient to reach those levels.
- Guaranteeing the availability of airport infrastructures for Hydrogen specifically (Supply, storage, processing and filling tools for the aircrafts' tanks)
- Guaranteeing an international collaboration and coordination in fuel supply and sufficient airports infrastructures. It should allow the new planes to handle international flights without the use of "Fuel tankering", an irrelevant option due to the volume of onboardHydrogen.

Observations:

- The development of those aircraft would allow the achievement of the objectives in energy consumption reduction during the period 2020-2050 (based on a fleet renewal of 15 years). At the same time it is necessary to develop an aeronautical program to create vehicles adapted to the travel conditions of 2045. As this roadmap is judged very optimistic, and by not having any specific information today, we did not take into account the new aircraft generation for 2040-2045. In any case, considering the renewal time, this new generation would have little impact on the total emissions before 2050.
- In addition, freight transport could benefit from the development of aerostats, which expected consumption is vastly inferior to planes', but will need further investments in research and development. An industry already exists in France targeting the development of 60 tons aerostats.

CO_2 Impact

The gains on CO_2 emissions brought by these roadmaps are effective but depend on the acquisition, the commercial startup of those planes by the airlines, the renewal pace of their fleet (cf 7.2.2.4) and the availability and filling rate of SAF, H_2 availability (cf. 7.2.2.3) and its dedicated airport infrastructure.

Consequently, the effective gains expected from the roadmap "INDUS" or "INDUS+5" will be estimated by combining them with the assumptions on alternative fuel and the fleet renewal pace, in 2 "converging" scenarios presented in 7.2.3.

Externalities

Financing

The European tender SRIA (Strategic research and innovation agenda) "The proposed European Partnership for Clean Aviation" must be approved in the context of European programs linked to the Green Deal (Horizon 2020, then Horizon Europe). It includes:

• A 12 billion euros budget on research and innovation for the 2020-2030 period ,

• A 45 billion euros need to develop 3 kinds of aircraft (15 billion € each) between 2030 and 2035 (In comparison, a new plane development program - like the A380 - is about 10 billions €).

• An estimated cost of 5000 billions € for the fleet renewals (26 000 planes) from 2035 to 2050.

In a context where the traffic's growth could be questionable, either unwanted like in the COVID-19 crisis, or willingly operated through measures of sobriety to control GHG emission or fossil energy dependency, the question of a viable business-model for the aviation industry and the financing of those programs takes a whole new meaning. If the sector alone (industries and airlines) cannot afford those programs' costs and renew their fleets, and if it is done by public financing, then the priority management for public money will rise, in a possible context of global reduction of the economy.

Employment

Maintaining and financing this roadmap would allow a few thousand direct high-value jobs to be maintained each year (research and development), to assist the program implementation and deal with the technological risks met by industrials 249. A more detailed study of the employment impact is presented in paragraph 9.

Recycling industry

Developing a recycling industry for composite materials would also benefit the Wind Turbine Industry (for which the volume to be recycled is on par with air transport's one).

Resources and energy

The supply capacity of alternative energies is at the core of the success of such a strategy. PTL, electricity and hydrogen have to be produced through low-carbon processes (e.g. electrolysis for H_2), even zero-carbon processes (capturing CO_2 in the air or leaving the factory for PTL), themselves powered by low-carbon electricity. The preferred option for the aviation sector seems to be wind turbines. In any case, according to the roadmap and fleet renewal pace, it is mandatory to properly dimension the entire alternative fuel and low-carbon electricity production. This point is of utmost importance considering the physical limits of fuel production, the consequences on the electric grid already in place, and the most-likely inter- sector competition to access those resources, each one having to follow a trajectory of reducing its emissions.

This point will be detailed during the analysis of converging scenarios in paragraph 7.2.3

249 Clean sky 2 joint undertaking third amended bi-annual work plan and BUDGET 2018-2019

https://www.cleansky.eu/sites/default/files/inline-files/CS-GB-2019-04-09%20Third%20Amd%20WP%2018-19%20published_1.pdf - page 96/97

7.2.2.3 Use of alternative fuels instead of kerosene

Axis 7 : Use of alternative fuels

Concerned actors : Airlines, manufacturers, engine manufacturers, fuel and electricity sectors, public authority

Contextual elements

Alternative fuels are suggested as a central solution for the decarbonation of air transport.

In the emission reduction trajectory announced by the airline industry, the target of 100% alternative fuel used by 2050 is stated (cf 5.9.1).

But as of today, the biofuel production (first generation only for now, competing with agricultural surfaces) is **far from being available in proper quantity to replace oil**. For example, in its Agricultural perspectives 2016-2025 250, the OECD and the FAO point out that "the global production of ethanol should increase slowly, going from 116 billion liters in 2015 to 128.4 billion liters in 2025. Brazil will be responsible for half of it. The global production of biodiesel will increase driven by policies in place in the United States, Argentina, Brazil, and Indonesia, and to a lesser extent, by the implementation of the RED's objectives (Renewable Energy Directive). It should then go from 31 billion liters in 2015 to 41.4 billion liters in 2025. The production of advanced biofuels shouldn't take off during this time period". This means 251 a total of 170 billion liters in 2025, 2.9 million barrels per day, or **3.5% of the global oil consumption** (2.9% when considering condensates, non-oil hydrocarbures and refining gains which adds up to a global oil consumption close to 100 millions barrels per day).

Thus, the airline sector is planning to use only 2nd generation or later biofuels, this to avoid deforestation and competition with the agro-food industry, but available quantity is still a crucial matter. (cf. 8.1 et Annex 1 in 12.1)

The fuel industry in general, and alternative fuel in particular (biofuel, agrofuel, synthetic fuel, hydrogen…) is complex and unveils physical and industrial realities very different from one fuel to another.

We offer here a panorama of the different kinds of fuels, of their capacity to contribute to the emissions' reduction of the airline sector. One of the main subjects being the low-carbon production and supply capacity, the physical limits of the production, and a 2020-2050 trajectory on the French perimeter.

Detailed description

A panorama of alternatives fuels.

The different fuel families can be represented like this :

250 http://www.fao.org/3/a-BO103f.pdf

251 Neglecting, as first approximation, the conversion subtleties, all of the liters not having the same energetic value.

Figure 39 – The different families of fuel

Fuels / Synthetic fuels / Alternative fuels / Biofuels / Agrofuels / Power-to-Liquids / Hydrogen / Fuels made from natural gas / Fuels made from coal / Fuels made from oil

A synthetic fuel, or synfuel, is a mix of hydrocarbons obtained from any other resources than oil.

Among those synfuel, some are from fossil resources like natural gas or coal, the others are named alternative fuels. The latter are interesting because of their energetic potential, less carbonated than the fossil ones;

There are various kinds of alternative fuels (liquid or gaseous), distinguished mostly by the source material used and the process of transformation. They can be used in aviation as a complement by mixing them with regular kerosene with variable ratios, depending on their characteristics. Some, like hydrogen, can be used alone, but only in an aircraft specifically designed for it (cf. 7.2.2.2)

Sustainable Aviation Fuel (SAF) is an alternative fuel certified with social, environmental, and economic consideration, which gives it an advantage on kerosene. SAF is said **« drop-in », which means it can be injected with kerosene without technological modification of the existing planes.**

Biofuel is an alternative fuel made from organic non-fossil materials, called biomass. Some are SAF, others are not.

Agrofuel is one of the biofuels : it's produced from agricultural products only, which does not include, fuels from forest biomass nor seaweeds. Then, the English word for "biofuel" can easily be confusing.

The **Power-to-Liquids (PtL)** are another kind of alternative fuel. It consists in liquid hydrocarbon production made from electric energy, from dihydrogen (H_2) (preferably obtained through a low emission process), and from CO_2. The supply of CO2 can be done by direct air capture, or from various industrial sources.

The decarbonising power of biofuels and PtL does not come from their emissions, which are equivalent to kerosene, rather to the upstream absorption of the CO_2 needed for their production and manufacturing process. Then, the decarbonisation related to the use of those alternative energies cannot be evaluated without taking into account the full life cycle, from production to combustion during the flight. This is why it is necessary to include the upstream emissions of kerosene (oil extraction, production, transportation…) in order to really determine the emissions reduction impact. (cf.5.9.2)

Finally, **hydrogen** can be used as an alternative fuel for aircraft in two situations :

- With the direct combustion process of the dihydrogen in a thermal engine,
- In a fuel cell supplying electricity to electric engines.

Table 6 – Some stereotypes and a few answers on alternative fuels

Stereotype	**Answer**	**Detail in Annex**
"Biofuels compete against food processing industry and require deforestation"	**Mostly TRUE** for the first generation of fuel (1G) **Mostly FALSE** for the second (2G) and later fuel generations	13.1.1
"Biofuels have a worst carbon impact than kerosene"	**FALSE** for most of them.	13.1.2
"Biofuel emissions "excluding CO2" are worse than those of kerosene"	**We don't know**	13.1.3
"Biofuels will never have enough supply to support the airline sector"	**Probably**	13.1.4
"All current planes can fly with 100% alternative fuels"	**FALSE**	13.1.5
"If alternative fuels are not yet available on the market, it's because they are too expensive to produce"	**RIGHT** and **FALSE**	13.1.6
"Using Hydrogen is emission-free"	**FALSE**	13.1.7
"Green hydrogen would allow air traffic to have no environmental impact."	**FALSE**	13.1.8

How much alternative fuels can decarbonate? 252

Airline industry aims at using 2G (or more) biofuels, in order to have much less impact on deforestation and not to compete with the agro-food industry.

Fuels considered here are those for which the processes are scientifically mastered and have the lowest CO_2 emissions. The fuels are “drop-in”, meaning they can be used in today’s aircraft.

[252] Complete panorama of alternative fuels, details and sources available in the Calculation Note

Considered fuels are therefore "FT-Synthesis" 2G biofuels produced from agricultural, forests and municipal waste, as well as Power-to-Liquid fuels (PtL). Hydrogen is treated separately as it is not a drop-in fuel. The use of liquid hydrogen (LH_2) has been retained further on, as it enables lowering the onboard volume of fuel for the same useful energy quantity. As for PtL, CO_2 emitted by LH_2 consumption may vary according to manufacturing processes, and in case of a production through electrolysis, according to the way electricity was produced. Therefore, the use of hydrogen and PtL technologies is only efficient to decarbonate the airline industry if the electricity mix is below a defined carbon intensity threshold.

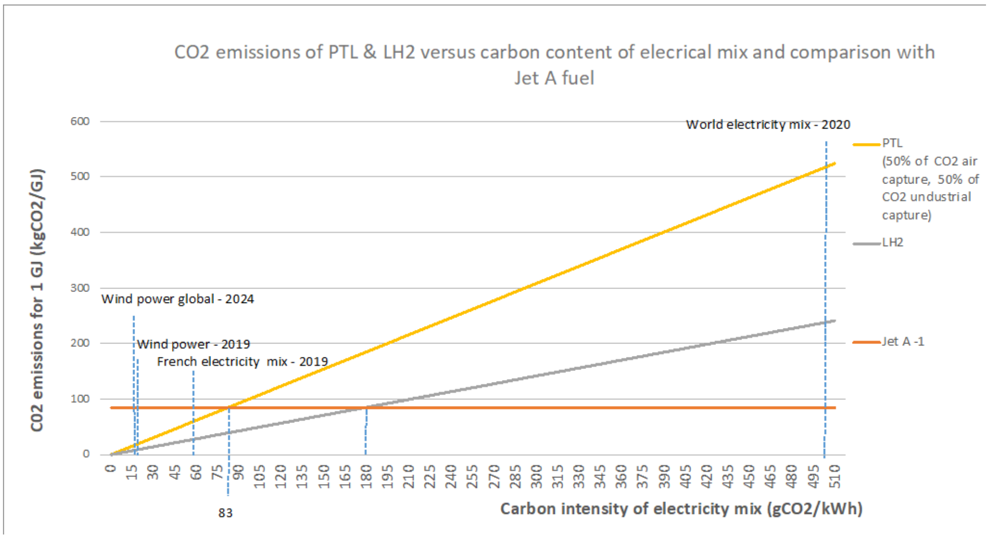

Figure 40 - CO_2 emissions for Jet A-1, PtL and LH_2 depending on electricity mix carbon intensity

With an electricity mix emitting more than 180 CO_2g/kWh, planes flying on hydrogen will emit more CO2 than planes flying on kerosene. Moreover, with an electricity mix above 83 CO_2g/kWh, the use of PtL is more emissive than kerosene. In a worldwide decarbonation strategy massively using this kind of fuels, it is essential that the electricity produced meets those criteria. Several options are to be considered:

- **Massively decreasing emissions from the average world electricity mix** (today around 500 CO_2g/kWh 253). This should be the best option because of its global effect, and because it avoids competition on access to low carbon electricity. This average mix emissions must therefore decrease to reach the objective but reaching below 100 CO_2g/kWh on a world average before 2050 remains a colossal challenge, from which the aviation industry would depend, as an actor in its end-to-end energy supply chain.

[253] 180 gCO2/MJ estimated in the GIEC SR15 – https://www.ipcc.ch/sr15

- **Using only low carbon energy sources**: it is the most quoted path by the sector, particularly as to wind power. Theoretically, it works (wind power emitted 14.9 CO_2g/kWh in France in 2019[254] and around 11 CO_2g/kWh[255] worldwide in 2014). A large-scale development of these energies would be necessary, as well as anticipating the future demand of the airline industry in this development roadmap. According to traffic growth scenarios, the energy need for airline transportation would be a main sizing parameter (see the study on energy externalities per scenario in 7.2.3) and would naturally compete with other sectors depending on available capacity. Furthermore, this method would also compete with direct use of electricity. Production is even more marginal if we consider only the use of excess renewable electricity, as for electrolysis for instance (by not being absorbed by the grid, it does not compete with direct use).
- Locating LH_2 and PtL production in areas where the electric mix carbon intensity is the lowest. This option theoretically also works. For instance, in France, the electric mix carbon intensity is much lower than critical thresholds, especially because of nuclear power (57 CO_2g/kWh globally and 6 CO_2g/kWh for nuclear power in 2019[256]). Nonetheless, the geographical location raises the question of transport to the fuel tank, increasing the logistics complexity (particularly for hydrogen), as well as CO_2 emissions[257].

Whatever the considered strategy, the question of low carbon electricity production in sufficient quantities for the airline industry is at the heart of Hydrogen strategies (LH_2 and PtL). It is one of its key factors of success.

Table 7 – Decarbonising power of alternative fuels considered in the France study

Alternative fuel type	CO2 emissions compared to conventional jet fuel (kerosene)		
	Least favourable scenario	Most favourable scenario	**Value used for simulations**
FT-Synthesis from agricultural waste (wheat and maize) and forest waste	-87,4%	-90,8%	**-90,8%**
FT-Synthesis from municipal waste	-68,3%	-68,3%	**-68,3%**
Power-to-Liquid	-78%	-86%	**-82% ***

LH_2	-92%	-92%	**-92% ****

(*) Hypothesis: 50% of CO2 captured directly in the air and 50% captured from the plants, synthesised from H_2 by electrolysis and wind electricity in France

(**) H_2 produced by electrolysis and wind electricity in France

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[254] ADEME: https://data.ademe.fr/datasets/base-carbone(r)

[255] Several concordant sources announce between 11 and 13, from which IPCC 2014 and Electricity Map (IPCC source): https://www.electricitymap.org/zone/FR

256: ADEME carbon basis (2018)

[257] It is an even stronger issue as countries such as Morocco, Saudi Arabia, and Australia plan to massively produce hydrogen (mainly green and blue) in view of exporting it. Germany already builds partnerships with Morocco, Japan, and Korea with Saudi Arabia and Australia. These governments seem to plan on a local demand higher than their production capacity. Hydrogen export is shaping up to be a growing challenge.

How much available production for air transport?

It is considered here that energy production for air traffic in France is produced in France. This assumption implies the following advantages:

- Simpler supply chain and easier new distribution networks setup
- National sovereignty on fuels
- Proximity between raw material, processing plants and airports, therefore mitigating emissions induced by fuel transport (choosing the hypothesis of a favourable decarbonised power)

If this assumption revealed itself limiting enough to challenge the results from the "converging scenarios" presented in 7.2.3, other paths would have to be investigated (other types of fuels, imports)

Concerning Biofuels, the physical production limit is directly linked to agricultural and forest surfaces, or the annual quantity of municipal waste. Considering the uncertainties on how these surfaces will evolve over time, notably because of climate change and how it will affect ways of life and consumption, actual supplies are considered stable over time.

Concerning PtLs, we have not found any production target reliable enough. Therefore, we assume a production large enough to reach 100% alternative fuels in 2050 in the most favourable scenario (cf. 7.2.3.1). This production would then be around 4 Mt/year in 2050. It should be noted that ADEME mentions a target of 15 Mt of captured CO_2 using CCUS (Carbon Capture, Utilization, and Storage)[257] which could mean a 5 Mt PtL production if capture was directed towards this objective. This order of magnitude seems acceptable, without considering the production's energy externalities.

FT 2G fuels from agricultural and forest waste or municipal waste are not commercialized in France yet. Technology is mature, but production is nil. Marketing in France could start shortly: it is considered here starting as soon as 2021. In contrast, it is necessary for PtL production to set up the low carbon hydrogen supply chain. A 2030 start is considered here.

If production growth is considered on a progression of 25% per year for the first 10 years and 15% onwards, we can establish with all previous assumptions a first production scenario.

[257] ADEME : https://data.ademe.fr/sites/default/files/assets/documents/captage-stockage-geologique-co2_csc_avis-technique_2020.pdf

The "CAPA 100" assumption is the one where air transport is the first beneficiary of production. In this assumption, available quantities in 2050 are as follow[258]:

Table 8 – "CAPA 100" assumption, annual production in 2050

Year	Fuel	Annual available quantity for airline transport (Mt)
2050	FT 2G agricultural Waste (wheat and maize)	1,23
	FT 2G Forest Waste	0,16
	FT 2G Municipal Waste	1,36
	PTL	4

Maximum production capacity reached in 2050	6,76

Next, we will look at the "CAPA 50" assumption where air transport has "only" access to 50% of the total production. This assumption is still very favourable to the air industry and would require a strong arbitration towards it. The essential aims here are to assess the sensitivity of this parameter on decarbonation pathways and to inform a decision, without prejudice to a favourable or unfavourable arbitration towards the air industry at this stage.

Concerning hydrogen: In its report on hydrogen in France dated 2018[259], the French Association for Hydrogen and Fuel Cells (AFHYPAC, now France Hydrogène) displays an objective of a 5.5 Mt hydrogen production capacity. This is to meet the needs of the chemical industry, road transportation, or to be blended in gas networks. In its hydrogen plan for Energy Transition[260], the French government mentions a national need of 1 Mt. The main objective of this plan is to decarbonise this hydrogen, produced today with 94% fossil energy. For instance, it aims to decarbonise 40% of the total by 2028, with slightly more than 0.1 Mt dedicated to mobility, and only road transportation. To adhere to this roadmap, France has planned a 7.2 billion Euro budget for the next ten years, associated with the construction of hydrogen gigafactories, producing from renewable or nuclear energy[261].

In the following scenarios, it is considered that hydrogen production is not limited. Nevertheless, a study of energy externalities associated with the necessary hydrogen production and a comparison with actual French roadmaps could measure its feasibility and the hydrogen level of demand from air transport industry.

[258] See details, calculation references and complete pathways in the Calculation Note

[259] http://www.afhypac.org/documents/divers/Hydrogene-en-France-2018.pdf

[260] https://ecologie.gouv.fr/stes/default/files/Plan_deploiement_hydrogene.pdf

[261] https://www.revolution-energetique.com/bruno-le-maire-veut-une-gigafactory-francaise-de-production-dhydrogene/

- **CO_2 Impact**

Gains on CO_2 emissions brought by alternative fuels are, of course, only effective depending on their actual consumption. The latter depends on traffic and the different kinds of aircraft in the fleet, itself conditioned by the plane roadmap (cf. 7.2.2.2) and the fleet renewal pace (cf. 7.2.2.4).

Thus, expected actual gains in the "CAPA 100" and "CAPA 50" assumptions will be evaluated combining them with the alternative fuels and fleet renewal assumptions. This will be done in 2 "converging" scenarios presented in 7.2.3.

- **Externalities**

Consequences of the transformation of the fuel industry are not studied here. But PtL and H_2 production needs electricity in the best-case scenario. The required quantity of electricity results in a number of consequences:

- GHG emissions, depending on the energy mix used to produce electricity,
- The dimensioning of electricity production capacities, with its effect on the local territories.

The McKinsey & Company report for Clean Sky 2 "Hydrogen-powered aviation, A fact-based study of hydrogen technology, economics, and climate impact by 2050" in May 2020 was used as a reference to quantify the energy needed to manufacture 1 ton of hydrogen or 1 ton of PtL. This report is supported by most of the French industries directly concerned by the hydrogen question (amongst them are Airbus and Safran). We hence consider that 1.7 kWh of electricity is needed to produce 1 kWh of H_2, and 4.6 kWh to produce 1 kWh of PtL with CO_2 direct air capture (against 2.8 kWh by capturing CO_2 from industry). These figures take into account the whole chain: for H_2 electrolysis, compression and CO_2 capture, and for PtL transport, storage and distribution.

The size of the externalities will then depend on the chosen scenario. To keep in mind some order of magnitude, to obtain the 4 Mt PTL per year mentioned above, one would need to produce **approx. 181 TWh electricity, meaning 5 times the total energy produced by the French wind farms in 2019**[262]**.**

7.2.2.4 Acceleration of the fleet renewal rate

Axis n°8: Acceleration of the fleet renewal rate

Relevant stakeholders Airlines, banks, plane rental companies, manufacturers, public authorities

[262] 45.3 kWh/kg PTL (cf. Calculation Note), 33.9 TWh produced by French windfarms in 2019 (source RTE https://bilan-electrique-2019.rte-france.com/)

Context

The replacement of old generation aircrafts making up the airlines fleets by new generation aircrafts is a virtuous process in terms of fuel consumption and therefore in terms of reduction of greenhouse gases. Indeed, the carbon cost of manufacturing an aircraft represents only a small fraction of its complete lifecycle emissions. Available estimations are around 0.5%[263]. This carbon cost is therefore quickly paid for (from an emissions point of view) as soon as the energy efficiency of a new plane is improved. For example, replacing planes from the A320 CEO family by equivalent planes from the A320 NEO range is quickly worth it from an emissions point of view, as their cruise consumption is announced to be 20% lower[264].

The energy efficiency savings pool is important regarding an analysis of the average age and composition of airlines fleets. For example, the average age of the Air France fleet in 2020 is 14 years[265], and 89% of its aircraft are old generation models. The average fleet age of comparable European airlines is about 11 years, whereas Gulf and Asian airlines fleets are around 6 years old.

According to ICAO, the world fleet is renewed every 25 years.

Detailed description

Issues raised by an accelerated fleet renewal

Significantly accelerating the fleet renewal rate is a complex issue.

For an airline, purchasing new generation aircrafts (whether renewing the fleet or expanding it) can be interesting in terms of OPEX reduction and environmental performance improvement. However, a new generation plane bought just after its release is an important investment, and its short-term ROI can be risky. Particularly:

- If an older generation plane answering the same needs is available on catalogue, the price difference between them can lead the airline to choose the cheapest.
- If the airline already operates planes of the same generation, it will optimize its maintenance costs when minimizing the range of its fleet.

[263] A first step towards the integration of lifecycle assessment into conceptual aircraft design, A. Johanning and D. Scholtz, 2013

[264] Manufacturer's data. Source: https://www.airbus.com/aircraft/passenger-aircraft/a320-family/a320neo.html

[265] Source: https://www.airfleets.fr/ageflotte/Air%20France.htm. Before the COVID-19 crisis, the aim was to lower the average fleet age to 10 years in 2030, according to the Horizon 2030 press kit.

- The purchase of newly released planes has an element of risk for airlines as less mature technologies can lead to lower reliability. An airline expressly equipping itself with the latest aircraft is exposed to a risk on its whole fleet which can quickly lead to an important loss in revenue (for example: rise in the cost of maintenance, availability rate decrease, etc.). In turn, this can lead to expenses from the whole sector related to product changes, new necessary certifications or even the grounding of new plane models.

The fleet renewal rate depends on the fleet size, the maximum possible operating time of a plane (from 20 to 25 years), and the high price of a new plane. But it also depends on the airlines' financial health, their available cash (for fully owned planes, the airline will pay 100% of the price upon delivery), their growth perspective and therefore the level of investment dedicated to fleet renewal; and finally of their financing capacity from banks (obtaining loans or negotiating lease agreements). In time of economic crisis, the investment rate naturally strongly decreases for a longer or shorter period of time, as seen now with COVID-19 and previously during other crises. Many airlines cancel and delay deliveries of ordered planes to preserve their cash.

From an industrial point of view, increasing the renewal rate means increasing production capacity. Today, there are 15 to 20 years between two generations of aircraft. Given the high number of old generation planes in circulation (for example 116 from the CEO range at Air France), it is a strategic decision for aircraft manufacturers and their suppliers, particularly in times of crisis and business uncertainties. Production capacity needs to be planned on the long term, synchronised with the plane programs calendar. Also, it calls for important efforts in R&D as well as heavy industrial and human investments.

CO2 impact

Structuring study assumption[266]

We will study here the impacts of a 15-year fleet renewal against 25 years today, whichever the aircraft category.

The fleet renewal is based on the plane roadmap, defining the timetable of new aircraft availability as well as their performance level.

The model used operates according to the following guidelines:

[266] See details of the model, assumptions and sources of simulations in the Calculation Note

- Every year, 1/15th or 1/25th of the fleet of an aircraft type (Commuter, Regional, Short-haul, Medium-haul or Long-haul) is renewed with the best available aircraft according to the plane roadmap.
- New planes replace the least-performing ones of the fleet.

In the scope of this study, the annual CO_2 emissions gain is calculated by applying the rate of performance gain of the renewed fleet in proportion to the 2019 emissions evaluated of the French perimeter, per type of aircraft. This evaluation is primarily based on the DGAC report on gas emissions[267].

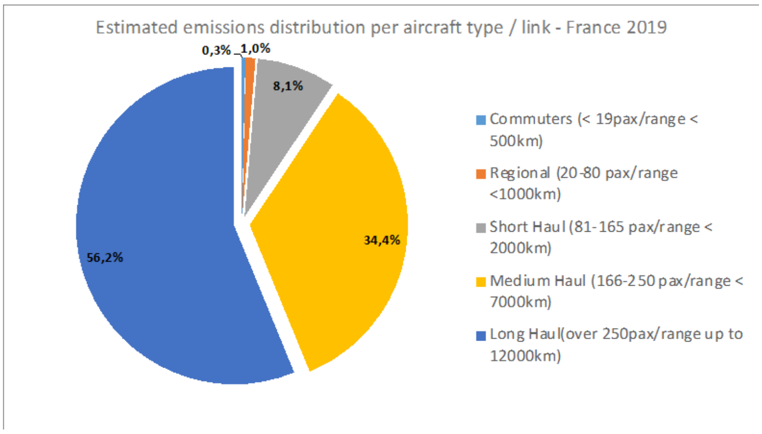


Figure 41 - Emissions distribution France 2019 per aircraft type/link

This chart reflects the traffic distribution per type of aircraft in the 2019 fleet over France for all airlines, as measured by the DGAC. This distribution is assumed to be constant over time. So, if the medium haul fleet improves its performance by 50% in any given year, contribution to the total emissions reduction will be calculated at 50% x 34.4% = 17.2%.

It should be noted that this assumption is a structuring factor as it conditions the real effectiveness of the plane roadmap on decarbonation. Indeed, in its report for the ICCT, McKinsey evaluated medium haul at 42% and short haul at 30% of worldwide emissions. This means for example, that the replacement of the world medium haul fleet with hydrogen planes will have more impact than in France alone, where the size of the country, its overseas links and tourist attractiveness all favour long haul traffic.

For a given plane roadmap, and on the basis of an optimised emission trajectory, the simulation compares emission reductions on a 15 and a 25-year renewal scenario.

Finally, given the actual crisis, it is considered that the 15-year fleet renewal scenario could only start from 2025.

[267] https://ecologie.gouv.fr/sites/default/files/bilan_emissions_gazeuses_2019.pdf

Effective expected gains are measured by taking into account assumptions from the plane roadmap, production of alternative fuels and fleet renewal rate. This is summed up in the “Converging Scenarios” presented in 7.2.3.

Implementation possibilities

In the context of a highly competitive and international air transportation, current economic reality makes implementation particularly difficult. Nonetheless, a rapid spread of technological change in the current fleet is essential in a climate change environment. All options favouring or imposing fleet renewal must be considered.

Financially supporting fleet renewal

The acceleration of fleet renewal presupposes higher spending on a shorter period of time for airlines. In order of magnitude, at constant traffic acquisition costs are multiplied by 1.7 (for example for Air France, a purchase of 17 new aircraft per year instead of 10). This increase will only be partially compensated by fuel economy.

In the actual COVID-19 crisis, state financial support to airlines targeted on fleet renewals seems essential to make associated expenses bearable. Since June 2020, preliminary measures have been put in place by governments through the support scheme to the aeronautical industry[268]. These were primarily to increase support from BPIFrance on export insurance, acting as a crisis buffer. These measures also allow an airline to request a 12-month moratorium starting March 2020 on capital repayment on export credit loans[269].

Incentive and financial support could continue in the form of a "scrapping bonus" on replaced aircrafts, as in the case of the automobile industry[270]. Its amount or form must bring enough flexibility to the airlines cash flow to provide expected benefits. Moreover, obtaining it must be subject to strict conditions. For example: early compliance of the new aircraft to post-2028 ICAO emission certification standard, a 10% minimum decrease on per passenger fuel consumption, mandatory dismantling of the replaced plane by a certified company in the European Union, etc. Premiums on this scrapping bonus could be awarded in case of fleet reduction, if several old generation aircraft are replaced with a single new one.

[268] https://economie.gouv.fr/covid19-soutien-entreprises/plan-soutien-filiere-aeronautique# section « soutien à la demande avec le renouvellement d'une flotte plus écologique »

[269] the beneficiary companies must undertake not to pay dividends or any other amounts to their shareholders (including loans) and not to implement any share buy-back program until complete refund of the deferred credit

[270] https://economie.gouv.fr/covid19-soutien-entreprises/mesures-plan-soutien-automobile

State financial support raises the issue of competition conditions between airlines if support is not at the same level. Harmonised support conditions inside the European Union are desirable. Nonetheless, this course of action can be looked at on a national level as long as competition rules are respected. It seems clear that prioritising vital decarbonation objectives may need to reconsider prevailing common operating rules.

Part of this financial support could be financed by the tax described below.

From an industrial point of view, this increase in fleet renewal rate could take several years to fall into place. In the mid-term, it is necessary to provide financial support to the airline industry in the modernisation of their production means in order to make more competitive, insure optimal environmental performances, and consolidate the industry. This could be done in particular through governmental initiatives taken in the support scheme to the airline industry[271], which could be extended or renewed in the next decade to meet these objectives.

A Bonus/Malus scheme through regulation

As a first step, an airport tax (on landing) could be introduced. Its amount would gradually increase in proportion to the difference between the fuel consumption per passenger and kilometer of the plane operated by the airline, and that of the best available plane serving the airport. This tax could be included in the price of the flight ticket, together with an awareness-raising information (cf. 7.4.2). This way the end-user would be an actor in the choice of aircraft and would naturally promote a more efficient filling rate for the most performing aircraft.

In a second stage, planes for which a newer model exists for 10 years or more, and which's fuel consumption per passenger and kilometer is lower by 10% at least, would be forbidden to land or takeoff from French airports. Furthermore, authorized aircrafts would have to comply with the CO2 emissions ICAO standards[272]. The schedule of implementation of this standard could serve as a basis for the timetable of the ban.

This regulation would be applied to all airlines landing on French soil. To reduce the risk of transfer of traffic to bordering airport hubs, regulatory harmonisation at least on a European level is more than desirable.

- **Externalities**

[271] https://economie.gouv.fr/covid19-soutien-entreprises/plan-soutien-filiere-aeronautique# section « Le soutien à l'offre en consolidant la filière et renforçant ses investissements pour améliorer sa compétitivité ». To this day, it is noted that 630 million Euros have been made available to consolidate the industry (see article in Les Échos dated 28 July 2020 : Aéronautique : plus de 600 millions d'euros débloqués pour consolider la filière | Les Echos

[272] https://www.icao.int/environmental-protection/Pages/ClimateChange_TechnologyStandards.aspx

Public funding

The moment a public funding is involved in an economic sector, it deepens the public debt for actual and future generations and gets out of the sole sectoral problematic. Just as for GHG emissions, this point goes beyond the industry players and their customers. This report solely deals with the airline industry, but it is important to keep in mind that in the context of an overall GHG emissions reduction, investment decisions must also be subject to inter-sectorial arbitration. Anticipation and priority usages are essential to keep control of one's development.

Jobs

The acceleration of fleet renewal enables the creation or preservation of some jobs in the whole airline industry, in relation to the continued need for new planes. Industrial job demand is linked to the plane roadmaps and rate of production, being demand driven. This demand from the airlines is strongly dependent on their traffic forecasts and their financial capacity. In a crisis, the balance between all these parameters is complex and could lead to economic models' evolution. Detailed study on jobs can be found in Chapter 0.

7.2.3 Converging scenarios[273]

CO_2 emission reduction in the airline industry is conditioned by a series of technical assumptions. The level of achievement of these assumptions can significantly change the emission trajectories. In particular, three axes can be considered highly interdependent:

- Innovation (7.2.2.2)
- Alternative fuels (7.2.2.3)
- Fleet renewal (7.2.2.4).

They are also strongly linked to the crisis context, economic recovery, strategic decisions to come, finance, inter-sector arbitrations, industrial projects successes or energy policies…

It is not reasonable to predict the future, but we can study the influence of the above structuring parameters on the emission trajectories.

To do so we have done sensitivities on these parameters in 2 specific converging scenarios: MAVERICK and ICEMAN[274], and analysed their results and associated externalities.

In this chapter, the traffic assumption does not vary: return of traffic to 2019 levels in 2024, then a 4% increase every year between 2025 and 2030. The objective is to measure the parameters influence for any given traffic. Traffic assumptions will be adjusted if necessary to reach the carbon budget defined in 5.9.3.

You can find a recap table of all the assumptions of each scenario in annex 13.3.4 page 130.

7.2.3.1 MAVERICK Scenario

MAVERICK Scenario

[273] Detailed information, calculations and other sources associated with setting these scenarios are available in the calculation note.

[274] If it were not destined to die, this scenario would have been named GOOSE.

Definitions and Assumptions
In the MAVERICK Scenario, the technical performance settings are pushed to their maximum. It is a scenario in which : - The optimistic plane roadmap for the industry does not fail ("INDUS" Roadmap, as defined in 7.2.2.2). - The production of French alternative fuels goes in priority to air transport ("CAPA 100" Assumption, as defined in 7.2.2.3). - All airline fleets contributing to the French emissions scope are renewed in 15 years, starting 2025 ("15 years" Assumption, as defined in 7.2.2.4). - Hydrogen required for hydrogen planes or for PtL synthesis is produced using electrolysis and the associated electricity mix is 100% wind energy, with the performances of the 2019 French wind park. - CORSIA* programme (CORSIA on all airways, including domestic ones, for all airlines) is enforced and the offsetting is indeed subtracted from the emissions. This is a high-risk scenario, of which we can discuss the practicality, that maximises the efficiency of the emissions reductions on a technical level, that maximises CORSIA's potential beyond its real scope, that maximises employment in the air industry and that requires the most investments.
Carbon trajectories

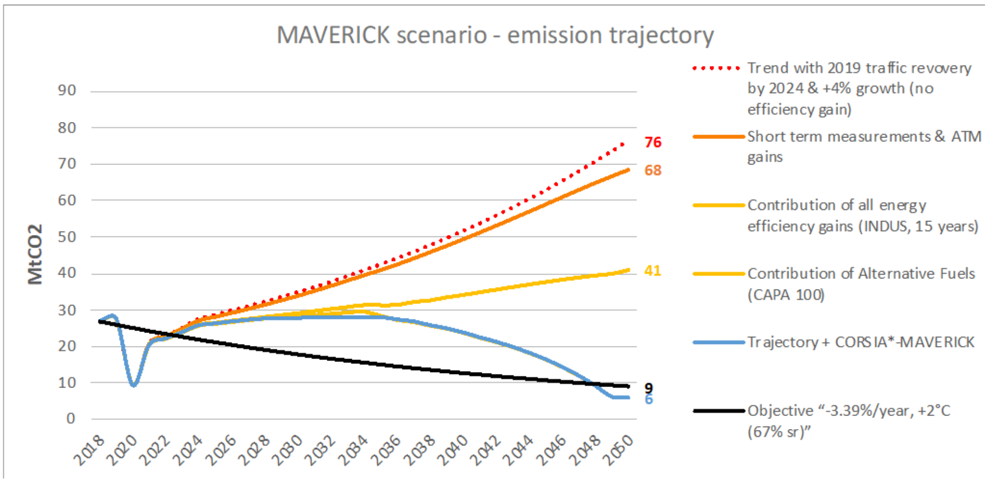


Figure 42 - Annual emissions, MAVERICK Scenario - France

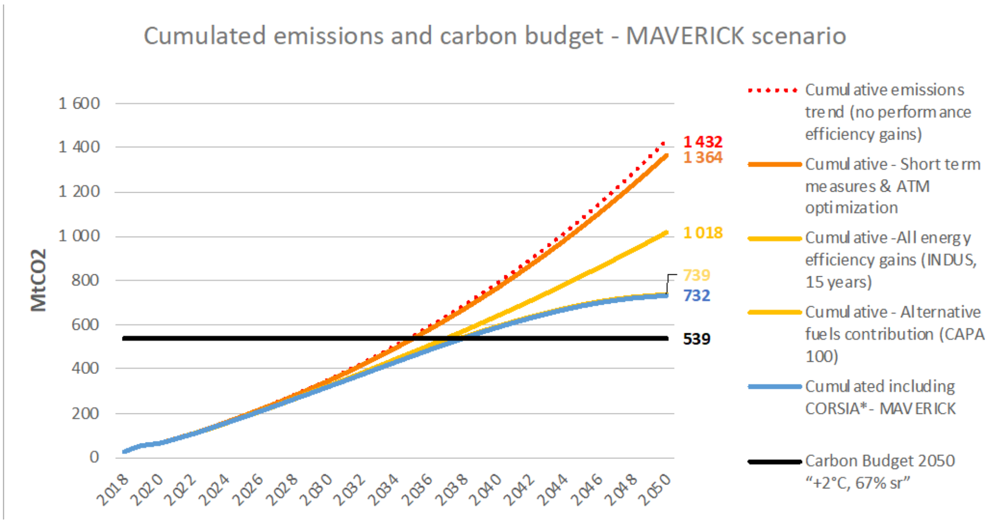


Figure 43 - Cumulative emissions and carbon budget, MAVERICK Scenario - France

Highlights

The fleet renewal within 15 years, starting from 2035, with short- and medium-haul planes fuelled by hydrogen and long-haul planes with a 100% blending rate of alternative fuels and improving the performances by 25% causes a significant inflexion of the emissions curve.

In 2050, all the Regional fleet, short and medium-haul, is replaced by hydrogen planes, the whole long-haul fleet is replaced with the new plane and flies on 100% alternative fuels.

The ultra-performing improvement trajectory makes CORSIA* matter only a little (6 CO2Mt offsetted between 2028 and 2034).

Results and CO2 impacts

The average annual energy efficiency progression is about 2.14% from 2024, that is to say beyond the optimistic scenarios of the sector.

Nevertheless, the budget is exceeded around 2038 and cumulative emissions exceed it by around 36%.

The significant inflexion of the emissions curve takes place almost when the budget is met. The decarbonisation pace is not enough to stay within budget.

Consumption and energy externalities

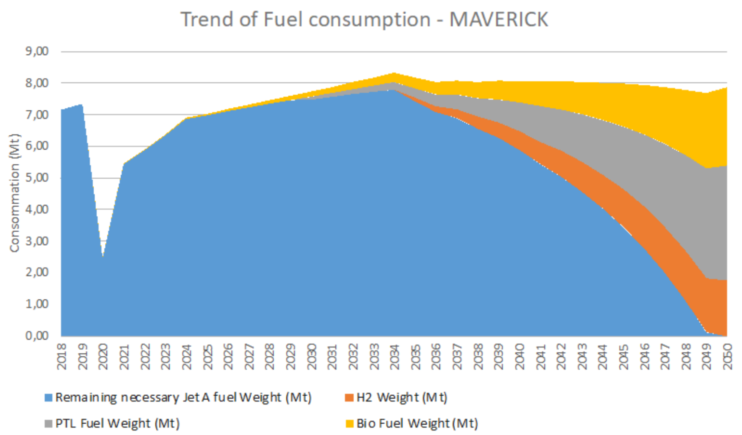


Figure 44 - Fuel consumption trajectories in the MAVERICK Scenario – France

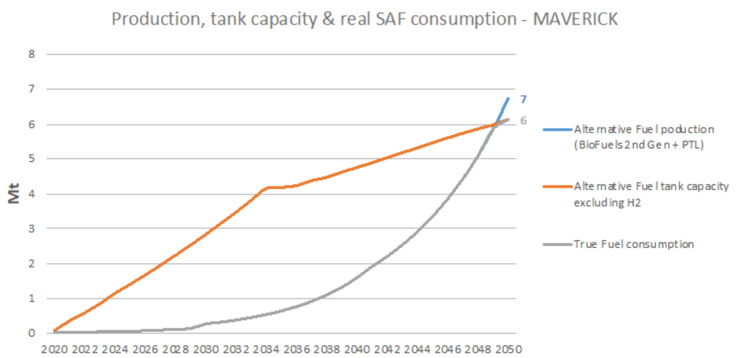


Figure 45 - SAF production, cargo capacity and real consumption (2G Biofuel and PtL) - MAVERICK - France

Table 9 - Fuel consumption in 2050 in the MAVERICK Scenario - France

Fuel consumption in 2050 (Mt)

A-1 Jet	Biofuel	PtL	H_2 (excluding PtL)
0	2,49	3,65	1,76

The target quantities are not limited by the fuel production assumptions. However, before 2049, the available quantities stay below needs (cf. Figure 45). Accelerating alternative fuels production in order to reach the target quicker would improve carbon emissions in this scenario, in other words going beyond an annual growth of 25% and then 15%.

The electricity required to produce these quantities of PtL and H_2 is about 265 TWh (165 TWh for PtL and 100 TWh for H_2), which would require a wind park dedicated to the air industry, about 8 times bigger than the 2019 total French wind park.

Regarding hydrogen production, the 1 Mt/year target (cf. 7.2.2.3) is largely exceeded in this scenario (all the more if we take into account the hydrogen required for PtL synthesis).

The energy externalities from this scenario are thus substantial, in particular concerning electricity production. In order to reduce it, one way could be to increase the level of biofuels and to decrease the PtL production. Having a look at import or betting on other types of biofuels (3rd generation, ...) would be of the essence. Either way, it appears that the dimensioning planned by the French energy sector would not be -by far- big enough to satisfy the needs of such a scenario.

Jobs externalities

This scenario is more favorable to jobs in the industry. The jobs externalities of the scenarios are studied in more detail in paragraph 9.

Push even further?

By simulating availability of the target production (2.73 Mt) from 2030 for biofuels and from 2040 for PtL, cumulative emissions go from 732 CO_2Mt to 555 CO_2Mt. With 2.73 Mt biofuels in 2030, we would stand at ~34% of global needs, meaning ~7 times more than the set target in the December 2020 government roadmap [275]. Under these circumstances, de facto more than unrealistic with the current outlooks, the saving is important, but still not sufficient. The production in that case is exceeding the needs as soon as 2030. Organizational and energy externalities are not considered here because this scenario is already unrealistic. However, it

is a way of measuring the challenge to overcome if the solution was to be purely technological.
Conclusions
The MAVERICK scenario as it is does not reach the decarbonisation objectives and generates massive energy externalities, reaching a level in all likelihood not anticipated to this day by the French Hydrogen and energy sector. Nevertheless, accelerating the production pace for alternative fuels would open the door for improvements, though without complying with the carbon budget defined in a sustainable aviation world. The Maverick scenario is thus very risky and unrealistic as it stands.

7.2.3.2 ICEMAN Scenario

ICEMAN Scenario
Definitions and Assumptions
In the ICEMAN scenario, the technical implementation assumptions are more cautious. It is a scenario in which: - The industry optimistic plane roadmap shows a 5-year delay ("INDUS+5" Roadmap, as defined in 7.2.2.2) - Air transport can profit from "only" 50% of the French alternative biofuels production ("CAPA 50" Hypothesis defined in 7.2.2.3). - All airlines' fleets contributing to the French scope are renewed in 25 years ("25 years" Hypothesis defined in 7.2.2.4). - Hydrogen required for hydrogen planes or for PtL synthesis is produced using electrolysis and the associated electricity mix is 100% wind energy, with the performances of the 2019 French wind park . - CORSIA* programme (CORSIA on all airways, including domestic ones, for every airline) is enforced and the offsetting is indeed subtracted from the emissions.

[275] 7,98 Mt kerosene in 2030 in the MAVERICK France Scenario (see calculation note), an objective of 5% biofuels in 2030 for the air industry set in the roadmap dated December 2020: https://www.ecologie.gouv.fr/biocarburants#e6

Carbon trajectories

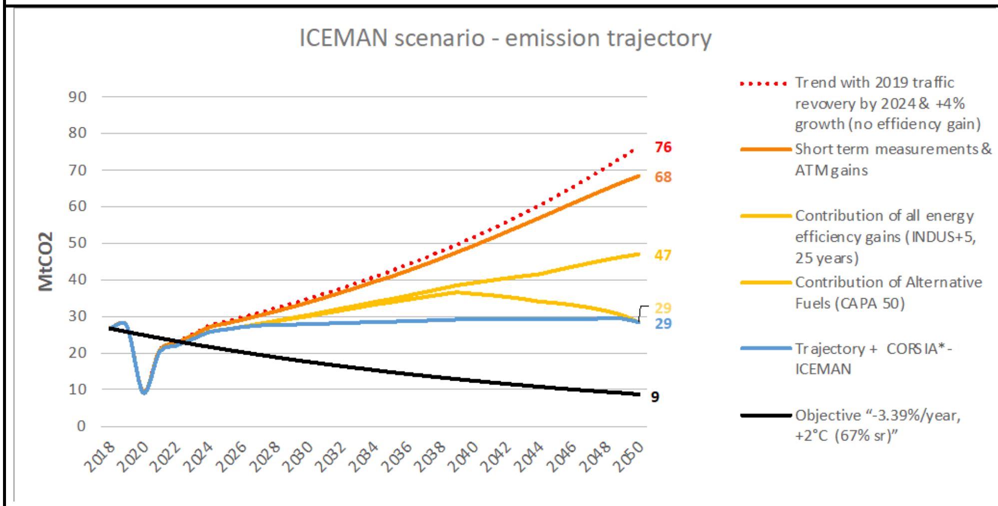


Figure 46 - Annual emissions, ICEMAN Scenario - France

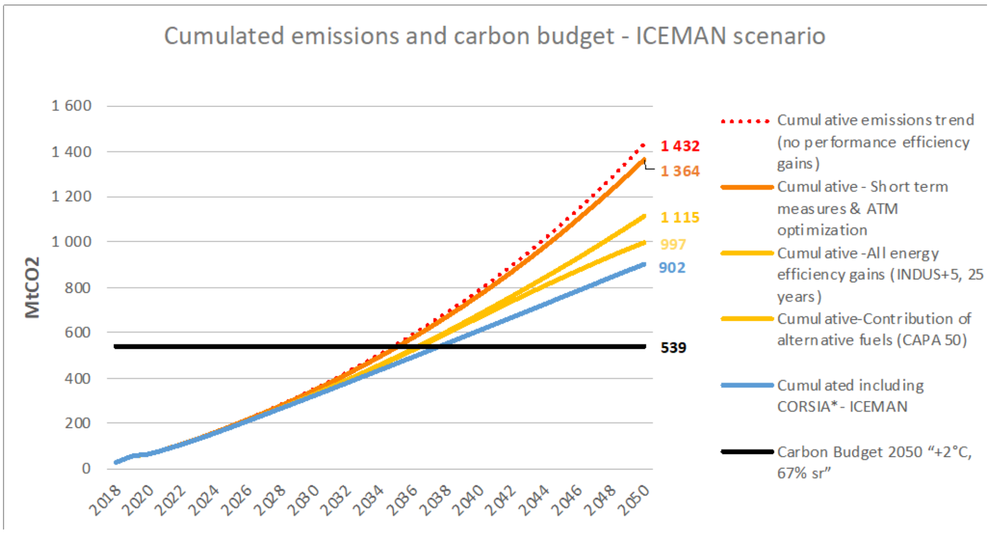


Figure 47 - Cumulative emissions and carbon budget, ICEMAN Scenario - France

Highlights

The process of decarbonisation is too slow, the level of 2019's emission is recovered in 2050 only.

In 2050, the Medium-haul and Long-haul fleets' renewal is not over, only 40% of the fleet has been renewed. The new plane generation has indeed been launched in 2040 and renewal takes 25 years.

Emissions are just above the 2019 level, the CORSIA* offset runs at full capacity and allows to offset 95 CO_2 Mt between 2027 and 2049 generating significant added costs for the airlines.

Results and CO2 Impacts

The average annual progression of energy efficiency is about 1.61% from 2024, it is below the most optimistic scenarios of the sector but still an ambitious objective, far from being a foregone conclusion.

The budget is exceeded around 2038 and cumulative emissions exceed it by around 67% in fine. This number is reached mainly thanks to offsetting.

If the decarbonation rhythm slows down, especially at the beginning of the period, the budget cannot be reached with these assumptions.

Consumption and energy externalities

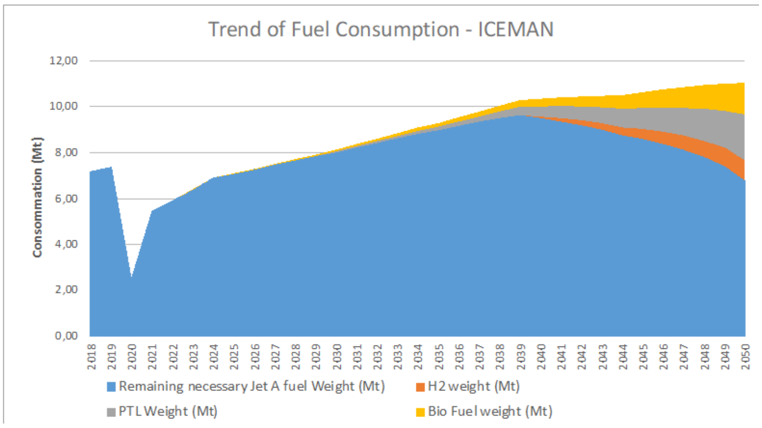


Figure 48 - Fuel consumption trajectories in the ICEMAN Scenario - France

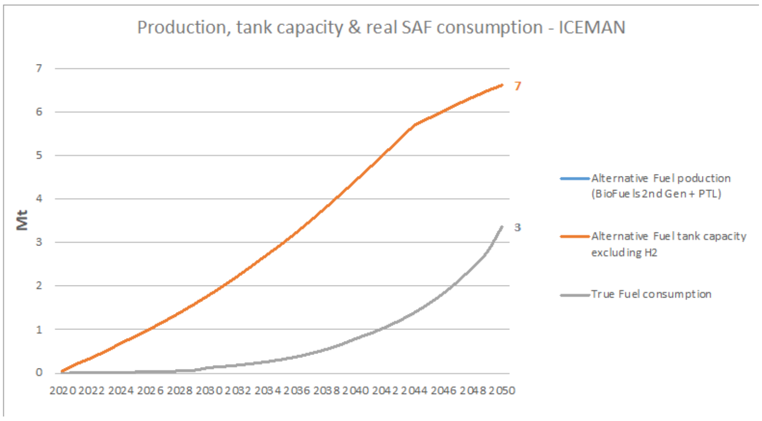


Figure 49 - SAF production, cargo capacity and real consumption (Biofuel 2G and PtL) - ICEMAN - France

Table 10 - Fuel consumption in 2050 in the ICEMAN Scenario - France

Fuel consumption in 2050 (Mt)			
Jet A-1	Biofuel	PtL	H_2 (without PtL)
6,77	1,37	2	0,9

Available production does not meet the needs in this scenario, it is 100% used during the whole period (cf. Figure 49). Accelerating production would improve the scenario outcome, but it would not reach the target in any case.

The electricity required to produce these PtL and H_2 quantities is about 141 TWh (91 TWh for PtL and 50 TWh for H_2), which would require a wind park dedicated to air transport around 4 times bigger than the 2019 total French wind park, about 2 times smaller than in the MAVERICK Scenario.

Regarding hydrogen production, the 1 Mt/year objective (cf. 7.2.2.3) is about the same order of magnitude, but it would mean that 90% of this production should be dedicated to air transport.

The energy externalities in this scenario are more reasonnable. Yet they are not insignificant and require an alignment of the whole energy sector and a trade-off in favour of air transport

Conclusions
The ICEMAN Scenario gives more margin to industrial risk management, to the supply of alternative fuels and to the management of energy externalities. However, while representing a major challenge for its implementation, it leads away from the decarbonisation target despite a strong solicitation of the offsetting system. It is thus non-acceptable by itself as it is.

7.2.4 Conclusion

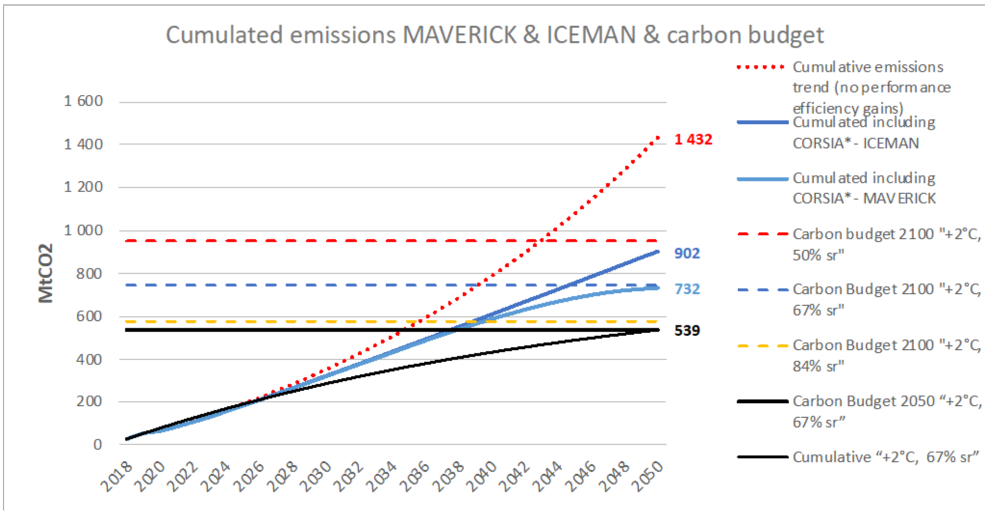


Figure 50 - MAVERICK and ICEMAN cumulative totals France compared to the carbon budgets

Even in the most optimistic scenario that causes significant energy externalities, with a traffic growth rate of 4% from 2024, technical progress only will not be fast enough to contain GHG emissions growth and stay within a carbon budget making it possible to stay below +2°C with a 67% probability in 2050.

In the more cautious scenario, we almost reach the total available budget for 2100 by lowering the probability to 50%, thus with no possibility of emissions between 2050 and 2100.

There are then theoretically 3 options to stay within budget:

- **Betting on even more and faster technical improvements.** The MAVERICK Scenario already pushes the improvement parameters beyond the sector's expectations. **Thus, it is extremely risky, and obviously not acceptable given the climate issues, to bet only on this option.**
- **Increasing the carbon budget for air transport.** The total budget being non-negotiable, except in case of adjustments of the IPCC estimates, the increase of the carbon budget in the air sector can only happen at the expense of other sectors. In the implementation of the technical

scenarios, the air sector is already in strong competition with the other sectors for access to resources, low-carbon energy, innovation funding, and for the acceleration of production rates. An arbitration on carbon budget remains theoretically possible (it is the case for the NLCS regarding air transport only), but it requires legitimate governance, based on carbon budgets analyses and covering the full scope of activity and emissions of air transport (cf. Proposal 0 in paragraph 6). This type of governance does not exist nowadays.

- **Scaling down of the traffic assumption.**

It is this last path that we now propose to study.

A decline in air traffic can be endured, as is currently the case, or it can be anticipated, in a dynamic of usage sobriety, helping air transport to remain in the long term while keeping its GHG emissions under check. Usage sobriety can come from a decrease of the transport offer or demand. These are 2 paths that we offer to study hereafter, by assessing the consequences on employment in the sector.

7.3 Adjusting the aviation offer to encourage sobriety and complementarity with low emissions means of transport

7.3.1 Introduction

Today, air transport contributes massively to the reconciliation between territories and people, as well as to the global economic model. Entering into a dynamic of voluntary traffic control is then not an easy decision to make, nor to be taken in an isolated manner. It requires to re-question usage, assessing the social and economic impacts, and supporting the transition. It is included in a transformation project of our ways of life, based on new priorities. This project is yet to be built.

Adjusting the transport offer in regard to that goal is implicitly enacting priorities of some uses over others, inside the available transport offer and the evolution of the need for transport in the face of climate change and of societal mutations that it is provoking.

4 axes for adaptation of the offer have been studied supra.

7.3.2 Increasing cabin density

Axis 9: Decreasing the number of First and Business cabins for the benefit of denser cabins	
Relevant stakeholders	Airlines, Companies (HR and travel policies), Travel Management Sector, Public Authorities

Context
Business and First cabins seats are heavier and take up more space than Economy seats. Thus, the fuel consumption per passenger in Business class is 3 to 5 times higher than in Economy[276]. It means that the Business class passenger consumes 50 to 100 litres per hour more than its counterpart in Economy. On a France-China or France-California round trip of 20 hours, the difference in overconsumption of a Business seat is 1.000 to 2.000 litres compared to an Economy one.

Detailed description
A smaller ratio of Business seats would absorb part of the increase in passenger volume without increasing air traffic or reducing the number of flights, keeping the demand constant. The decrease in Business and First traffic has to be smoothed and supported by regulations putting constraints on the demand as part of the commitment towards a decrease of global emissions. In today's system, the resulting increase of Economy class capacity would lead airlines to stimulate demand even more in order to compensate for overcapacity, provoking an increase in absolute emissions. Airlines purchase new seats every 7 / 8 years. It is then possible to begin this transition with the installation of the next seats to be changed or with those of planes on order. We can also mention the technical progress to generalise the "quick change" seats, which means replacing quite a few rows of Business seats with Eco seats in a short time (less than 1 month of aircraft grounding). Generalising this type of cabin adjustment, with technological evolutions to do it in less than 48 hours, would optimise these "more CO_2-intensive" cabins on demand, in a narrower setting. For example, in summertime, the airline can densify its cabin to meet the need for leisure travel by replacing the empty Business seats, considering that the demand for business trips decreases. Thus, cabin flexibility can decrease the number of flights at constant demand, and also optimise the airline's efficiency and revenue.
Implementation possibilities

Legislating on a minimum passenger density per plane

Within 5 years, a minimum ratio between the number of seats in the plane operational setting and the maximum number of seats on that plane, in an "all Eco" configuration, could be set by law. This density could be set at 90% (taking into account a Business cabin half in size compared to the actual situation, and the removal of First class). That way, the airline would still be free to equip its cabin the way it sees fit but would systematically reduce its high-end offer.

Today, airlines make their biggest operational margins in particular on Business class seats. Going in that direction would then require some adjustments on part of the business model.

Example: If we assume that the maximum number of seats in a Boeing 777 is 500, then a minimum of 450 seats is compulsory for the operated plane.

[276] One Business seat is more or less equivalent in surface to three Eco seats and one First seat is equivalent to six Eco seats, cf. Calculation note.

Encouraging demand limitation

Considerations on demand are detailed in 7.4. Nevertheless, here are some specific ideas to limit demand for Business class trips:

• Raise awareness among Business class passengers by informing them of their CO_2 consumption, and perhaps going as far as to differentiate between the different Business seats, promoting the seats which are "optimised" regarding space and weight, and therefore CO_2 consumption.

• A good part of Business class traffic is for the purpose of "business trips". Thus, raising awareness among companies would be useful to limit the number of trips of their staff, by encouraging them to promote their carbon footprint reduction through a sober plane usage policy. In a broader and deeper consideration, the organisational model of highly intensive transport activities should be questioned, and options to limit this need should be considered (videoconferences, decentralising to get closer to the customer, …). Companies can also encourage their staff to travel with airlines set up with optimised cabins which are the most frugal in terms of CO_2 emissions. Hence, optimised cabins, seemingly less comfortable, can potentially become a competitive advantage if they attract travellers incentivised by their employer.

• One could imagine a tax incentive, for example by granting tax reductions consequent to a carbon footprint reduction on business trips from one year to the next.

These ideas can seem difficult to implement today because the climate argument is not critical for employment contracts discussions, ticket purchase negotiations or tax policies. Moreover, the Business trip is identified as a necessity for the "Road Warriors", or even as social recognition. This type of proposal requires to change these criteria of priority, performance, acknowledgement and to reconsider its company organisation in accordance. Furthermore, it requires some adjustments to the CTP (Company Travel Policy) and HR policies. This is particularly true for the "Road Warriors" who travel more than twelve times a year and for whom flight conditions are among the criteria in the hiring negotiation. For these intensive users whose activity requires a high travel frequency, maintaining reasonable comfort should be taken into account when optimising cabin density.

CO_2 impact277

Based on the above assumption (a 50% decrease in Business class and removal of First), avoided CO_2 emissions for Air France would be about **260 CO_2kt per year for 5 years (around 1% per year), that is to say, 1.3 CO_2Mt in total (between 2021 and 2025).**

Not to mention that if all of the planes are equipped with "Economy class" seats, we would gain 2.4 CO_2Mt in total between 2021 and 2025.

[277] See details in the Calculation note

Table 11 - CO2 gains linked to the cabins densification, France scope (DGAC) 2018

2018, CO_2Mt	**Average classic cabin (AF type)**	**100% Eco cabin assumption**	**No First and -50% Business cabin assumption**
CO_2 emissions France-international flights	17.8 CO_2Mt	15.1 CO_2Mt	16.3 CO_2Mt
CO_2 emissions France total flights	22.6 CO_2Mt	19.8 CO_2Mt	21.1 CO_2Mt
CO_2 gain compared to classic cabin (international)		-15.4%	-8.4%
CO_2 gain compared to classic cabin (international + domestic)		**-12.2%**	**-6.6%**
CO_2 gain compared to classic cabin		**-2.7 CO_2Mt**	**-1.5 CO_2Mt**

By planning a 6.6% gain with the intermediate scenario (50% decrease in Business and removal of First) in regards to the baseline scenario (cf. §7.1), we can estimate a gain of 87.3 CO_2Mt in the 2018-2050 period.

Generated externalities

- If a law on minimum cabin densification was only applied when leaving France, it would risk weakening companies based in France, because "business" traffic can be easily diverted via other European hubs to find a larger and more "comfortable" business offer (but much more CO_2-consuming). Such a law would seem more balanced if it was at the European level278. However, the risk should be assessed more precisely because the speed of implementation is a determining factor in the success of climate trajectories.

- Nowadays, it is particularly in Business class that airlines are doing the largest operating margins. Thus, the loss of part of this market share requires a change of business model.
- Quick adjustments in the number of Business seats versus Eco ones to best adapt to demand may become a definite competitive advantage279. The demand influence for more reasoned business class travel could also encourage companies to fly fewer planes for the same numbers of passengers carried.
- Furthermore, the shift of the most frequent travellers toward the business aviation market is a risk that must be assessed and controlled, for example by reducing the supply in this segment through regulatory means (see section 7.3.4).

278 This measure is extremely restrictive from a competitive point of view and seems to be applicable only internationally. Moreover, airlines are already adjusting the number of First/Business seats downwards, as demand is declining, in favour of intermediate classes such as Premium Eco.

279 Even if the rationality of the airline side is to fly the aircraft at maximum capacity, thus limiting grounding and maintenance time. It is therefore unlikely that airlines will commit themselves to this type of flexibility according to the season, because the overall bill will be high for a limited gain in emissions. Moreover, taking into account the impact of Covid on business traffic and the realism of companies regarding their travel expenses, it is likely that the number of business seats sold will not resist video-conferencing for long.

7.3.3 Eliminating air transport offer where the existing rail alternative is satisfactory

<u>Axis 10:</u> Eliminating air transport offer where existing rail alternative is satisfactory 280	
Actors affected by the measure	Airlines, public authorities
Background elements	
• Rail transport in France has a very significant advantage owing to the very low CO_2 emissions that its use generates, thanks to mainly low carbon electricity. Thus, for the same journey, a train journey emits on average between 30 and 40 times less CO_2 than air travel 281, once the infrastructure is built.	

- For a large number of domestic or international air connections (mainly to bordering countries), an acceptable rail alternative exists. By "acceptable", we mean that the rail offer, in addition to serving stations located near cities or areas of activity, must allow trips of which the duration or frequency can be considered as satisfactory and comparable to those of air transport (point-to-point). Moreover, low-carbon "door-to-door" technical reservation techniques that can be integrated into the reservation tools of companies (Self-Booking Tools) could be developed and supported without delay.
- In what follows, it will be considered that a train travel time of 4.5 hours is admissible and acceptable from the point of view of travellers' needs. This limit makes it possible to integrate air links whose railway alternative is suitable, because arrangements have already been made in this direction (such as the high-speed line Sud Europe Atlantique and Bretagne - Pays de la Loire), and makes it possible to integrate European connections.
- There are **36 domestic connections** in France for which there is a rail alternative (high speed or conventional speed) with a journey time shorter than 4.5 hours.
- There are **11 international connections** from Paris to bordering countries for which there is a rail alternative with a journey time shorter than 4.5 hours.
- A distinction must be made between direct routes (or "point to point") and connecting routes (to reach a "hub" such as Roissy CDG). At this stage, it is important to preserve the connecting journeys because this keeps international flights on airport hubs, in strong competition with each other. However, if a train connection shorter than 2.5 hours is available for connecting journeys, the associated air connection would be suspended (except from Nantes and Bordeaux where the train connection is not yet satisfactory to CDG due to a too low frequency282. In addition, direct Bordeaux-CDG by train is usually over 2.5 hours).

280 Train travel <4.5 hours, airport access facilitation for connections, timetables corresponding to travellers' needs

281 By taking an emission factor of 3.7 CO_2g/p.km for the TGV and 5.6 CO_2g/p.km (ADEME carbon base) and 150 CO_2g/pass.km for the plane (DGAC reference).

- The criterion of 4.5 hours for shifting to train may be considered too high, especially in relation to the reality of business travel today. It is indeed above most companies current travel policies. The whole difficulty is in the practical implementation, in accepting to transform its uses and its organisation in-depth and in the long term.

Current railway capacities

Although the allocation of train paths on the French rail network is only 88%, observed saturation is mainly due to demand at certain peak times, a phenomenon that concerns airports, as well as all transport infrastructure (airports, metro and RER stations, ring roads, highways, services to major metropolises). Thereby the most used lines are concentrated mainly in the Paris region, and around Lyon, a notorious railway junction. SNCF's strategy in this area consists in favouring fares modulation (both in terms of passenger tickets and, and this is new, on the charging of tolls) and the increase in the number of seats made available. A room for manoeuvre visible on the filling rate which is around 67% for the TGV, 71% for the international lines, and 44% for Intercités, and on effective TGV traffic which has fallen since 2015. This is why the rail traffic density indicator does not allow ART 283 to conclude that the network is saturated 284.

The transfer of connecting passengers (around 200,000 per year 285) to Roissy TGV station would be almost painless for this structure which already accommodates more than 14 million passengers, 70% of which are connecting passengers. The many Parisian stations (including Massy TGV and Marne La Vallée-Chessy TGV) still have the possibility of accommodating the almost 7.5 million additional travellers affected by this measure. It should be remembered that following Air France's announcement to eliminate unprofitable national lines, transfer to train is inevitable. This could be reinforced, in the longer term, by some improvements in the station, such as those underway at Gare du Nord. For Lyon and Marseille, increased use of the Lyon-Saint-Exupéry and Aix TGV stations would make it possible to increase passenger capacity.

The saturation of the Paris-Lyon axis is being resolved thanks to the installation of more efficient signage, which means that any construction of additional tracks should not be considered for this modal shift of passengers.

The deletion of the previous lines, keeping only connecting passengers, will necessarily play on flight frequency, in order to avoid chartering less crowded planes on these routes. This could make them less profitable, and indirectly shift demand to TGV-Air.

282 Apart from frequency issues, two other major problems arise; effectiveness of intermodality and contractual aspects of the commercial offer. Responding to them requires an integrated approach to transport solutions.

283 Transport Regulatory Authority, formerly ARAFER (Regulatory Authority for Rail and Road Activities)

284 French passenger rail transport market 2017, ARAFER

285 A calculation note attached to this report explains all the data of the proposal.

Detailed description
Domestic air connections for which connection can be substituted by a train journey lasting less than 4.5h. The following connections would therefore be suspended, excluding connecting flights: PARIS – MARSEILLE PARIS – MONTPELLIER PARIS - BREST PARIS – TOULON PARIS - CLERMONT-FERRAND PARIS - BASEL/MULHOUSE PARIS – LORIENT PARIS - LA ROCHELLE PARIS – LIMOGES PARIS – TOULOUSE PARIS - BIARRITZ PARIS – PAU PARIS – QUIMPER PARIS - BORDEAUX PARIS - LYON PARIS - NANTES PARIS - BRIVE LYON - RENNES LYON - STRASBOURG LILLE - LYON

LYON - METZ/NANCY

MARSEILLE - TOULOUSE

LILLE - STRASBOURG

LYON - ROUEN

LYON - TOULOUSE

LYON - NANTES

LILLE - NANTES

BORDEAUX – NANTES

BORDEAUX - MONTPELLIER

BORDEAUX – RENNES

LYON - MARSEILLE

LYON - POITIERS

PARIS - AGEN

PARIS - LE PUY EN VELAY

Certain connecting flights, in particular to Roissy-Charles de Gaulle, are maintained.

• **International air connections from Paris which can be replaced by a train journey lasting less than 4.5h.** This would only apply to point-to-point flights, and connecting flights would be retained. More specifically, the following links would be suspended:

CDG – Gatwick

CDG – Heathrow

CDG – Luton

CDG – Southend

CDG – Geneva

CDG – Zurich

CDG – Francfort

CDG – Amsterdam

CDG – Bruxelles ORY – London City ORY – Geneva This proposal should be discussed with the European, English and Swiss partners involved. Transfer to the train will be acceptable if this transport proves to be reliable, which implies significant work lead on the reasons for cancellations and delays 286. According to the balance sheets of ARAFER (now named ART) in 2017 and 2018 the main causes are first attributable to the network operator then, apart from saturation at rush hour, social movements, and for Paris region commuters, the state of the rolling stock. The assumption of the SNCF's debt should make it possible to make investments on the lines, on the one hand, and in the equipment, on the other, which were not allowed anymore to him.
Implementation possibilities
Suspension of operating authorizations for the overhead lines concerned
Stopping a domestic air link is the responsibility of the administrative authority in charge of issuing the authorization to operate a regular line. Legislative proposals have already been made in this direction 287. In the event of the stoppage of an air link, it is important that in parallel airport capacity at all airports concerned be reduced by the same amount, in order to prevent airport slots from being allocated for other routes, by competing companies where applicable. As regards the suspension of international air links, precedents have been set 288. The Dutch Parliament has passed a motion calling on its government to find agreements with stakeholders to phase out Amsterdam-Brussels flights in March 2019 289, which incidentally concerns the Paris-Amsterdam rail line mentioned below.
CO_2 impact

286 Note that it is very difficult to compare the delays displayed in air and rail for the following reasons:

• Structural reasons: one dimension for the train, against three for the plane. When there is a problem on a railway line, it is impossible to divert the traffic planned on it.

• Slot allocations: these are made six months in advance for the train, three hours before in the aviation. This means that the structural problems of saturation are less visible concerning the rail network.
• A company's tactical choice: it may favor a longer route, or another level of flight, to leave on time, which a train cannot. Indeed, the rail network is more rigid, and adapts less.
• Number of passengers transported: should we compare the percentages, the number of passengers affected, or the delay per kilometer traveled? Separate the transilien network from the national network? Compare on a line? Each choice results in a bias.

287 See the bill to replace domestic flights with the Batho, Panot, Ruffin train of June 3, 2019.

288 The implementation possibilities are mainly based on a commercially relevant transport offer proposing a point-to-point transport offer for connecting passengers. Otherwise the traffic will be diverted from French operators to foreign operators and hubs less scrupulous about emissions.

289 See the article in Les Echos of 11/03/2019 (https://www.lesechos.fr/monde/europe/ca-se-passe-en-europe-les-vols-amsterdam-bruxelles-bientot-rayes-de-la-carte-999327). See also the text of the motion carried (in Dutch).

Suspension of operations of the non-connecting domestic lines listed above would reduce CO_2 emissions from air transport by nearly 0.7 CO_2Mt per year by 2025, i.e. 30% of emissions of metropolitan air traffic (~ 2.3 CO_2Mt in 2018 290). Suspension of operations of international lines to border countries listed above would reduce CO_2 emissions from air transport by nearly 70 CO_2kt by 2025, i.e. less than 1% of international air traffic emissions attributable to France (~ 17.9 CO_2Mt in 2018 290). With regard to the reference scope, this gain represents 3.13% of 2018 emissions (26.9 CO_2Mt). Assuming that the traffic on these lines evolves in the same way on the perimeter average, we can as a first approximation, consider that this gain can be carried over every year after a gradual ramp-up until 2025. The total gain on cumulative emissions brought about by this measurement is then 41.4 CO_2Mt.
Externalities
The decrease in the number of domestic and international airlines to border countries would generate: • A decrease in the number of jobs in French airlines. • A decrease in the number of jobs in the airport areas concerned (staff of the airport and economic basin of the airport).

• A risk of postponing a trip to a foreign hub because of the relaxation of correspondence (for example a Toulouse-Istanbul-Dehli or Toulouse-Dubaï-Dehli would perhaps be longer than Toulouse-London-Delhi because of the connection). Hence the interest in managing this problem at the level of the European Union (+ United Kingdom), whether for flights in

correspondence or modal shift. The latest news on this is rather encouraging with the announcement of KLM's wish to operate a train line instead of its shuttle between Schiphol and Brussels 291, like the Charles-de-Gaulle - Brussels line in service for more than twenty years 292. Or the recent meeting of 24 European countries, about the development of the network international "long-distance" train (up to 800 km) 293.

The increase in the number of passengers on rail lines leads to :

• A slight increase in the number of jobs on lines and in stations
• No construction of new lines, because the filling rate of trains (69% for TGVs, 44% for intercity) is currently low
• Reduced development of the few stations that require it (such as the Gare du Nord renovation, which has already started)

290 See https://www.ecologie.gouv.fr/sites/default/files/bilan_emissions_gazeuses_2019.pdf

291 https://www.railtech.com/policy/2019/09/18/trains-will-replace-planes-on-amsterdam-brussels-link/

292 Which requires special logistics and the "purchase" of cars by Air France.

293 https://www.euractiv.com/section/railways/news/24-countries-sign-pledge-to-boost-international-rail-routes/

The rail network and stations can absorb the passenger surplus, which is in the order of 9 million per year, without building new lines 294.

If we consider that in the medium term, connecting passengers could also be transported by train (more efficient and integrated intermodality: single ticket, communication, luggage transport, synchronization of train and plane timetables, etc.); an addition/extra of 250,000 CO_2t/ year (based on 2018) would be avoided on the mentioned lines (national and international).

Total carryover?

The total postponement scenario (i.e. all domestic lines and an increase in shifting to international lines) to the train is not discussed here. Such a scenario would require large scale railways adjustments (construction of LGV lines, for example). In this case, it would be necessary to integrate the emissions linked to the line construction site, as is done in the pre-studies of these sites. The opportunity to shift traffic from plane to train in the event that the construction of an LGV line is required must be studied on a case-by-case basis (depending on overall traffic and expected shifting modals) from the point of view of the emission balance, and more broadly of the environmental performance.

7.3.4 Limiting business aviation traffic

Axis 10: Limiting business aviation traffic	
Actors concerned	Business travel sector, Public authorities
Contextual elements	
Business aviation refers to the branch of air transport devoted to transporting passengers on demand for non-tourism purposes. It thus differs from regular civil aviation and relates in part to the use of "private jets". CO_2 emissions associated with business aviation on a global scale are estimated at 2% of those in the aviation sector 295, i.e. 0.4 CO_2Mt if we extrapolate this figure to France, where business aviation experiences an annual growth in traffic of around 4% per year 296. In 2017, Paris-Le Bourget Airport emitted 146 CO_2kt for 118,980 passengers transported, or 1.24 CO_2t per passenger for an average flight distance of 982 km 297, and an average consumption of around 100 L per 100 km.passenger. Depending on the type of aircraft used and how it is filled, it can be estimated that business aviation generates between 3 and 20 times more CO_2 per passenger than commercial aviation. Beyond the problem of distribution of efforts concerning the reduction of the individual carbon footprint, with such a level of emissions per passenger, it is essential to globally control the growth of this mode of transport and to promote all possible alternatives.	

294 New lines and developments are planned in the new railway pact, the LOM, and the SNIT of

2011, and the developments of railway nodes in the Lyon region have been the subject of a public debate

295 https://nbaa.org/wp-content/uploads/2018/01/business-aviation-fact-book.pdf

296 https://actu-aero.fr/2018/01/25/avec-4-de-croissance-en-2017-laviation-privee-est-elle-sortie-de-la-crise/

297 https://www.ecologique-solidaire.gouv.fr/sites/default/files/Emissions_gazeusesVF.pdf

This high emissivity is explained by a low occupancy of space: in Europe, there is an average of 4.7 passengers per flight 298, and 40% of flights are even made without passengers on board 299. Boeing and Airbus, for example, market A320 or B737 type business jets, which only carry around 20 passengers at most in their business version, compared to > 150 in commercial aviation.
Detailed description
1. Modal shift and renewal of the fleet 300 In Europe, business aviation allows an average reduction in transport time of 125 minutes (46% compared to a commercial flight) per flight on average and serves around 25,000 routes not operated by commercial aviation (27% of movements are made directly between these unserved regions). Within the remaining 73% of movements, flights between two hubs (proportion not quantified) could well be subject to a modal shift to commercial lines, thus dividing the CO_2 emissions per passenger carried by a factor 2 to 7 (depending on the type of device, the load, and the link considered), or even more in cases where modal shift to train is possible. For example, iconic links such as Paris-London, Nice-Moscow or Paris-Nice, are very well served by commercial aviation or by train. Among the other possible levers for reducing emissions in business aviation, we will also mention the renewal of older aircraft in favour of latest generation turboprop engines. Such a measure would make it possible to maintain links to isolated regions while substantially reducing consumption (see 7.2.1.2). **2. Contribution of business aviation to the advent of tomorrow's technologies** However, the use of business aviation remains a solution in the absence of an alternative, as well as for uses such as diplomatic, medical or military transport (non-exhaustive list). In the context of such uses, business aviation must promote in the short term the development and industrialization of more respectful technologies by becoming an experimentation laboratory and a showcase for the innovative concepts developed by the sector (in line with development programs for 2035).

Implementation possibilities
1) Obligation of modal shift to train or commercial aviation for the best-served routes, excluding justified uses (government, diplomacy, medical, military, etc.) 2) Strong incentive for the use of technologically disrupted airplanes (hydrogen, hybrid propulsion, short-haul aircraft with low passenger capacity) for the remaining flights

298 https://www.ebaa.org/app/uploads/2018/01/EBAA-Economic-report-2017_compressed.pdf

299 https://www.privatefly.fr/art-de-vivre/les-chiffres-de-l-aviation-privee

300 https://www.ebaa.org/app/uploads/2018/01/EBAA-Economic-report-2017_compressed.pdf

3) Taxation/compensation of private aviation on the basis of CO_2 emissions and/or taxation for flights not complying with the above points **OR (more radical / less easily acceptable)** 4) Pure and simple ban on private aviation outside justified uses
CO_2 Impact
The scope of business aviation is not included in the scope of commercial aviation studied in this report. Nevertheless, in view of the emissions per passenger.km and the growth rates, it is important to deal with the air transport component. For information, stopping business aviation would contribute to a 2% drop in emissions over the global scope, or around 0.4 CO_2Mt.
Externalities
Employment The sharp decrease in business aviation in France would lead to: • A decrease in the number of jobs (flight crew, sales staff, pilots, and airlines operating these lines); • Decrease in the number of jobs in the airport areas concerned (airport staff and the airport's economic basin). The substantial reduction in the number of business flights on French

territory has a very strong impact on airports such as Paris Le Bourget or Nice Côte d'Azur, which are among the main European hubs for business aviation, and represent around 6,000 direct, indirect and induced jobs 301; • A decrease in the number of jobs with manufacturers in proportion to their market share for business aviation in France. Among the avenues for securing jobs in this sector, we can mention in particular: • The development of maintenance skills specific to hybrid electric and hydrogen propulsion aircraft. • Hosting innovative companies and their flight testing and certification activities. • The creation of a low-carbon intra-European business aviation offer from France, with French airports enjoying a geographical advantage within Europe.
Impact for users
Modal shift: decrease in flight flexibility, increase in transport time.

301 https://www.ebaa.org/app/uploads/2018/01/EBAA-Economic-report-2017_compressed.pdf

7.3.5 Rethinking the mile system

Axis 11: Rethinking the mile system	
Concerned stakeholders	Business travel sector, Public authorities
Context	
Loyalty mileage plans reward frequent travellers. These miles are stored in an account and 80% are used by the traveller to make "free" personal trips and thus increase emissions, most often as a windfall. Business class and very frequent travellers collect a very large number of miles. In addition, airlines have developed agreements with third parties such as American Express which earn miles for everyday purchases, further accentuating this windfall effect.	

Accounting only for Air France, the stock of miles represents a "debt" of the company of € 7,20M. Each year, € 300M are consumed in the accounts, but above all, they represent more than 5% of the total passenger.km traffic of the Air France-KLM group and therefore of CO_2 emissions. The concept of mileage plans does not exist in low-cost companies. Globally, the stock of miles is 30 trillion, the equivalent of the annual emissions of several companies such as Air France-KLM if they were consumed.
Detailed description
The objective would be to significantly reduce flights made by pure windfall effect and to encourage the use of miles to finance the decarbonisation of air transport, for example.
Implementation possibilities
1. Systematically suggest to travellers not to receive their miles and to transform them either into carbon compensation, donations for NGOs or donations for R&D for less carbon-intensive aeronautics (donations are possible today but not at all highlighted). 2. Secondly, organize the interoperability of loyalty programs with railways and propose the use of air miles in the rail sector. 3. Prohibit the marketing of miles to third parties (AMERICAN EXPRESS cards, etc.). 4. Apply a 20% surcharge on mileage tickets as a carbon tax (at the time of booking), which amounts to reducing the CO_2 value of the stock of miles and of all future mileage tickets by 20%. 5. Decrease the number of miles earned in business class (for example, the business class traveller would earn the same number of miles as in economy class instead of 4 to 6 times more as is often the case) 6. Prohibit the personal use of miles collected on a business trip (or at least, set up taxation of benefits in kind that can be directed towards the decarbonisation of the aviation sector) A more drastic approach would be to do away with the miles system altogether. Low Cost companies for example work without.
CO_2 Impact
Of the 16.2 Mt of CO_2 emitted by Air France's flight operations in 2019, 5% are produced by Miles tickets 302, i.e. almost 1Mt of CO_2, and according to an expert, at least 50% of them are additional windfall trips that would not have been made without miles.

We can consider that by reducing the miles used by the proposed measures by 85% (excluding complete elimination, cf. calculation note), we can reduce Air France's emissions by 0.34 CO_2Mt per year (excluding upstream). Effects could be relatively immediate.
Externalities
Employment Employment impact linked to 2.5% less traffic (cf. 9) **Competition** Loyalty systems are an integral part of the airline business model. These systems provide real time in-depth customer knowledge and decision-making data, allowing the dissemination of more relevant marketing offers. It is at the heart of air alliances (Skyteam for example). The relationship to miles for some users is fusional. The Miles system can be seen as an important criterion in choosing an airline. As it is often the case in air transport, a wider possible international harmonization of legislation on this subject would of course be desirable. Nevertheless, in a dynamic of global paradigm change and the need for massive traffic reduction, orient a first step of sobriety towards pure opportunity flights remains a possibility to push to the maximum, at all levels of governance.

302 https://www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/miles-ahead-how-to-improve-airline-customer-loyalty-programs

7.3.6 Conclusion

These proposals have the effect of reducing air traffic, and therefore emissions. From a methodological point of view, we must apply them first, technical improvement measures then being applied on a reduced emissions base.

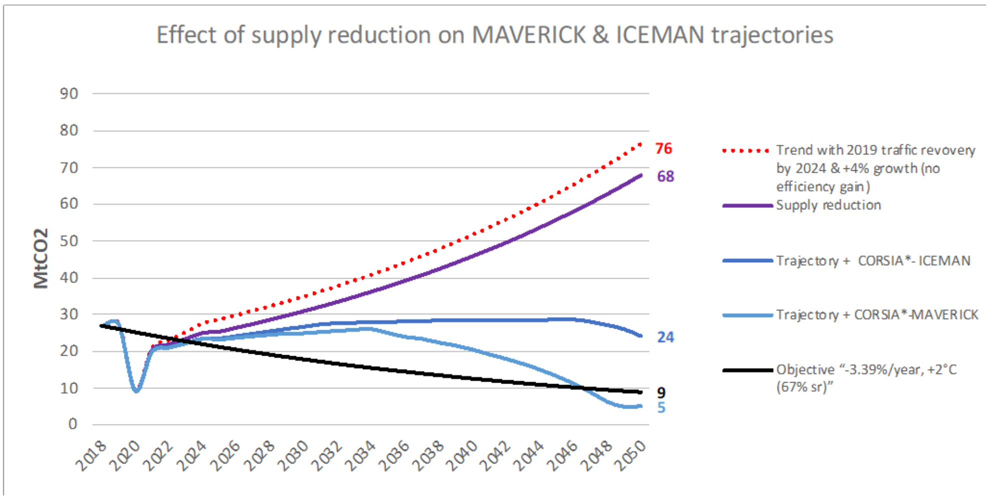


Figure 51 - Reduction in supply and annual trajectories MAVERICK and ICEMAN - France

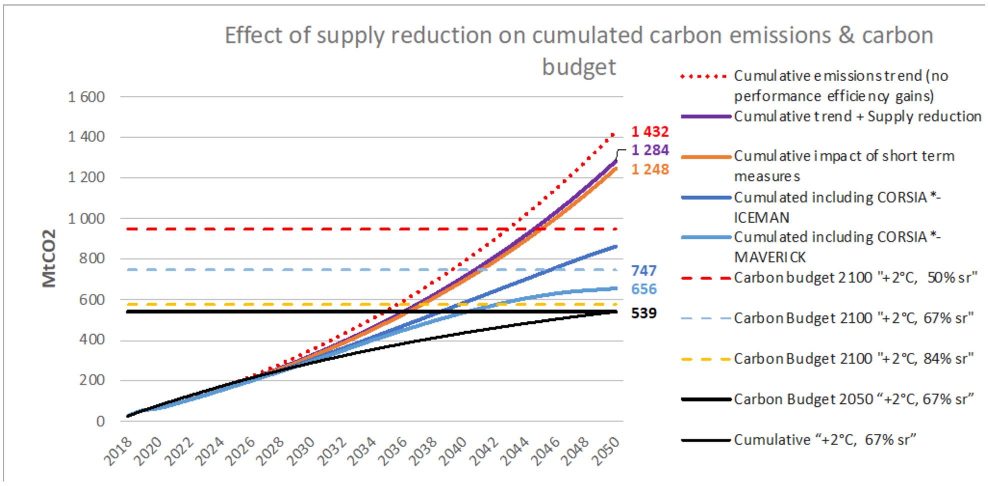


Figure 52 - Cumulative emissions with reduction in supply 2 scenarios and carbon budgets for France

The measures to adapt the offer allow a first visible change in trajectories and have a significant effect on cumulative emissions (-10%) because they are applied in the very short term (between 2021 and 2025). Combined with short-term technical measures, they can "save" around 1 year before reaching the carbon-budget.

They correspond to a reduced traffic of 11.2% compared to the growth curve of 4% / year.

In this hypothesis,

- The MAVERICK scenario falls below the 2050 target of the "-3.39% / year" trajectory with low-carbon electricity need reduced by 11% (235 TWh, or around 7 times the 2019 French wind farm).
- The ICEMAN scenario is still very far from the decarbonisation objective, however, the amount of CO_2 to be offset has fallen by 68% to 30 CO_2Mt and the need for low-carbon electricity only fell by 4% (135 TWh, i.e. around 4 times the 2019 French wind farm) because the quantity of PtL consumed remains stable, capped at the production limit.

In both cases, the level of sobriety provided by these measures to adapt the offer still does not allow to stay within the carbon-budget

2018-2050 budget is reached around 2038 and, in the ICEMAN scenario, the total carbon budget available between 2018 and 2100 is reached around 2046. This means that, in this hypothesis, the only option to remain below "+2° C "with a 67% chance by 2100 is to stop traffic abruptly from 2046.

In the rest of the report, we look at the traffic hypotheses and the options to avoid this disastrous scenario and the consequences of these hypotheses on aviation sector jobs.

7.4 Proposal for additional ways to stay within the carbon budget

7.4.1 Introduction

As the scenario outlined above does not allow for sufficient reduction in aviation emissions to remain within the carbon budget with an acceptable level of risk, the need to organise traffic moderation is necessary (see 7.2.4).

This option is not an easy decision, and its implementation will be all the more painful as anticipation will be weak, as in the same way the brutal stop of the sector due to the COVID pandemic is. Once again, societal choices will be necessary to determine the place and role that we wish for air transport.

Taking the opposite gamble, i.e. considering growth and technical progress as the unique lever for emissions reduction, is not factually manageable:

1. While time is against us, the path of exclusive technical innovation is a more than uncertain bet on the future, and in any case too late, whereas sobriety is applicable now with certainty.
2. Both options are not exclusive. Traffic reduction may be preferable in the short-term, while waiting for a potential development of an abundant low-carbon source of energy. In this case, one must notice that the necessary investments for the sector could not be funded by growth. A response from the state will be necessary, in continuity with the aviation bailout plan presented in June 2020 (see 5.10) and on a larger scale, through France's economic recovery plan.
3. If option 1 fails, an entire industry will collapse in a very brutal and sudden manner, whereas the progressive and managed reduction of traffic makes it possible to organise a smooth and planned transition, especially in terms of jobs.
4. Giving oneself the possibility to decrease traffic in a controlled way is in any case a way to mitigate the risks of delay in implementing a decarbonisation strategy. As a theoretical illustration, any emission reduction project aligned with a 5% per year reduction produces 5% additional cumulative emissions per year of delay in its implementation. In other

terms, for a given year, if all the technological levers combined do not permit to achieve the 5% annual emissions reduction target, it is possible to support it with the reduction of traffic corresponding to the missing part in order to respect the objective. In that sense, the reduction of traffic is the only measure allowing a sure reduction of CO_2 emissions of the aviation sector.

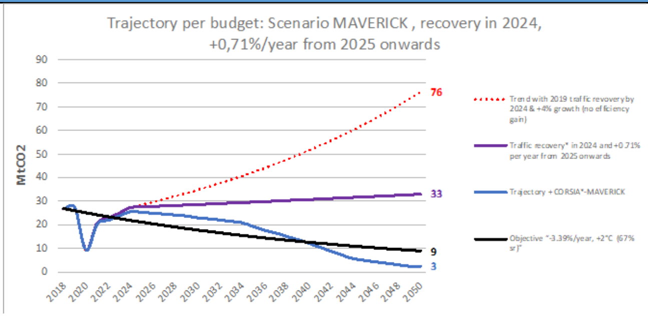
5. This active traffic control enables reducing potential rebound effects, and introduces the possibility of a long-term planification of the degrowth of aviation emissions.

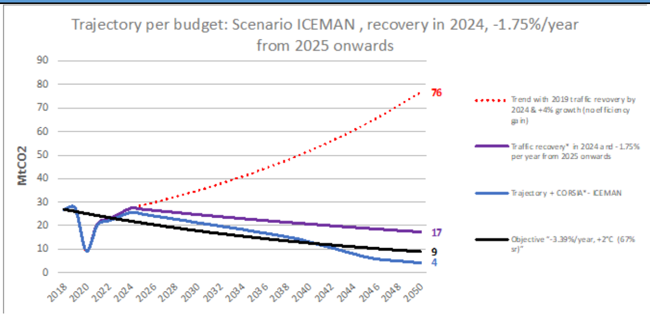
Furthermore, the restraint of passenger traffic and, consequently, of related global emissions, shows two induced advantages:

- A short-term reduction of non-CO_2 effects due to a globally decreasing emissions trajectory ;
- Fluidification of operations with the possibility, for example for air traffic control, to better optimise the trajectories (when the traffic is low, the direct trajectories are higher, typically at night nowadays), provided that other users do not reserve the vacant slots (such as military planes for example).

To understand the required extra sobriety effort, we adjusted the hypothesis of traffic growth from 2025 on the 2 scenarios to stay within the carbon budget.

Table 12 - 2 scenarios respectful of the French carbon budget

<table>
<tr><th>MAVERICK</th><th>ICEMAN</th></tr>
<tr><td>

Traffic recovery* in 2024
Traffic: +0.71% per year from 2025 onwards</td>
<td>

Traffic recovery* in 2024
Traffic: -1.75% per year from 2025</td></tr>
</table>

*by "Traffic recovery", we mean here "Return to 2019 traffic level".

In the rest of this section, we propose some ideas to organise a potential decrease of traffic if this lever appeared necessary. We want above all to open a public debate on this subject and do not claim to have all solutions. Our analysis can be broken down according to the 3 axes conventionally studied by sobriety implementation policies:

1. Inform and build awareness of the stakeholders.
2. Lead a citizen reflection around the aircraft purpose, the prioritization of the uses and the possibilities of alternative choices of consumption.
3. Make a first inventory of regulatory levers.

7.4.2 Inform stakeholders and build their awareness at the level of what is at stake

<table>
<tr><th colspan="2">Inform stakeholders and build their awareness at the level of what is at stake</th></tr>
<tr><td>concerned Stakeholders</td><td>General public, consumers, leaders of the aviation sector actors (airlines, industries, etc.), political, administrative or economic decision-makers at a local, regional or national scale.</td></tr>
<tr><td colspan="2">Context</td></tr>
<tr><td colspan="2">Raising awareness among stakeholders and providing factual and comprehensive information on the environmental impact of products and services are fundamental levers for changing habits and behaviours, as the French Citizens' Climate Convention indicates in its final report.

These levers are applicable to air transport considered here as a service, as well as to the aviation industry, by directing them towards different types of stakeholders ranging from the general public to consumers and future consumers of travels, as well as political and administrative decision-makers (at local, regional and national scales).

It would be largely preferable, for both fairness and efficiency reasons, to extend all these measures to the transport sector in general. Indeed, this would allow comparisons to be made between the different means of transport on the basis of similar factual information, without inducing over or under information bias between them.

To date, however, they have not been implemented effectively, as the following observations show. Maintaining this status quo appears to be in conflict with France's greenhouse gas emissions reduction targets: it will not allow the involved stakeholders</td></tr>
</table>

to become fully aware of the environmental impacts of the choices made and decisions taken, in relation to the air transport or aviation industry.

In the following parts, the observations are made within the scope of air transport, but the measures are proposed for the entire long-distance transport sector (air, road, rail, sea, etc.), with air transport thus leading the transport sector in terms of information and awareness.

Observation 1: There are currently no large-scale awareness-raising campaigns organised by the State for the general public, presenting the issues, figures and climate impacts associated with air transport in a factual and independent manner.

A popularisation infographic 303 produced in partnership with the French State, ADEME and the Climate Action Network, is accessible from the ADEME website, but the question arises as to whether it is being disseminated beyond the circle of people who feel concerned (and have found it). It presents rather complete and up to date information, situates air transport in the historical context, analyses its development and presents the efforts of the aviation manufacturers to reduce plane emissions. It gives everyone some perspectives, either in the post-COVID context, or to reduce the greenhouse gas emissions during one's travels.

303 https://multimedia.ademe.fr/infographies/infographie_vacances/

Other information can also be found online, but this too is left to the initiative of those interested or concerned about the subject. Moreover, these items are mostly produced by influential groups: they generally present the subject in a very biased way, to promote, by taking two extremes, either the development of air transport (example of the site by ATAG, the Air Transport Action Group), or its almost total cessation (example of the site produced by the Stay Grounded network).

Observation 2: one can question the completeness and independence of the information provided to policy and administrative decision-makers before they take decisions relating to the air transport and aviation industry, as well as the depth of their awareness. This issue relates to the elements already described in relation to general public awareness, with the emphasis here on a greater level of detail and documentation regarding local, national, economic and social climate impacts associated with air transport and the aviation industry. An analysis of the support plan for the aviation industry launched by the State in June 2020 was carried out by the collective Supaero-Décarbo. This analysis raises several issues, in particular the use of expressions that are not scientifically valid (e.g. "a zero CO_2 emission aircraft"), the lack of quantified and time-bound targets, and the fact that this plan was mainly developed and will be steered by GIFAS. In addition, the absence of any explicit mention of the involvement of scientists, climatologists, sociologists and citizens, all of whom are stakeholders on the subject, indicates an asymmetry in the elaboration of the sector's recovery plan, where taking into account broader opinions would have resulted in greater neutrality.

Observation 3: many online tools allow the assessment of the carbon footprint of a flight, but provide heterogeneous results that are difficult to interpret by their users or the general public without prior awareness. Examples include the ICAO's carbon calculator, the calculators of the Directorate General of Civil Aviation (DGAC), Atmosfair, MyClimate.org, Good Planet, which use different, sometimes complex, estimation methodologies.

To estimate fuel consumption, they generally use the average fuel consumption of all aircraft types on the specified route to date. This is regularly updated, particularly for the ICAO, DGCA and Atmosfair calculators. The latter provides an additional level of detail by allowing optional specification of the aircraft type. Only some calculators allow you to specify the class used by the passenger for the flight (economy, business, first, etc.) and can thus better take into account the extra consumption associated with the highest classes (ICAO and Atmosfair calculators). Some calculators take into account the well-to-tank emissions (production and distribution of jet fuel), while others do not. Several even directly display non-CO_2 effects (see 5.7.2) in their estimates, without however mentioning the current uncertainties in their fine understanding (it can also be noted that some of the calculators integrating non-CO_2 effects are provided by organisations proposing commercial offers to offset the greenhouse gas emissions associated with a flight). Others do not include these effects (ICAO and DGAC calculators). Depending on the calculator, users are thus facing noticeably different estimates for the same flight. Finally, access to the details of the estimates, let alone understandable explanations, is often difficult, or even impossible, on the concerned websites. This does not allow users to correctly interpret the results and make informed decisions about the choice of air travel as a means of transportation.

Observation 4: the information available to consumers on the carbon footprint of their air travels is not very visible and is difficult to use when they buy their tickets on the websites of travel operators or airlines.

Since 2013, in France, transport providers, both passenger and freight, must inform each customer of the quantity of greenhouse gases emitted by the requested transport. Initially limited to CO_2, all greenhouse gases are now covered since 2017. The regulatory calculation methodology used in France is based on the draft European standard on the calculation and reporting of energy and greenhouse gas emissions from transport services (NF EN 16258). It takes into account emissions from the upstream part (production and distribution of kerosene).

However, the carbon footprint of the trip the customer wishes to do is often difficult to access before the purchase decision: he needs to navigate deeply into the websites of travel operators or airlines to identify precisely this information, which is usually displayed in small print. In addition, some airlines offer only limited calculation details.

Many travel operators or airlines also mention that the CO_2 emissions of some of their flights are fully offset. This information may therefore make passengers believe that the climate impact of their journey will be zero. This will mislead them if they are not made aware beforehand of the principles of carbon offsetting, and of the risks and the questions raised by these mechanisms (see 5.6 and 5.7).

Observation 5: future travel consumers face many asymmetrical incentives to fly throughout the process that guides them to the final decision to purchase their tickets.

Advertising campaigns for airlines, or travel operators, are mainly based on low fares. They tend to encourage the consumption of increasingly affordable services (particularly since the emergence of low-cost airlines) and, beyond that, contribute to increased air traffic and therefore its climate impact. Although there is a lack of data and public studies to measure the effect of these campaigns on the increase in air traffic, it is not negligible, given the significant advertising investments made in France each year. However, such incentives, whatever their medium are, are in no way qualified or compared to the climate impact of air transport

In addition, when purchasing airline tickets online, messages are displayed on the booking websites, in case of only a low number of seats are still left for a given price (e.g. "3 people are looking right now to book a seat on this flight and there are only 2 seats left at this fare"). This advertising pressure, which is common in the online sale of goods and services, can lead to rushed purchase, without taking into account any other impact than financial.

Detailed description of the suggested measures

The measures described below attempt to provide a response to the above findings and to go beyond the current status quo. In particular, they complement several of the proposals of the French Citizens' Climate Convention, by applying them to long-distance transport.

Although they are intended to be applicable throughout French territory for all the players concerned (including foreign companies operating in France offering travel for sale from France), they would only make sense in a European or even global context, without which the expected effect will be eroded by distortion of competition or by international traffic shifts.

Measure 1: develop educational resources on the climatic, technical and economic challenges of air transport, the aviation sector and long-distance transport in general, ranging from sensitization to more advanced awareness-raising, then systematise associated educational curricula.

These educational resources will have to be collaboratively designed between citizen groups independent of pressure groups, sociologists, trainers, specialists in long-distance transport (air, rail, sea, car, bus, etc.), representatives of the aviation industry, scientists and communication specialists. They should be validated by experts (according to the principle of peer review). They will have several targets, from the general public to already aware populations, as well as governmental actors and local or national elected officials. They will have to be regularly updated according to the evolution of knowledge and context.

Everyone will need to be able to understand the information and this will require an educational curriculum at all levels and at all stages of personal and professional life (as proposed by the French Citizens' Climate Convention in proposals C5.1 to C5.3 of its final report).

It would also be interesting to make such a compulsory course for all elected representatives and national and local officials concerned by long-distance transport, and to deploy in-house training courses based on it for all employees of companies in the long-distance transport sector.

Measure 2: create and promote an official public portal for the long-distance transport sector, for the general public, transport companies, elected representatives and administrations, and launch regular and wide-ranging information campaigns on the existence of this portal.

This portal should be run by a government agency or body (e.g. ADEME). It will host, as a first priority, the "official" educational resources (see measure 1 above) and facilitate access to the reference calculator of the carbon footprint of a journey according to the means of transport (see measure 3 below). It should also link to all regulatory resources, the various relevant pages on the websites of government agencies and ministries, as well as to local and national open-data information and statistics, with the capacity for dynamic visualisations. Its availability should be associated with regular information campaigns for the general public, with a large coverage.

Measure 3: Revise the regulations associated with Article L1431-3 of the French Transport Code (Articles D1431-1 to D1431-19) and the associated methodological guide provided by ADEME so that the GHG information on air transport services takes into account the seat class and the aircraft model (except for the specific cases described in articles D1431-16 to 18) in addition to the upstream and operational phases already covered by the regulations. Extend this global vision of impacts to all long-distance means of transport, according to their specificity.

Comprehensive documentation and outreach materials for the general public should be made available and easily accessible. The calculation methodology should be regularly updated to take into account the state of the art in knowledge on the climate impact of transport (air, rail, sea, etc.), and be validated by an independent committee of scientific experts. The revised method will be subject to an amendment to the European standard for the calculation and reporting of energy and greenhouse gas emissions from transport services (NF EN 16258).

For air travel, the mandatory inclusion of seat class is necessary because of the higher carbon impact of higher seat classes. The inclusion of the average fuel consumption achieved by an airline with the different aircraft models it uses on the routes it serves will make it possible to assess the operational progress made by the airline. It will thus encourage the renewal of older generation aircrafts.

Measure 4: provide the public and long-distance transport companies with an official open-source and open-data carbon footprint calculator for all types of transport, giving access to the total equivalent CO_2 with display of the associated uncertainties. For air travel, it will have to take into account the class of seat considered, integrate emissions from combustion and well-to-tank emissions.

It should serve as a reference in France for GHG information on transport services. The results provided should be able to serve as a source of level 1 data for the carbon footprint associated with a given journey, thus falling within the framework defined by proposal C1.1 on page 18 of the Final Report of the French Convention for the Climate13 and the regulations of Article L1431-3 of the French Transport Code15.

For air transport, this calculator could be derived from the update of the DGCA's TARMAAC calculator. It should allow the specification of the seat class (and possibly the aircraft model). The data used, assumptions, parameters and calculation details should be easily displayed on request by users, in order to promote transparency, objectivity of results and public awareness. Uncertainties should be clearly indicated as an interval of CO_2 equivalent values (90% confidence interval).

It should graphically display, where relevant, a comparison between the greenhouse gas emissions of the different means of transport, as can be seen for example on the "Move around" section of ADEME's Ecolab comparator, as well as the percentage of individual carbon budget compatible with the Paris Agreements (approximately 2 tCO2e) that the value obtained represents.

It could be customised by carriers and transport industries using their own data, for comparative display purposes with standard results to highlight the technical and operational progress of the sector's stakeholders. In these specific use cases, the displayed data shall be mainly observed data. If they correspond to optimum use cases that are very rarely achieved, this shall be explicitly stated and the use of these results will be prohibited for regulatory purposes. For example, in the aviation sector, if the Air-France fleet is more efficient and less emissive than those of its competitors, this should be promoted to the general public while minimising the risk of contestation.

Measure 5: Strengthen by regulation the obligation for transport providers to display the quantity of greenhouse gases emitted for all journeys, on all associated advertising materials or when consumers purchase transport tickets, in the form of a CO_2-Score.

This proposal requires at least a revision of articles D1431-2 and D1431-20 to D1432-21 of the regulation related to article L1431-3 of the French Transport Code. It applies elements from proposals C1.1 and C2.3 drawn up by the French Citizens' Climate Convention to the transport sector and presented in detail on pages 18 and 26 of its final report13. It should apply to

any long-distance tickets, regardless of its point of departure and of destination (necessary modification of article D1431-2 of the regulation related to article L1431-3 of the French Transport Code).

The CO_2-Score adopts the terms used in measure C1.1 of the French Citizens' Climate Convention. It is defined here as the display of the CO_2 equivalent emissions of a long-distance journey by using a mandatory graphic charter defined by regulation (minimum size relative to the

visibility in relation to the price of the service, proportions, colours, fonts, etc.). It must graphically integrate the proportion of the individual annual carbon budget compatible with the Paris agreements consumed by the value displayed.

Each transport provider will have to use this CO_2-Score to display information on the amount of greenhouse gases emitted for any long-distance journey offered, calculated according to the regulatory method defined in measure 3. The effects of any carbon offsetting measures implemented by the provider shall not be subtracted from the total displayed in the CO_2-Score. The service provider may, however, mention a contribution, linked to the journey in question, that favours the increase of terrestrial carbon sinks, exclusively in the context of projects benefiting from the Low Carbon Label and on condition that the size of this reference is smaller than the size of the CO_2-Score.

When a consumer makes a purchase, the CO_2-Score associated with the journey concerned must be available as soon as the results of a ticket search are obtained. The information shall be put into context, if possible in the form of a graphic or a message such as: "The carbon footprint of this trip represents x% of the annual and individual carbon budget compatible with the Paris Agreement target". The CO_2-Score and its contextualisation should also be visible and confirmed by the consumer, to allow payment transactions to be initiated.

For comparison purposes, carriers will be able to display the standard CO_2-Score obtained from the calculator for a given journey, in order to highlight their technical and operational progress on the route. A carrier using this dual display for a given flight should, however, generalise it for all the routes it offers for sale, in order to avoid possible distortions of competition.

Measure 6: Regulate travel advertising in order to limit unchosen incentives to consume or promote travel with the highest CO_2-Score, and display a mandatory statement encouraging sensible travel consumption on all relevant advertising media. This measure is an adaptation to long-distance transport of proposals C2.1, C2.2 and C2.3 developed by the French Citizens' Climate Convention and presented in detail on pages 25 to 27 of its final report13. It is planned in several steps from 2023. From that date onwards, all advertisements associated with long-distance journeys will have to include a written or audible statement encouraging the consumption of travel in a sustainable manner, in addition to the CO_2-Score proposed in measure 5. The duration of the journey, if mentioned, should be calculated on the basis of the average time spent by a traveller, including time spent at stations, airports and ferry terminals, and not on the basis of the journey time alone. Lastly, after fixing by decree in the French Council of State the threshold level of CO_2-Score beyond which the environmental impact of a journey will be deemed excessive, journeys whose CO_2-Scores exceed this threshold will be subject to a ban on all advertising, whatever the medium (television, radio, paper, internet and physical signs, telephone and SMS, emails, etc.), with the exception of the exclusions defined by the Evin law I.
CO2 impact
These measures aim to introduce a reasonable use of air travel and to lead to careful medium- and long-term consideration of investment choices by policy, administrative or economical decision-makers. Their effect on the reduction of greenhouse gas emissions is difficult to assess. In the short term, the effect of these measures will be small. However, changes in behaviour and modifications in investments or local policies induced in the medium and long term will make these levers increasingly effective and will likely lead to significant reductions.
Generated externalities
The application of these measures should make it possible to stabilise or slow down the growth of air traffic (domestic and international from France) and to stabilise investment in terms of airport infrastructure extensions or new construction, at least in France. In order to avoid any distortion of competition or international traffic shifts, it is recommended to transpose these measures into European regulations and to apply them throughout the European Union territory. Their implementation in France will require additional jobs and budgets in the ministries and state agencies that need to be involved (Ministry of Ecological Transition, Ministry of Transport, Ministry of Education, Youth and Sports, ADEME, CITEPA, DGAC, etc.). It will also require extensive

coordination between several non-state stakeholders, which will generate jobs. Resources and jobs will also be needed to develop educational resources related to the environmental issues of air transport, to implement the training at all levels (from primary school to the highest authorities), carry out life cycle or environmental impact assessments. Companies in the tourism or transport sector will need to change their calculation methods for the carbon footprint of travels, implement the CO2-Score, and change their travel booking systems and advertising habits, which will lead to necessary investments but also internal mobility. The regulation of advertising will also have a strong impact on the marketing and communication departments of these companies, as well as in advertising or communication agencies specialising in this type of advertising, with a high proportion of their business in France. It is likely to have a smaller impact on employment in the non-specialised advertising sector (communication agencies, actors, models, image banks, etc.). Finally, it will potentially lead to a loss of revenue for broadcasters (television, press, websites, etc.). The consequences on employment in the concerned companies are therefore not to be neglected: they will require professional mobility, uncontrolled departures or professional retraining and state subsidies to increase their acceptability. The reduction in expenditure for companies currently paying for this type of advertising in France could, however, make it possible to finance part of the retraining of the employees concerned towards the job opportunities identified in this section.

7.4.3 Collectively organising the prioritisation of uses

Collectively organising the prioritisation of uses	
Concerned stakeholders	General public, consumers, policy decision-makers.
Observations	
The uses of air travel are very diverse, and a fundamental reflection here is essential to organise a reduction in demand for air transport that is acceptable to all.	

Business flights accounted for 28% of air travel demand in 2016 304 and some of them can be replaced by a videoconference. It is conceivable, at first, to keep physical

304 https://www.ecologique-solidaire.gouv.fr/sites/default/files/ENPA_2015_2016.pdf

meetings and therefore business trips for the most important occasions (commercial approaches, signing of contracts/strategic partnerships, the most important scientific conferences, guest researchers, consulting activities that cannot justify the impossibility of sending a local expert, etc.). The draft version of the Plan for the Transformation of the French Economy by the Shift Project predicts that the development of videoconferencing will reduce kilometers travelled for business purposes by 25%, i.e. 15 billion passenger-kilometres in 2050 305.

The COVID-19 crisis played the role of an accelerator here, by raising awareness of the enhanced possibility of using digital solutions and by increasing the acceptability of such a measure by the population. In addition, the desirable relocation of other activities (also for ecological reasons) will help to reduce the need to travel or make other means of transport competitive. Companies can play a pioneering role here by standardising a business travel policy adapted to the climate constraint, although regulation will certainly be necessary to universalise this practice.

Holiday and leisure flights (just under 48% 306) are among the uses that were previously strongly developing, mainly among the middle class, in which they tend to be considered as normal. Advertising conveys messages associating travels to a distant destination with an escape from daily life as a well-deserved break. The emergence of new behaviours like Bucket List (things to do before passing away) 307 or F.O.M.O. (Fear Of Missing Out) 308 are increasing the demand for air travel. There is even the emergence of a small number of people who spend most of their time travelling and promoting this lifestyle on blogs and social networks 309.

To what extent is air travel, the only means of transport that now allows long-distance interconnection between cultures and people, partially diverted from this honourable objective by abundant supply and sometimes aggressive advertising 310? What is this desire to escape and travel to which the extensive use of air transport for leisure purposes responds today? The question is worth asking, when Deutsche Bahn claims to have increased its revenues by 24% thanks to a campaign targeting Instagrammers 311: photographs of faraway destinations are compared with very similar ones of regions accessible by train for less money. Furthermore, what is the link between the supply of low-cost air transport and mass tourism, whose impact on the destinations visited (standardisation, massive overbuilding, gentrification 312) and the socio-economic usefulness of its carbon footprint are increasingly questioned 313?

Even in the worst case scenario where the energy efficiency of air transport fails to grow, a 50% reduction in the number of French passenger-kilometres compared to 2017 would bring this number down to 1998 levels 314. Was that, not so long ago, synonymous with deprivation in our desire of exploration, culture and discovery of others?

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305 État d'avancement du Plan de transformation de l'économie française (PTEF) - Mobilité longue distance, The Shift Project, July 2020

306 https://www.ecologique-solidaire.gouv.fr/sites/default/files/ENPA_2015_2016.pdf

307 See an example here https://www.passeportsante.net/fr/psychologie/Fiche.aspx?doc=bucket-list-idees

308 See an example here https://www.fomotraveler.com/. Arte also dedicated a programme to this movement: https://www.youtube.com/watch?v=Z5Us9snCMD4

309 See an example here https://www.justonewayticket.com/i-want-to-travel-for-the-rest-of-my-life-travel-bloggers-tell-how-to-do-it/, https://www.forbes.com/sites/celinnedacosta/2016/11/29/how-these-6-millenials-travel-the-world-for-a-living/#424571ae2443 or https://www.salonblogueursvoyage.fr/.

310 https://blogs.letemps.ch/pascal-kuemmerling/2018/08/04/compagnies-aeriennes-la-bataille-des-pubs-sexy/

311 https://arts.konbini.com/instagram/lieux-plus-instagrammables-version-low-cost/

312 https://www.francetvinfo.fr/decouverte/vacances/cinq-preuves-que-le-tourisme-de-masse-est-une-plaie_2403100.html

313 https://www.lumni.fr/article/tourisme-de-masse-quels-avantages-et-quels-inconvenients and https://www.viepublique.fr/eclairage/24088-le-surtourisme-quel-impact-sur-les-villes-et-sur-lenvironnement

314 Source 2017 : DGAC commercial air traffic statistics bulletin for France in 2017 (376 billion PKT)

Source 1998 : MTES https://www.data.gouv.fr/fr/datasets/trafic-en-passagers-kilometres-transportes-30381934/

Does limiting the use of air transport to a level compatible with a goal of energy sobriety imply a total abandonment of the exchanges necessary to maintain a global social fabric?

Finally, 21% of flights respond to a need to visit close relations. Even though it is a priori difficult to imagine reducing this type of usage, it is likely that the demand for such trips will decrease in the long run if air traffic is constrained, thus discouraging candidates from self-initiated expatriation (315).

Avenues for reflection

We are in favour of the organisation of a collective and democratic choice between the uses we want to reduce in priority versus those we want, in contrast, to keep. If we do not do that, it will result in a prioritisation of uses depending on restrictive measures put in place by public authorities (price evolution, constraints put on individuals and professionals, …). On the contrary, a collective agreement on priority usage ensures a better acceptability of the industry's evolution and of the measures taken in that direction. We present some avenues for reflection for organising the prioritisation of uses, with the goal of contributing to opening the public debate on these questions. We are not pretending to know the truth nor to foresee the technical measures that would allow us to reach that repartition.

Encouraging sobriety of use requires an acute understanding of our air transport demand. **Here, the term sobriety, now written in the energy transition law of 2015 (316)means moderating energy intensive uses without necessarily renouncing them entirely.** If it goes against excessive over-consumption (insofar as it is not compatible with climate objectives), it is not synonymous with abstinence.

Energy sobriety is not a negative approach meaning to abandoning essential consumptions but instead a reduction, by creating a hierarchy of needs, of unnecessary consumptions. It simply translates the necessity for our consumption to find some limits in a world with finite resources. The fundamental question here is to know which authority is legitimate for hierarchising needs. Once again, we defend the idea that prioritisation is only acceptable by users if established by a collective that represents them. The latter can be led by businesses as well as by the state which can act alone or delegate part of this mission to citizen groups.(317)

What companies can do

Companies all over the world try to improve their environmental performance and communicate publicly on these topics. By reporting their emissions, by acting on multiple aspects of the sustainable growth of their operations, companies can benefit for instance from reducing their costs, acting directly on their employee well-being and satisfaction, showing leadership and contributing to a positive social change. The company's reputation in the eye of the general public and more importantly of investors is thus improved.

315: Without questioning the absolutely essential role of air transport in international exchanges, here we simply defend the idea that if air transport is constrained in the future, there will be less expatriation seekers.

316: LOI n° 2015-992 from 17 August 2015 related to energetic transition for green growth. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000031044385/

317: https://blog.fairjungle.com/pourquoi-le-voyage-daffaires-vous-co%C3%BBte-beaucoup-trop-cher-eacd210b5ca4

Regardless of their destination, business trips have a high cost for a company. For the same itinerary, a business trip costs on average two and a half times more than a leisure trip (318). According to the Key Corporate Solutions cabinet they would amount to between 0.8 and 1.8% of the total budget of firms. Transport, either by plane, train or ferry, is the largest expense entry and represents half of a company's travel budget. (319)

However, streamlining expenditures can lead to a 15 to 18% reduction of their travel budget. This task is usually given to a dedicated working group involving purchasing, finance, human resources and employees. Why not then involve the CSR governance (320) in order to include environmental criteria in the implementation of a long-distance travel policy? Instead of trying to only optimise travelling costs deemed inevitable, that body could also define the conditions under which travelling is avoidable, and think about alternatives that are cheaper and have a lesser environmental impact. This consideration follows on from proposition D1 of the Citizen Convention for Climate (321) which offers to involve companies and administrations in thinking about and better organising the movements of their employees or agents, while extending it to long distance mobility.

The COVID-19 crisis has pushed numerous companies to change their view on remote work. The service industry, which includes 67% of jobs in France (322), would unquestionably benefit from following the methods and tools implemented long ago in highly distributed companies where remote work is the rule (323). Developing a real culture of remote collaboration should help question the relevance of business trips. This approach allows for instance some digital companies to canvass prospects without meeting them, by betting on personalised video demonstrations.

Of course, it is not about affirming that human contact is unnecessary in the professional world. It would be difficult to imagine consultants doing their job away from their clients. But can we not favour hiring local collaborators who can visit clients using a low-carbon daily mobility service? Even if it means encouraging coworking to avoid additional structural costs?

For businesses specialised in Travel Management (324), reducing the use of air transport is also an opportunity for diversification. Instead of selling a trip at the best price, why not offer in addition a consulting service to best evaluate the suitability - economic and environmental - of business trips in a given context? And take advantage of it to train a company's employees to modern remote collaboration tools and methods? The air transport moderation that health constraints impose today already encourages travel management to question itself. We believe that in the future the job of travel management will first be that of a collaboration facilitator rather than of a trip organiser.

318: https://blog.fairjungle.com/pourquoi-le-voyage-daffaires-vous-co%C3%BBte-beaucoup-trop-cher-eacd210b5ca4

319: http://www.journaldunet.com/management/0606/0606138voyages-affaires.shtml

320: CSR governance already looks at the problem. In general, CO2 emissions from business trips are not taken into account in yearly company reports. Indeed, data presented is expressed within the activity scope and methodology defined by the GreenHouse Gas Protocol (GHG Protocol). However, emissions linked to professionals trips come under the optional scope 3, as opposed to scopes 1 and 2 which are mandatory. So, in 2020 it is not mandatory for a company to report emissions linked to business trips. Consequently, efforts to monitor and limit business trip induced emissions - at least until the Covid-19 pandemic - relied on voluntary company action, with their own tools and calculation method.

321: https://propositions.conventioncitoyennepourleclimat.fr/pdf/pr/ccc-sedeplacer-impliquer-les-entreprises-et-les-administrations-pour-penser-et-mieux-organiser-les-deplacements-de-leurs-salaries-ou-agents.pdf

322: https://www.insee.fr/fr/statistiques/4277675?sommaire=4318291

323: https://medium.com/swlh/a-remote-work-retrospective-three-years-in-56e52ada55d5

324: https://fr.wikipedia.org/wiki/Travel_manager

Corollary to this, the need to take a plane to join a seminar, a team-building session, a works council trip, must be questioned, and the company responsible can no doubt come up with other plans, even if it means investing in simultaneous local events in case of significant geographic disparity.

All these actions could be valued by companies as part of the implementation of a process of continuous improvement of environmental management which is the subject of ISO 14001 certification, and to which consumers are more and more sensitive (325).

What the State can do

Among the incentivising measures that the government can take, a first option would be to include a section on air transport in the Mobility Plan. Formerly called Business Trips Plan, the Mobility Plan, mandatory for companies over 100 employees, is a set of measures that aim at optimising and making more efficient the business trips taken by a company's employees, to reduce pollution emissions, road traffic and to favour the use of alternative transport modes to the individual car (326). By extending the scope of the long-distance mobility Plan, the State could choose to condition ADEME's technical and financial support to the establishment of incentives for companies to reduce their use of airplanes. It is worth noting that a support solution to the implementation of remote working will have to be thought about for small structures that do not necessarily have resources to dedicate to finding innovative solutions.

The State can also go further in encouraging the development of remote work from shared spaces rather than from home and not only in urban or medium density areas. Remote work, often used as a means to reduce the need for daily mobility, can also have an impact on long distance mobility since someone well-versed in the tools and methods that distance requires can collaborate equally with people a few kilometres away or on the other side of the world, time difference constraints aside. The State already recognises that shared working spaces or "co-working" represent an alternative to traditional organisation of work, by pooling resources and creating a collaborative fabric between the people working there who are then not isolated. This support must increase while strengthening the territorial demographic balance: if half of the coworking space offer is concentrated in Île-de-France (Paris region), the State can play a role in support to alternative structures, ecovillages and other rural initiatives that result in repopulating areas that were until then deserted.

The State can also facilitate the implementation of solutions often recommended at the individual scale, like for instance flying less often in exchange for a longer stay. A way of encouraging this type of initiative would be for instance to make the time savings account (327) mandatory for all employees, in order to give them more flexibility in taking their time off.

325: https://www.iso.org/fr/iso-14001-environmental-management.html

326: https://www.ademe.fr/entreprises-monde-agricole/reduire-impacts/optimiser-mobilite-salaries/dossier/plan-mobilite/plan-mobilite-quest-cest

327: https://www.service-public.fr/particuliers/vosdroits/F1907#:~:text=La%20mise%20en%20place%20d,pas%20oblig%C3%A9%20de%20l'utiliser

Finally and possibly most importantly, the State would benefit from surrounding itself with a citizens collective of air transport travellers in order to ensure that policies that encourage shifting towards less energy intensive transports are truly aligned with citizens' expectations. Here again we take proposition D3 from the Citizen Convention for Climate which proposes to include citizens in mobility governance at both local and national levels (328), by extending it to long distance mobility. Citizen consultation tools at the disposal of the general secretary for the modernisation of public action are not lacking (329). We would favour, however, frameworks that allow the designated citizens to receive sufficient training before being consulted. This is the case for instance of the citizens conference in which members are trained by experts and therefore provide educated and collectively built opinions that support public decisions and limit disputes.

7.4.4 Reflections on regulatory levers

Several avenues to reduce the number of passengers through regulation can be considered, at a scale ranging from national to European or even global. Obviously, the effectiveness of the measures is directly linked to their geographical application scope; a local coercive jurisdiction will only result in the transfer of travellers to neighbouring countries.

We offer here a list of regulatory levers, and try for each of them to estimate its acceptability level, difficulty of implementation, possible workarounds and associated externalities. Once again we do not intend to be exhaustive. Our first and foremost goal is to start a civic debate and to allow a consensual hierarchisation of usage.

Progressive restriction of slots	
Expected result	Reduction in the number of flights and flights over the territory and/or associated air space block.
Citizen acceptability	Medium
Industry acceptability	Low
Implementation difficulty	European laws must be modified for overflights whereas environmental motive is enough to limit airport slots. The measure will also require arbitrating between airlines over the attribution of slots and managing competition (for instance, Air France refuses to yield its slots to Emirates).
Possible workarounds (including rebound effect)	Flights avoiding French skies or the central European air space block. Increase in the size of airplanes.
Externalities	Activity reduction in airports and therefore job losses.

Comment	The measure can be made more flexible by a kilometric emission threshold which would leave the slot open for a future airplane that is sufficiently clean/low-carbon.

328: https://propositions.conventioncitoyennepourleclimat.fr/pdf/pr/ccc-sedeplacer-inclure-des-citoyens-dans-la-gouvernance-des-mobilites-au-niveau-local-comme-au-niveau-national.pdf

329: https://www.modernisation.gouv.fr/sites/default/files/fichiers-attaches/boite-outils-demarches-participation.pdf

Removing the 80% occupancy constraint on slots	
Expected result	Airlines adjust their flights to the real demand and not to the necessity of keeping their slots. This should make it possible to avoid lightly filled airplanes which are of little economic and environmental relevance (330).
Citizen acceptability	Really good.
Industry acceptability	Good for airlines which already have slots.
Implementation difficulty	Competition problem as it blocks new players if vacant slots are not available. Involves a deep reworking of the attribution system.
Possible workarounds (including rebound effect)	Implementation of new attribution rules for the occupancy of abandoned slots.
Externalities	Fluctuating incomes for airports and ANSPs (Air Navigation Service Providers).

330: This measure is incidentally a request from the industry in a pandemic period. See https://www.air-cosmos.com/article/adaptation-crneaux-horaires-les-aroports-et-les-compagnies-tombent-daccord-23540.

Progressive restriction in the number of passengers per airway	
Expected result	Reduction in flight frequency.
Citizen acceptability	Low, especially if prices increase as a consequence.
Industry acceptability	Low.
Implementation difficulty	Relatively easy, use airport slots which have a passenger reception component and do the same with all overflights, using airplanes' carrying capacity.
Possible workarounds (including rebound effect)	Must be expanded to the European scope to have a sufficient impact and avoid the overflow of passengers towards neighbouring countries.
Externalities	Potential shift of parts of the traffic towards train travel if available or car travel.

Aircraft fuel tax	
Expected result	Incentive to consume less fuel.
Citizen acceptability	Good, public opinion is generally in favour.
Industry acceptability	Low.
Implementation difficulty	A unanimous vote of all 191 member states of the ICAO would be essential for any challenge to the Chicago Convention. Nevertheless, the latter is only destined to govern international flights and it would therefore be possible for the executive to establish the TICPE on aircraft fuel for domestic flights. Additionally, sector

	opposition on the basis that the tax duplicates CORSIA or EU-ETS is to be expected.
Possible workarounds (including rebound effect)	Fuel tankering if the implementation is limited to a single state. Becomes interesting over several airspace blocks, at a continent scale.
Externalities	Cost increase passed over to the ticket price. Social inequalities emphasised. Possible redistribution towards decarbonation.

Passenger tax	
Expected result	Trafic reduction.
Citizen acceptability	Low. Can reinforce the socially unfair aspect, unless progressive and based on the number of journeys or on distance travelled (331).
Industry acceptability	High at first glance given that it is a consumption tax hence without impact on airlines margins even though the goal is obviously to dissuade from consuming.
Implementation difficulty	Regressive tax at first glance (social inequalities accentuated, unless applied progressively), can be seen as buying a right to pollute. The tax amount must be really discouraging (and so it will be hard to accept) and the money collected must be transparently assigned towards investments that citizens buy into (332).
Externality	Possible redistribution towards decarbonation.

Control of airlines subsidies

Expected result	Low-cost carriers reduce their activity. Service reduction for unprofitable airports.
Citizen acceptability	Good.
Industry acceptability	Really good for regular airlines.
Implementation difficulty	Proposition under review by the European Union (333).
Possible workarounds (including rebound effect)	Fuel tankering if the implementation is limited to a single state. Becomes interesting over several airspace blocks, at a continent scale.
Externality	Can weaken already unprofitable airports.

331: In the manner of Frequent Flyer Levy and Air Miles Levy proposed in England by the Committee on Climate Change. https://www.airportwatch.org.uk/2019/10/report-for-the-ccc-recommends-not-only-a-levy-on-number-of-flights-someone-takes-but-their-length-and-seat-class/

332: In 2018 a study was conducted in Sweden on the acceptability of a carbon tax on plane tickets (https://www.tandfonline.com/doi/full/10.1080/14693062.2018.1547678). The study concluded interestingly concluded that reintroduction of revenues from such a tax into projects that help transform the industry (Earmarking revenues) would improve citizen acceptability.

333: https://www.capital.fr/entreprises-marches/l-ue-veut-limiter-les-aides-publiques-aux-compagnies-aeriennes-1102164

Control of airport subsidies	
Expected result	Unprofitable airports close down.
Citizen acceptability	Good.

Industry acceptability	Low for affected airports.
Implementation difficulty	Isolating risk, reluctance from affected local authorities. Proposition already under way at the European level.
Possible workarounds (including rebound effect)	Partial shift towards more important platforms that do not distribute subsidies.
Externalities	To mitigate the isolating risk, high demand for rail development in the affected regions. Abandonment feeling from employees in those airports, already significantly harmed by the Covid crisis. Possible alternative: condition subsidies on the implementation of a sobriety plan.

Moratorium on the building of new airports	
Expected result	Slowing down traffic growth.
Citizen acceptability	Good.
Industry acceptability	Medium.
Implementation difficulty	Easy to implement, can be accompanied with restrictions on the extension of runways and airplane parking space.
Possible workarounds (including rebound effect)	Air traffic shifts towards other platforms if the application perimeter is too small.

Setting a price floor on tickets	
Expected result	Avoid windfall gain effect.
Citizen acceptability	Medium.

Industry acceptability	Medium.
Implementation difficulty	We could for instance analyse the impact of Austria's decision on carriers departing from the country to fix a price floor of €40 (334). Covering at least all costs pertaining to producing the service in the ticket price seems justified and understandable by users. A study on price sensitivity would be interesting to carry out: from which price increase threshold does traffic start to fall? This would make it possible to evaluate price efficiency on emissions reduction potential.
Possible workarounds (including rebound effect)	Increase in loyalty programs, compensatory reduction in the price of extras for low-cost carriers.
Externalities	Accentuated social inequalities, unless the measure is progressive and the price floor avoids social dumping for industry workers (see low-cost carriers).

Quota scheme	
Expected result	Fair distribution of the right to travel.
Citizen acceptability	High because socially fair. Proposition already supported by some politicians.
Industry acceptability	Medium.
Implementation difficulty	Questions of resale options, of non-usage reward, of accumulation over time are to be studied. Requires a specific management for territorial continuity (overseas and Corsica).
Possible workarounds (including rebound effect)	Transfer over to legal entities (companies) if the measure only applies to real persons.

334: https://www.air-journal.fr/2020-06-09-autriche-600-millions-pour-austrian-et-un-prix-plancher-5220744.html

Lottery	
Expected result	Fair distribution of the right to travel.
Citizen acceptability	Low at first glance. Random drawing to gain access to a right receives bad press in France, as evidenced by its withdrawal for access to higher education in sought-after programs (335).
Industry acceptability	Medium.
Implementation difficulty	Must be presented in a fun way and/or plan a financial compensation. For instance, the State could organise a draw for some leisure long-haul flights and cover a part of the ticket cost.
Possible workarounds (including rebound effect)	Organisation of a secondary market for winning tickets, concentrating access right on wealthier people.
Externalities	This measure can be used as a tool to complement the management of emissions in the airline industry, by regulating from year to year the number of tickets based on the sobriety goal we need to reach.

Freight limitation	
Expected result	Reduce the number of freight movements.
Citizen acceptability	Good.
Industry acceptability	Low.
Implementation difficulty	Need to Define an acceptable alternative given that shifting to train or sea freight is rarely possible. The shift to

	road freight is to be studied based on the need to transport some goods fast, a necessity that will have to be regulated first.
Possible workarounds (including rebound effect)	Shift to passenger flights which load factor is sometimes optimised with freight.

335: https://www.ccomptes.fr/sites/default/files/2017-10/20171019-rapport-admission-post-bac_0.pdf

Restrictions on leisure use	
Expected result	Reduce demand for tourist flights which today amount to about half of the uses.
Citizen acceptability	Low.
Industry acceptability	Very Low.
Implementation difficulty	Fear of a significant activity drop in the French tourism sector, the ticket buying process becoming more complicated (need to provide a professional trip or family reunification certificate).
Possible workarounds (including rebound effect)	Forgery.
Externalities	Potential jobs loss in international tourism. In France, shift towards more local tourism, or sustained European tourism through a shift towards train and road travel (more than 75% of tourists who visited France in 2018 were Europeans (336)).

Business trips limitation

Expected result	Reduce far away in-person meetings in favour of video conferencing and remote collaboration tools.
Citizen acceptability	Good.
Industry acceptability	Low.
Implementation difficulty	Requires a good coordination between all services in a company (HR, purchase, finance) to be efficiently implemented and accepted. Difficulty to reach the Optimum between the benefit and (financial and ecological) cost of trips .
Possible workarounds (including rebound effect)	Company pressure to declare business trips as personal ones if no restriction limits them.
Externalities	Job creation in the support for deploying remote collaboration solutions.

336: https://www.entreprises.gouv.fr/files/files/directions_services/etudes-et-statistiques/4p-DGE/2019-07-4Pn88-EVE.pdf

7.4.5 Conclusion

To decrease the usages of air transportation is not a project in itself, it is a way to address the physical constraint imposed by climate change. However, this assessment should be the beginning of a social debate on transportation uses in general, and air transport in particular: what should be the priority uses of airplanes in a low carbon world? Once the physical context is defined, answering this question as informed citizens, convinced about the necessity of changing our way of life, offers much more thrilling perspectives than the basic idea of decreasing without wanting to. Furthermore, answering this question could be determinative, even for an industrial strategy. If, for example, the plane was considered vital mostly for very large distances, say, to maintain the connection among the world's population, to enjoy the diversity of cultures and lifestyles, then, the industrial development strategies should focus on priority on long-haul flights. Legislation, tax systems, subsidies and bonuses are tools that can be activated to implement such a transformation project. However, if we don't change our vision of traveling and of moving around, then, limitation, bound to happen no matter what, will be a source of frustration and perceived as an injustice, as an authoritarian coercion of the freedom of moving, working, prospering and going on holiday. The more we refuse this reality, the more we delay this dynamic of change, the more we wait to make choices, the harsher and authoritarian the pressure will be and the more the airline sector will suffer.

We now have the opportunity to seize the climate constraint and integrate it into a different relationship to traveling and to tourism, in a whole reorganisation of work, holidays, business travels, in a new definition of our life priorities. In doing so, air transport will benefit from long term perspectives, in which innovation will play a key role and take all its meaning.

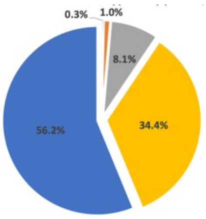
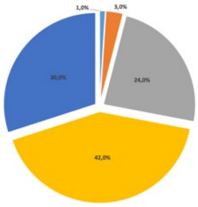
8. Worldscale scenarios of emission

We already stated this evident fact several times, by its very nature air transport, its usage and thus its market, takes place in an international context. If, today, the legitimate public powers are mostly at a national level (or at the level of economic unions of countries), the main airlines and engine manufacturers are on the global market. Thus, for Europe, and France specifically, which has an important part of the global aeronautic industry within its territories, the matters of decarbonisation, of innovation development, of the future of air traffic and of the economic growth of the sector and its social impacts, are posed at the international level. Furthermore, it is clear that most of Airbus customers are not French, and until now, growth prospects have come from Asia, Africa, the Middle East or even the United States, rather than Europe.

Therefore, if the analysis of the France perimeter, with its territorial, energetic and organisational particularities and all the national actors of the airline industry, seems to be mandatory to enlight national politics and mitigate the impacts on national employment of the airline industry, it is essential to shift to a global scale to assess the real climate trajectory and impacts on the industry's jobs.

8.1 World Hypotheses

Referential hypothesis	FRANCE (« DGAC » perimeter)	WORLD	Comments
2018 emissions ($MtCO_2$, CO_2 only + Upstream)	26.8	1,077	cf. 5.7.1
Carbon Budget 2018-2050 ($MtCO_2$, CO_2 only + Upstream)	536	21,598	cf. 5.9.3
Benchmark trend trajectory	66% fall of the traffic in 2020, recovery to 2019's level in 2024, then 4% growth	DITTO	Cf.5.9.4. French growth is inferior to the global average, but we state here the initial hypothesis for simplification purposes, the target being to adjust this hypothesis at the end to match the budget.

Short-term axis and flight operations	Detailed at §7.2.1 and 7.2.2.1 and leading to a 10,5% gain in 2050	Back to a 10,5% gain in 2050, including optimization operations.	Calculations based on the France hypothesis are not possible at a global scale at this stage and with this level of detail.
Aircraft roadmap	Defined in 7.2.2.2	DITTO	The aircraft market is international. Aircraft roadmaps are, consequently, available for all customers.
Alternative fuels	Hypothesis of national production: 2.37Mt of 2G biofuel at 80% of emission gains in 2050	500 Mt of 2G biofuels at 80% of emission gains in 2050 and 250 Mt of PTL at 95% of available gains in 2050	Cf. 7.2.2.3 and calculation note The hypothesis of a 500 Mt global production is detailed below (*). In the end, it matches an hypothesis where biofuel production can eventually fulfill the transport needs in the MAVERICK scenario. The “decarbonising power”, meaning the CO_2 emission ratio compared with kerosene, is kept the same between France and the World. The Mckinsey report shows other, more optimistic ratios, but they are not sufficiently elaborated. The decarbonising power of the PTL depends on the CO_2 capture process and the emissions of its electric mix’s production process. At first, we’ll stay on a wind turbine hypothesis on both perimeters.
Distribution of emissions by type of aircraft			 Cf. calculation note. The main difference is in the distribution between long haul vs. medium and short haul, particularly because aircraft roadmaps anticipate hydrogen technology to be available for medium haul at best. The impact of decarbonation by hydrogen

			technology is then particularly sensitive to this distribution, the World effect will be superior to the France effect. In both cases, those distributions are supposed to be consistent in time.
Fleets' renewal	15 or 25 years	15 or 25 years	Cf.7.2.2.4. 25 years is the average timeframe for the global fleet renewal according to the OACI. The renewal hypotheses chosen are identical at both France and World level.
Electric mix	Wind sector France 14.9 gCO_2/kWh	Wind sector World 11 gCO_2/kWh	Cf. 7.2.2.3. Choosing the electric mix and its carbon intensity is decisive for the decarbonising efficiency of the Hydrogen LH2 and PTL (cf. 7.2.2.30) technologies. The wind sector is selected as the first hypothesis because it is stated as a preferential energy source by the sector. The impact of its variability is studied in 7.2.2.3 and that of its externalities will be detailed in the scenarios to assess its feasibility, and the implications of those choices.
Compensation	CORSIA*	CORSIA*	CORSIA* is an ideal system (cf. 5.6.2) generalised to all roads, applied at 100% as soon as 2020, from which we took out the compensated volume from the real carbon balance. All those hypotheses over-estimate greatly the real decarbonisation effect of the systems of compensation.

(*) 500 Mt is the potential annual quantity of the global SAF 2G estimated in the McKinsey Report based on an estimation of the global biological resources available. Therefore, it's an estimation of the potential and a physical limitation, not a production forecast. Just as the France perimeter, we take the hypothesis, in the MAVERICK-World scenario, that this physical limit is reached on the production in 2050 with a production growth the first 10 years and 15% after that. The production trajectory being determinative on the results, we screen this hypothesis through some authoritative publications:

- The same McKinsey report (Chart #12) predicts a SAF production in 2025 going from 4.2 Mt (according to the annual announcement from the manufacturers), to 7.6 Mt. The MAVERICK trajectory, on the other hand, goes to 10 Mt in 2025.
- The OACI expects 6.5 Mt produced in 2032 [338], against 40 Mt in the MAVERICK trajectory.
- The SDS scenario from the AIE predicts a consumption of 75 billion liters in 2040 [339] meaning about 64 Mt [340].

337 Cf. figure 11, https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/scaling-sustainable-aviation-fuel-today-for-clean-skies-tomorrow

338 https://www.icao.int/Meetings/SAFStocktaking/Documents/ICAO%20SAF%20Stocktaking%202019%20-%20AI5-1%20Stocktaking%20Results.pdf

339 https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

340 Considering a volumic mass of 0,85 kg/L

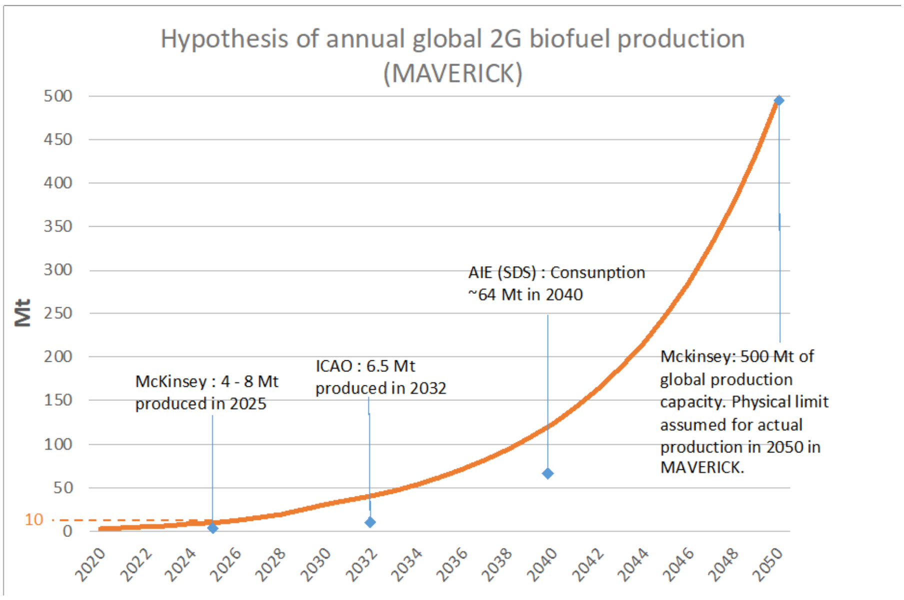


Figure 53 - Trajectory of annual production SAF MAVERICK - World

The SAF production trajectory of the MAVERICK-World scenario is, therefore, significantly above the actual forecasts. Let alone the discussion over the pertinence of the 500 Mt figure, it's a hypothesis where, ultimately, production does not limit consumption.

8.2 Expansion of the MAVERICK and ICEMAN scenarios to the World perimeter

8.2.1 MAVERICK-World scenario

MAVERICK-World scenario

Definitions and hypotheses

Cf. 8.1

Carbon trajectories

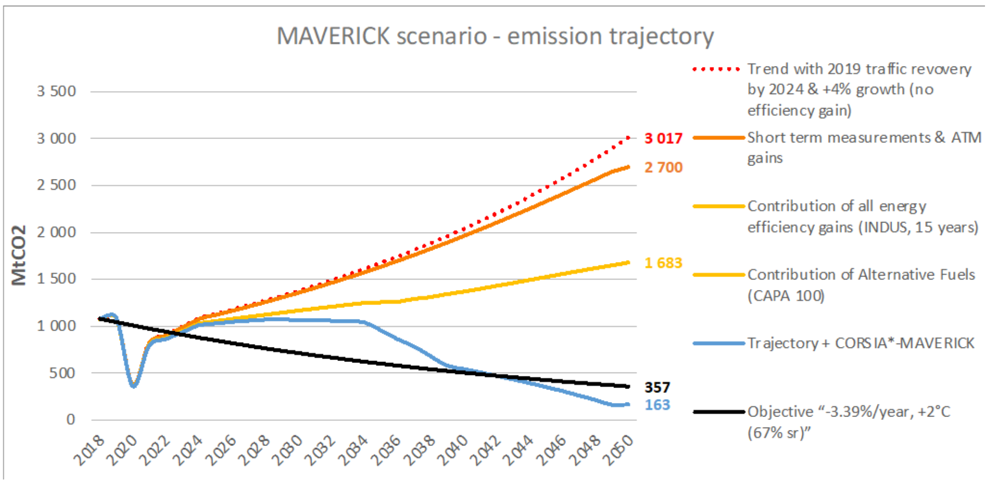


Figure 54 - Annual emissions, MAVERICK - World scenario

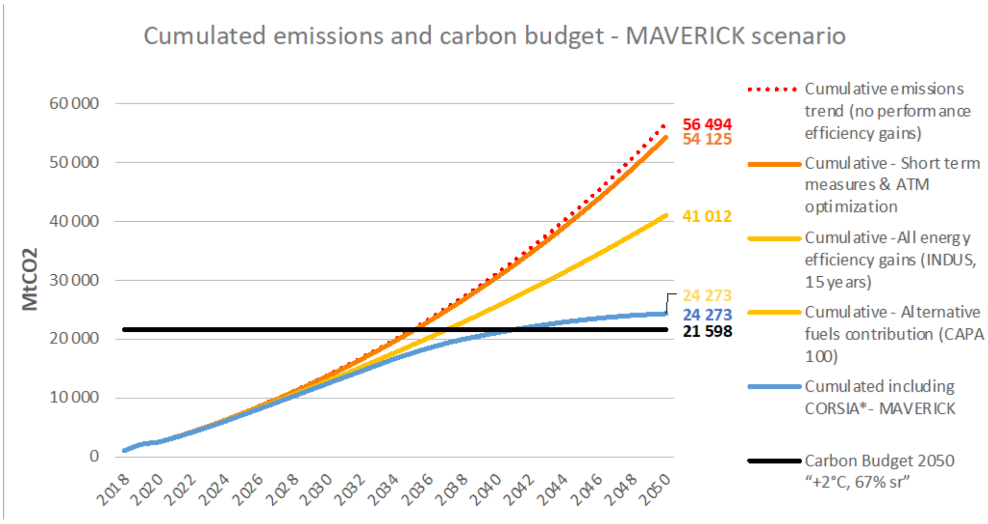


Figure 55 - Cumulative emissions and carbon budget, MAVERICK-World scenario

Highlights

We observe a significant change in annual emissions in 2035, meaning when the CC and Hydrogen MC enter service (with the global fleet's renewal rate at 15 years). Starting in 2040, 100% of the alternative fuel needs are covered by the production (biofuels + PTL).

In this scenario, the CORSIA* compensation mechanism doesn't activate, because the launching speed of new decarbonising technologies help staying under the emissions threshold of 2019 despite the traffic growth.

CO_2 results and impacts

The development of the average annual energetic efficiency is 2.01% starting from 2024. This value is in line with the sector forecast.

The annual target reached in 2050 is better than the Sector trajectory (cf. 5.9.5.3)

The budget is reached around 2041 and the cumulative emissions, in the end, exceed it by about 12%.

Despite the alternative fuel saturation, the hydrogen strategy and the speed up of the renewal rate at 15 years, the decarbonisation rhythm is not enough to stay within the budget.

Energy consumption and externalities

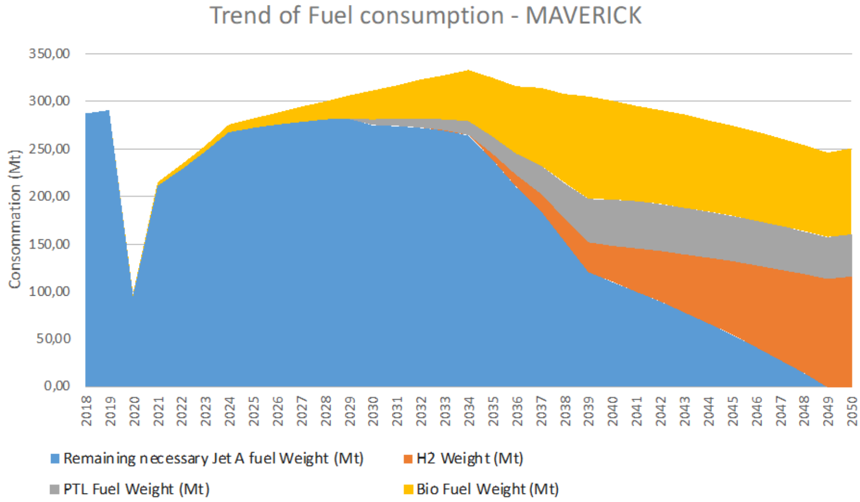


Figure 56 - Fuel consumption trajectory in the MAVERICK-World scenario

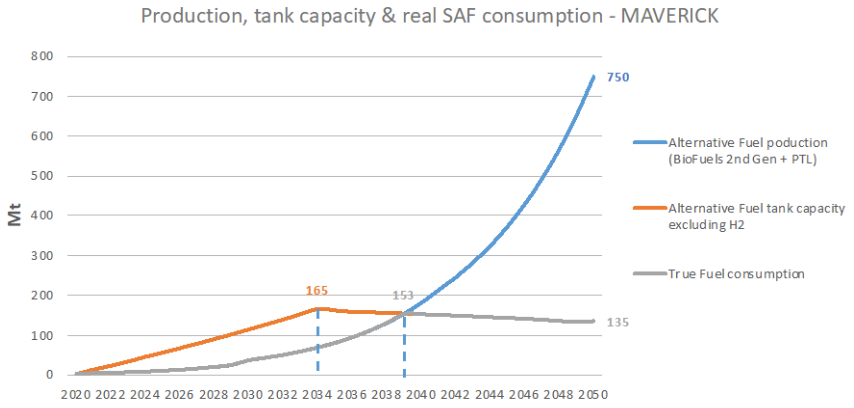


Figure 57 - Production, loading capacity and real SAF consumption (Biocarb 2G and PTL) - MAVERICK-World

Table 13 - Fuel consumption in 2050 in the MAVERICK-World scenario

Fuel consumption in 2050 (Mt)			
Jet A-1	Biofuel	PtL	LH2
0	90	45	115

The alternative fuel production is not a limiting factor anymore starting from 2039 in this scenario, and the maximum demand is 165 Mt. It is reached in 2034 (before the launching of the hydrogen medium and long hauls). The improvement of energetic performance brought by the fleet renewal decreases the global fuel consumption until 2049, but considering this scenario doesn't integrate new aircrafts before 2050 and the traffic continues growing, the consumption rises again after that.

The electric energy needed to produce such quantities of PtL and LH_2 is 8 571 TWh (2 033 TWh for PtL, and 6 538 TWh for LH_2), which would use a wind farm dedicated to the air transportation around 6 times bigger than the total global wind farm running in 2019.

In this scenario, energetic externalities are still considerable, particularly from the point of view of electricity production.

Job externalities

This scenario is better for the industry's jobs. The scenarios' impacts are studied in detail in paragraph 9.

Pushing even further?
The Chart #57 shows that, in this scenario, reaching the 165 Mt of SAF production as soon as possible would improve the emissions. In a scenario where the SAF demand would always be satisfied, we could get significantly close to the budget. But, for that, the production would have to go from ~7 to 165 Mt around 2034, meaning multiplying by 24 the actual projections. (cf. Chart #53)
Conclusions
The MAVERICK-World scenario allows to get close to the target of decarbonisation without reaching it, but it implies considerable energetic externalities and hypotheses on alternative fuels' supply, alongside an aircraft roadmap, an international organisation, and a flawless accelerated rhythm of fleet renewal. Thus, it presents a high level of risk and, as it is, the probability of its realisation are very slim.

8.2.2 ICEMAN-World scenario

ICEMAN-World scenario
Definitions and hypotheses
The ICEMAN-World scenario is defined with respect to the MAVERICK-World scenario in the same way as ICEMAN-France compared to MAVERICK-France: 5 years delay of the aircraft roadmap, 50% of alternative fuel production capacity, fleet renewal in 25 years.
Carbon trajectories

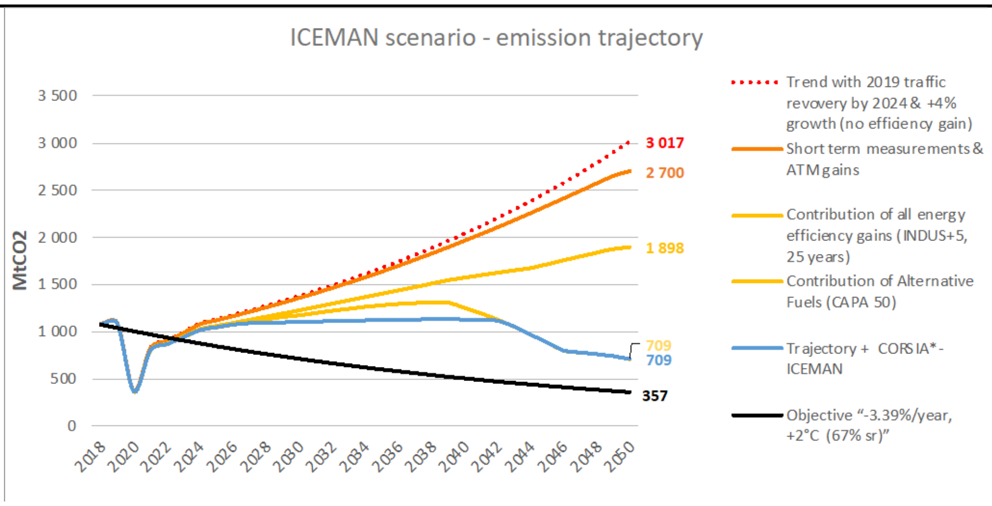


Figure 58 - Annual emissions, ICEMAN-World scenario

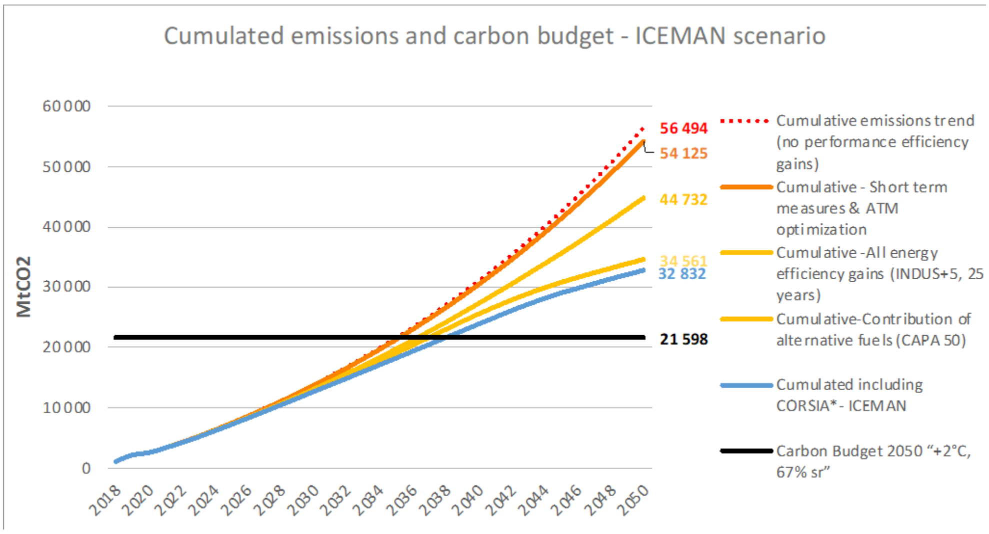


Figure 59 - Cumulative emissions and carbon budget, ICEMAN-World scenario

Highlights

The decarbonisation process is much slower.

In 2050, the renewal of medium-haul and long-haul fleets is not complete, with only 40% of fleet renewed. This is because the new generation of aircrafts is put into service in 2040 and renewal takes 25 years.

1.7 $GtCO_2$ to be offset by airlines between 2027 and 2042 through the CORSIA* system.

CO_2 results and impacts

The average annual energy efficiency gain is 1.56% from 2024 onwards, which is below the industry's optimistic scenarios but still an ambitious target, far from guaranteed.

The target reached in 2050 is very far from the sector target (cf. 5.9.5.3), yet this scenario is not particularly pessimistic.

The budget is reached around 2038 and cumulative emissions ultimately exceed it by around 52%, again, counting offsetting as decarbonisation, which in itself is highly questionable.

If decarbonisation slows down, especially at the beginning of the period, the budget remains unattainable under these assumptions. The outcome is better at world level than in France because hydrogen has a greater effect on medium and short haul flights.

Energy consumption and externalities

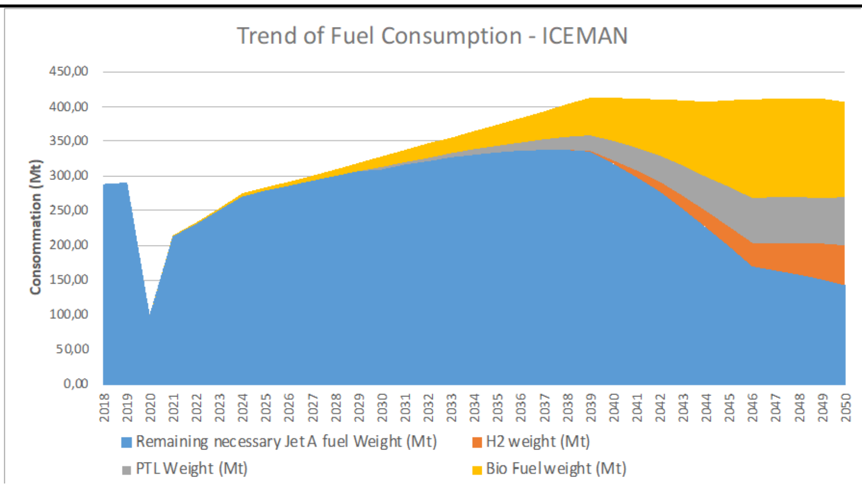


Figure 60 - Fuel consumption trajectory in the ICEMAN-World scenario

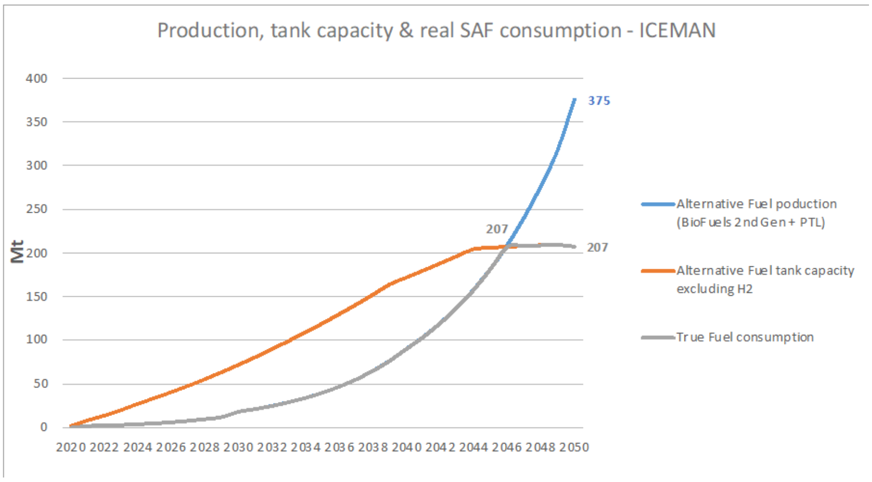


Figure 61 - Production, carrying capacity and actual SAF consumption (Biocarb 2G and PTL) - ICEMAN-World

Table 14 - Fuel consumption in 2050 in the ICEMAN-World scenario

Fuel consumption in 2050 (Mt)			
Jet A-1	Biofuel	PtL	LH2
142	138	69	58

In this scenario, available production ultimately meets the fleet's needs, but the delayed aircraft roadmap and renewal time means that the growth in kerosene consumption is delayed and slowed down and that the peak demand for SAF is higher than that of MAVERICK (209 Mt).

The electrical energy required to produce these quantities of PtL and LH_2 is 6,389 TWh (3,125 TWh for PtL and 3,264 TWh for LH_2), which would require an air transport wind farm 4.5 times larger than the total installed global wind fleet in 2019.

Conclusions

The ICEMAN scenario provides more margins for industrial risk management, alternative fuel supply and energy externalities' management. Yet, while representing a significant challenge in implementation, it significantly deviates from the decarbonisation target even though the offset system is heavily relied upon. It is therefore not acceptable as is.

8.2.3 Characteristic differences with the France scenarios

Even if they fail to achieve the budget target, the world scenarios appear to be significantly better than the France scenarios. The two structuring assumptions are as follows:

- **Biofuel abundance:** In both world scenarios, biofuel production better meets demand and is not ultimately limiting. The production in the ICEMAN scenario is closer to current sector projections by 2040 but remains very high by 2050.

- **Majority of short and medium-haul.** Short and medium-haul account for the majority of flights (66% in 2018), the decarbonisation provided by LH_2 technology (subject to a wind energy mix at 11gCO_2 / kWh) and therefore more efficient at the world level than at the France level where the majority of emissions are due to long-haul routes.

8.3 Conclusions

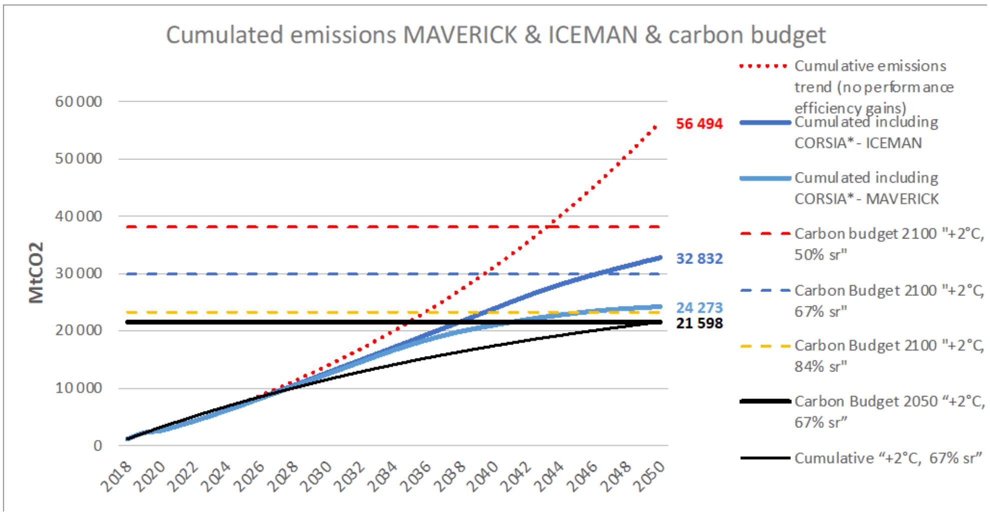


Figure 62 - Cumulative MAVERICK and ICEMAN World emissions and Carbon Budget

If the Global trajectories are better than at France level, due to the assumptions of fleet distribution and alternative fuel abundance, neither of the two scenarios manages to stay within a carbon budget that allows staying below +2°C with a probability of 67% if we maintain an average traffic growth assumption of 4%. It is a race against time that could only be won if the decarbonising technical and logistical progress and the necessary quantities of alternative fuels were already there. Furthermore, the "67%" criterion was retained because it is the one that refers to scientific publications (in particular those of the IPCC), however, this budget is significantly different from the "+1.5°C" target (with a probability of less than 20%), thus from the spirit of the Paris Agreement. The "+2°C at 84%" budget is obviously more demanding, but more in line with the Paris Agreement and, given the expected consequences of global warming beyond +2°C, very relevant to study. In addition, it should be kept in mind that, here, only CO_2 emissions have been studied, the contribution of air transport to global warming is much greater than that of the CO_2 emitted alone, in particular in a growth dynamic where the short-lived effects outside CO_2 are sustained over time by traffic growth (see 5.7.2).

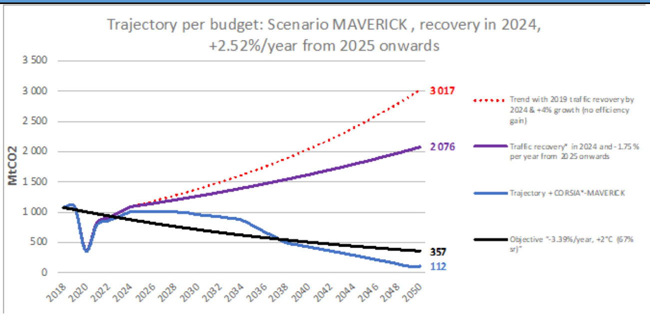
In any case, based on this observation, we still have three theoretical options to change the trajectories and stay within these budgets:

- **Betting on more technical improvements and faster than in the MAVERICK scenario**: this is a very risky bet, the MAVERICK scenario already being a very high limit of what can be expected from technical progress and already generates considerable energy externalities.

- **Raising the carbon budget**: this requires first hand to define it at international level, to manage it and to make strong cross-sectoral decisions, the overall budget being non-negotiable. It is important to keep in mind that there is no international governance in place today for this and that the aviation sector is already largely in competition with other sectors on access to low-carbon resources and the financing of its development programs. We are now quite far from that possibility. Overall budget management is a more than interesting target to achieve (see proposal 0 in §6), but it is not reasonable to rely solely on this option.

- **Revise the traffic hypothesis downwards**: It is essential to integrate this element into decarbonisation trajectories in order to establish a relevant and acceptable sobriety policy (cf. 7.4) and to anticipate the consequences on the jobs of the aviation sector.

Table 15 - Two scenarios respecting the global carbon budget

<table>
<tr><th>MAVERICK</th><th>ICEMAN</th></tr>
<tr><td>


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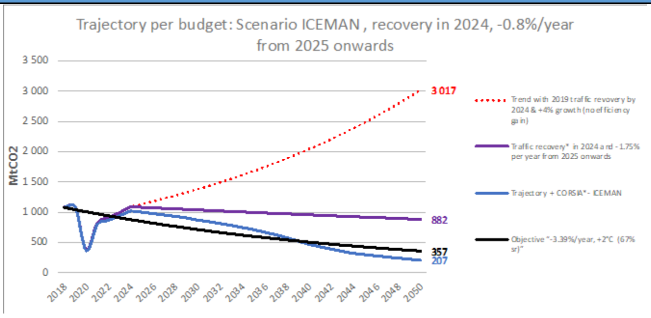

</td></tr>
<tr><td>Traffic recovery* in 2024

Traffic: +2.52% per year from 2025 onwards</td><td>Traffic recovery* in 2024

Traffic: -0.8% per year from 2025</td></tr>
</table>

By adapting the initial input traffic assumptions of the MAVERICK and ICEMAN scenarios, we can modulate these scenarios so that the cumulative emissions remain within the carbon budget envelope. The results are presented in Table 15 according to the assumption of recovery in 2024 at the 2019 level and assessment of the maximum growth / decrease necessary to stay within the budget. This exercise makes it possible to assess the order of magnitude of the required sobriety effort under the scenarios. Thus, in the case of a recovery in 2024, the average annual growth in global traffic from 2025 could vary from approx. +2.5% to approx. -1% depending on the scenarios.

It is important to recall here that:

- These figures are to be taken as orders of magnitude.
- These figures are global averages. The situations around the globe being very different from each other, the technical and sobriety solutions must be adapted to optimize their effectiveness and social acceptability.
- The MAVERICK scenario, allowing approx. +2.5% growth post 2024, is a highly unlikely upper limit given the technical, industrial, organisational and economic assumptions that determine it.

Thus, no scenario allows both to maintain the level of growth before the crisis and to remain within a carbon budget allowing to remain below +2°C with a probability of 67%.

Moreover, the two scenarios above remain highly theoretical regarding to the two strong assumptions underlying them, namely:

1. That traffic will return to its 2019 level in 2024.
2. That it will not pick up on its pre-crisis growth rate, either due to a lasting change in the market or a global consensus on the moderation of growth.

In the case of voluntary regulation by global consensus, this would require not only to be able to know at any given moment which industrial scenario is being realized, but above all to agree on an acceptable balance between the growth rates of the different regions of the world. What if this consensus was not established in 2025, but in 2030, or even in 2035? And that in the meantime the traffic continued to increase according to the trend? What would then be the additional sobriety effort to be made, assuming that the carbon budget has not already been exhausted?

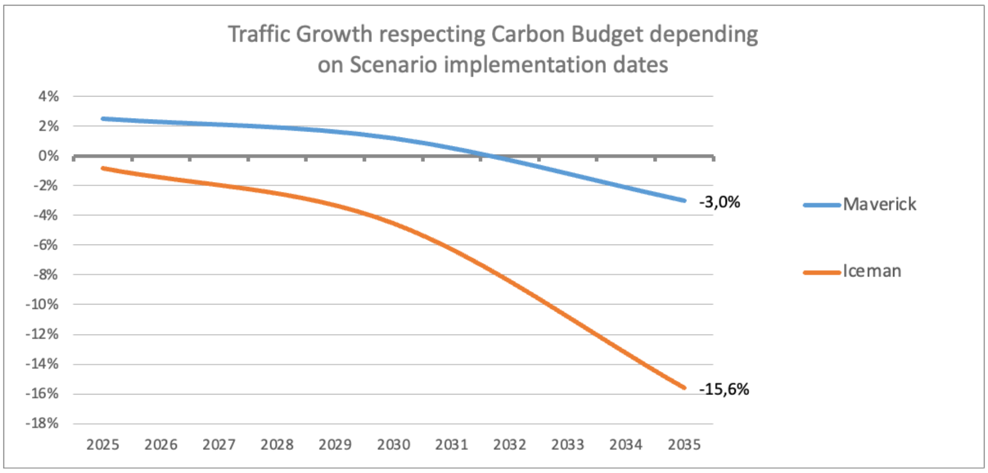

Figure 63 - Evolution of traffic growth compatible with the carbon budget according to the year in which the trajectory drops from the trend

Figure 63 shows the evolution of the sobriety effort to be made concerning the trend trajectory to remain within the carbon budget, according to the year in which the trajectory drops off the trend, spontaneously or because an international consensus is established on the moderation of traffic growth. Whatever the industrial scenario, any delay in the implementation of a reduced traffic results in an even greater reduction. For example, the Maverick scenario allows positive growth of 2.52% from 2025 only if an international consensus on this value is established by then. If international air transport takes another 10 years to agree on the need to moderate traffic, the latter will then have to decrease by 3% per year from 2035, at the same time as the hydrogen aircraft will enter into service. In the Iceman scenario, more likely bare in mind, the cost of not controlling short-term emissions is potentially devastating (-15.6% per year from 2035 if yearly growth of 4% resumes between 2025 and 2035).

Thus we find ourselves in a situation where we have to make both tactical choices enabling us to control short-term emissions and stay within the carbon budget, and strategic choices making it possible to sustain the post-2050 level of emissions from the aviation sector. With a constant carbon budget, the longer we delay, the greater the consequences will be on traffic, and therefore on the health of the aviation sector.

9 Thoughts on the future of employment in the aviation sector

9.1 Introduction

As with all energy-intensive sectors, decarbonising air transport is a crucial issue for its long-term survival in a low-carbon world. Even if the technological outlook bodes well for significant progress in the coming decades, it is reasonable to consider that we cannot avoid the sobriety of usage if we want to respect our carbon budget (see conclusions of technical scenarios 8.3 and 7.2.4). **This being said, what employment outlook can we imagine in a sector that is doubly threatened, in the short term by the health crisis, in the long term by environmental pressure?**

While the objective of this report is first and foremost to quantitatively assess the possibilities for aviation to reduce its emissions as well as to quantify the underlying externalities (in particular regarding the future availability and allocation of low-carbon energy), it seems essential to provide some forward looking information on the socio-economic risks weighing on the sector. Pointing out its strengths and weaknesses, including an in-depth analysis (which we do not attempt to conduct here), would lay the foundations for a diversification strategy.

We stress the importance of a holistic view of the potential diversification of the sector aimed at increasing its resilience in a more unstable future. In this approach, individual skills are only part of the equation. Any diversification or reclassification strategy that focuses solely on professions would miss out on much of the long-standing economic and industrial value built up over a long period of time by the sector, which is rich in many aspects:

1. **Human capital,** of course, that is to say all the individual skills and know-how whose level of expertise and excellence is no longer to be demonstrated.
2. **Collective human capital**, i.e. all social structures, from teams to corporate culture, including trade unions, forms the socio-economical link of the sector, driven by more than a century-long narrative of exploration and technological innovation.
3. **Knowledge structures**, which include all higher education and research institutions.
4. **Production and distribution infrastructures** (including airports), optimized over the decades to achieve the current level of excellence and efficiency.
5. **Operational efficiency**, i.e. all processes and methods anchored in the company's DNA which over the years have enabled it to optimize its operations processes. Airbus, for example, excels in the implementation of large industrial projects in a complex network of public-private interactions regulated by the administration (Airworthiness Authorities). It is also about the efficiency and maturity of the organization (processes formalization, forward improvement mindset, training of operators, quality processes).
6. **Territorial network**, i.e. the capacity of an industry to integrate itself in a coordinated way into local economies while pursuing a national or supranational strategy. Resilience

through territorial anchoring is also facilitated by all the partnerships already established with other companies, via the subcontracting and collaboration network and the bonds of mutual trust that have been forged there. All this is precious and long to build!

7. **Financial capital**, i.e. the actors ability to resist crises and raise funds.
8. **Commercial capital**, i.e. the image conveyed by the brand, but also the entire customer base.
9. **Non-human knowledge**, typically data, of both production and consumption, which holds an enormous knowledge potential about industrial optimisation sources and consumer uses.

9.2 World Scenarios

How does the requirement to respect the carbon budget affect long-term employment in the sector? To answer this question, we have chosen to consider only the scenarios on a global scale [341] and are exploring different ways of meeting the carbon budget that we have set for ourselves by 2050.

N.B. All the scenarios that we consider in this section are built in such a way as to **respect the carbon budget**. The emission reduction effort that cannot be supported by the technique is implemented via a **traffic moderation policy**. The levers for such a sobriety policy have been described in sections 7.3 and 7.4. We are interested here in its **effects on employment**.

Our analysis is based on two classes of scenarios:

1. **Industrial scenarios**, which essentially drive variations into the following factors:

a. Compliance with the deadlines of the aircraft roadmap vs. 5-year delay.
b. Fleet renewal rate: 15 years vs. 25 years.
c. Availability rate of alternative fuels for aviation: 100% vs. 50%.

2. The **traffic growth scenarios**. Here we make the double assumption that traffic will resume in 2024 to its 2019 level and that an international consensus will be established to moderate its growth in proportions that are compatible with respecting the carbon budget. The variable whose impact we are studying here is the date when this consensus is reached (2025, 2030 or even 2035).

Two of the three industrial scenarios presented here, Maverick and Iceman, have already been described in 7.2.3. We merely recall their characteristics here. However, we add an intermediate scenario called Charlie, in order to better assess the impact of the fleet renewal rate on long-term employment.

Table 16 - Reminder of the assumptions of the MAVERICK, CHARLIE and ICEMAN scenarios

	Maverick	**Iceman**	**Charlie**

Aircraft roadmap	No delay	Delayed by 5 years	Delayed by 5 years
Renewal rate	15 years	25 years	15 years
Availability of alternative fuels for aviation	100%	50%	50%

	Reasonable hypothesis
	Optimistic hypothesis
	Very optimistic hypothesis

341 The industry is in fact essentially driven by international demand. As for transport, insofar as international flights account for about four-fifths of the emissions considered within the French scope of this report, it does not seem wrong to us at first glance to size the jobs in companies and airports according to the global dynamics of changes in traffic.

The likelihood of realization of each industrial scenario depends on the degree of optimism of each assumption that composes it:

- An aircraft roadmap held 15 years after its announcement is an optimistic hypothesis, as delays are unfortunately frequent in development programmes. To name just a few recent examples: 18 months delay for the A380 [342], 2 years delay for the A350 [343], 2.5 years delay for the first flight of the 787 and 3.5 years for its commissioning [344]. This parameter is particularly structuring, because any delay in the implementation of a decarbonisation policy, within a constrained carbon budget, increases the annual effort required to reduce emissions [345].
- A 15-year renewal of the fleet is a very optimistic hypothesis. In the current context of the health crisis, the industry is slowing down and companies are being bled dry. Renewal is not on the agenda. In a "normal" situation, the current maximum production rate (approximately 1,600 aircraft per year [346]) is not enough to renew the world fleet in a context of growth. And in a context of slower growth, we can only doubt the natural propensity of companies to renew their fleets without any regulatory constraints. Moreover, the risks of bankruptcy weighing on the companies increase the probability, in

the coming years, of introducing significant volumes of aircrafts on the second-hand market.

- Finally, the availability of 100% of alternative fuels for aviation is an extremely strong hypothesis, because it assumes that other means of transport (especially road and sea) will be considered a lesser priority for their own decarbonisation.

For each industrial scenario we adjust, from 2025, 2030 or 2035, depending on the year in which a consensus on the need to moderate traffic is established, the annual growth rate in order to reach the carbon budget. We deduct thereof a traffic forecast for 2050 compared to 2019, which, considering as a first approach that the number of jobs is, at equal productivity, proportional to the traffic, gives us a good approximation of the number of future jobs in air transport.

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342 https://www.google.com/amp/s/www.europe1.fr/politique/Airbus-a-livre-son-premier-A380-avec-18-mois-de-retard-235354.amp

343 https://fr.wikipedia.org/wiki/Airbus_A350_XWB

344 https://www.lejdd.fr/Economie/Boeing-en-retard-sur-le-787-102193-3095234

345 To meet the carbon budget we have set for ourselves, we must reduce our emissions by 3.39% starting from now and each year. If we delay the start of decarbonisation by 5 years, then the reduction effort will be 4.15% per year, and 5.4% per year if we wait 10 more years.

346 https://fr.wikipedia.org/wiki/Concurrence_entre_Airbus_et_Boeing

For the jobs within the industry, we size them on the basis of a heuristic drawn from the observation of the reduction in jobs during the health crisis. In 2020, aircraft production fell by 40% and anticipates a similar drop for 2021. As a result, the Airbus group has announced that it wants to lay off just over 10% of its workforce. On the subcontractors' side, this figure could increase. Marwan Lahoud, Chairman of the Executive Board of ACE Management, declared: "Given the social plans that have already been announced and given the situation the industry is facing, an estimate [of job losses] between 15 and 20% seems to me reflecting what lies ahead." [347] As a first approximation, we will therefore retain that a 40% drop in production leads to a reduction in jobs of around 15% at least.

This heuristic is undoubtedly optimistic (in terms of the number of jobs) in the long term, for two reasons:

1. Short-term job cuts reflect the expectation of a quick recovery. Therefore, industry players prefer to maintain their technological and manufacturing skills, even if it means paying employees to produce less. The prospect of a long-term recession would certainly have a bigger impact on jobs.

2. The impact on employment intensity of a competitiveness policy, such as the French State intends to promote through the support plan, cannot be predicted [348].

In 2019, we consider that the global industry was capable of producing around 1,600 aircraft per year. This figure is obtained by summing the annual production of Airbus in 2019 and that of Boeing in 2018, so that we neutralize the negative side effects of the 737 MAX crisis. Finally, we consider the world fleet to date to be 23,000 aircraft [349].

9.2.1 Maverick scenario family

Table 17 - MAVERICK scenarios allowing to stay within the carbon budget according to the date of the dropout of the trend.

MAVERICK Scenarios				
Global fleet renewal period	Annual growth after + 4% trend drop		Projected traffic in 2050 compared to 2019	Aircraft production in 2050 compared to 2019
	Growth rate	From		
15	2,5%	2025	191%	176%
15	1,2%	2030	156%	144%
15	-3,0%	2035	91%	84%

347 https://www.usinenouvelle.com/article/notre-role-est-de-stimuler-la-consolidation-de-l-aeronautique-les-confidences-de-marwan-lahoud-president-du-directoire-d-ace-management.N1007239

348 The employment intensity could thus decrease by optimization of industrial processes or by relocating part of the value chain. But it could also increase as a result of reduced production in the long run resulting in higher marginal costs (the opposite effect of economies of scale). The Shift Project argues that in all cases the risks to jobs must be anticipated by state policy. In its Plan for the Transformation of the French Economy, The Shift Project thus raises the question of what must be implemented in terms of state planning to ensure the smallest possible job losses and easier retraining.

349 Airbus Global Market Forecast 2019-2038

In an extremely optimistic hypothesis where low-carbon energy is massively available for aviation and where technical progress allows rapid decarbonisation, traffic growth of 2.52% per year is theoretically possible from 2025. This figure however remains below the sector's trend path; even in the most favorable scenarios, the carbon budget will therefore not be met without moderation in growth. Moreover, the later this moderation (the implementation of which requires strong international cooperation), the lower the prospects for positive long-term growth. Thus, if no international agreement is found in 2025 to contain the traffic growth and if the latter resumes after 2024 (the most optimistic Eurocontrol scenario [350] today) at a rate of 4% per year, then we will be constrained, so as to meet the budget, to a growth of only 1.2% per year from 2030 and -3% per year in 2035 if the traffic moderation does not take effect until these respective dates. Organizing as soon as possible a “controlled” traffic growth therefore allows the sector to create more jobs in the long run (cf. the last two columns of the table above), even if it is at the cost of a slower recovery.

9.2.2 Iceman scenario family

Table 18 – ICEMAN scenarios allowing to stay within the carbon budget according to the date of the dropout of the trend.

ICEMAN Scenarios				
Global fleet renewal period	Annual growth after trend drops		Projected traffic in 2050 compared to 2019	Aircraft production in 2050 compared to 2019
	Annual growth	From		
25	-0,80%	2025	81%	45%
25	-4,52%	2030	46%	25%

350 https://www.eurocontrol.int/sites/default/files/2020-11/eurocontrol-five-year-forecast-europe-2020-2024.pdf

The Iceman scenario, which is much more realistic than the previous one, unfortunately leaves no hope for traffic to grow while respecting the carbon budget. Traffic growth in the Iceman scenario is at best -0.8% per year, which in 2050 will lead to a 19% drop in activity in transport and around 55% in the industry, which means at least a 20% job drop according to the heuristic set out above, based on the current consequences of the health crisis. The outlook is obviously even more pessimistic if traffic does not fall off the +4% trend until 2030.

In any case, the industry is in these scenarios largely underutilized by 2050 (at least 55% of current production capacity is no longer in use). If we do not mobilize it to produce something else other than planes, the penalty would be twofold: in addition to the jobs destruction, the risk of an industrial decline that will be very painful for France, in particular for the Greater West region (surrounding the city of Toulouse) would be added.

9.2.3 Charlie scenario family

Table 19 – CHARLIE scenarios allowing to stay within the carbon budget according to the date of the dropout of the trend.

CHARLIE Scenarios				
Global fleet renewal period	Annual growth after trend drops		Projected traffic in 2050 compared to 2019	Aircraft production in 2050 compared to 2019
	Annual growth	From		
15	0,07%	2025	102%	94%
15	-3,04%	2030	64%	59%

A possible option to limit the decline in employment in the industry would be to accelerate the pace of fleet renewal, from 25 years to 15 years, compared to the Iceman scenario. Note that while this possibility tempers the long-term effects on employment, it does not really allow a return to growth. In such a perspective, how will the airlines be able to ensure a forced renewal without growth, while those who will emerge from the health crisis will have to face a disastrous financial situation? An a priorii impossible mission without the support of states or without an in-depth review of the air transport's business model [351].

9.2.4 To sum up

A quick exit from COVID (i.e. a return in 2024 to 2019 levels) does not allow growth to return to the levels expected by the sector, and only the Maverick scenario allows for significant positive growth.

351 In particular the number of airlines authorized per territory.

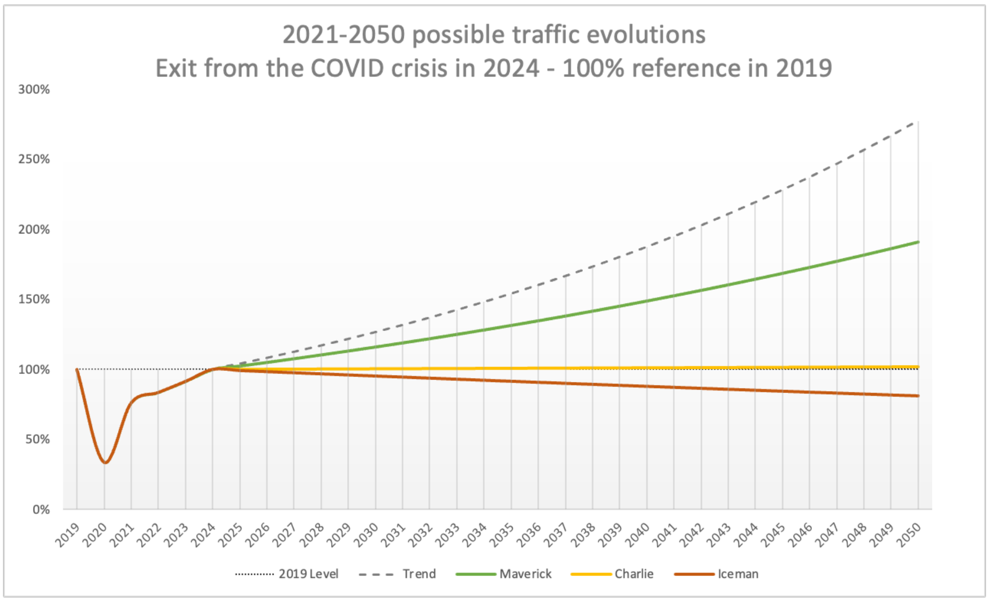

Figure 64 - Possible traffic trends by scenario, subject to recovery in 2024 and traffic moderation from 2025

Moderating traffic today allows to save up the carbon budget while the sector is not yet carbon-free, and therefore preserves the potential of the sector's growth by 2050.

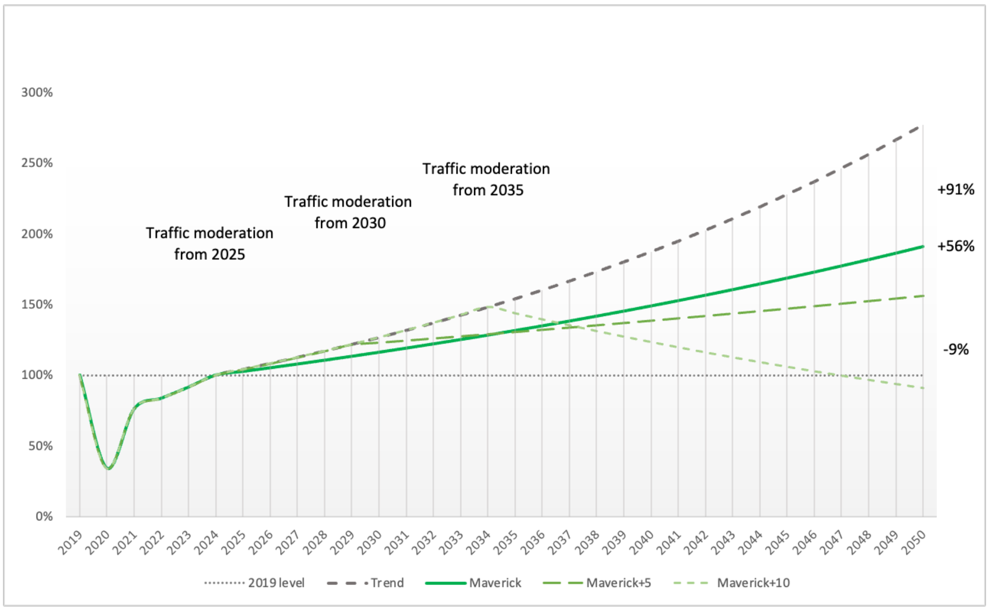

Figure 65 - MAVERICK scenarios - Effect on 2050 traffic of effective moderation in 2025, 2030 or 2035

The Iceman scenario, obviously far from being desirable, nevertheless remains the most likely possibility in our analysis framework.

The job loss in the aviation sector seems unfortunately very difficult to avoid in the long run if we wish to remain within the envelope of the carbon budget allocated to aviation.

It therefore seems capital to us to anticipate its consequences at best.

9.3 What future(s) for air transport in France?

9.3.1 Socio-economical situation of the sector

In 2019, the air transport sector in France accounted for 85,000 jobs, 70% of which in passenger transport [352]. Air France alone employed 41,000 people.

This is a sector whose profitability has been severely undermined over the past decade. In addition to the financial crisis of 2009, the sector suffered from the boom of low-cost and the development of the high-speed rail offer (which also includes a low-cost offer with Ouigo). Around 42% of French air passengers travel on French airlines today, compared to 63% 20 years ago. In eight years, France has gone from 5th to 8th in the world in terms of revenue per passenger-kilometer (RPK) [353]. The General Managing Direction of Civil Aviation (DGAC) predicted, at the start of 2020, an increase in passenger traffic of only 2% in the year, compared to an increase of 4% in the previous year, at 179 million passengers, despite the bankruptcies of Aigle Azur and XL Airways. This prediction envisioned the weakest growth over the last ten years [354].

Between 2012 and 2017, the air transport sector in France lost 7% of its jobs, while over the same period, passenger traffic at French airports (mainland and overseas departments and territories) increased by 20% [355]. Between 2010 and 2018, the Air-France KLM group lost 18% of its payroll. Air France has experienced various restructuring plans over the past fifteen years (notably Transform 2015 and Perform 2020), which have ultimately led to a stabilization of the workforce over the past 5 years.

As far as the age of workers is concerned, nearly one in three employees in the branch (32%) is over 50, a statistic in line with the national average [356]. The average age for employees in the branch is 44.3 years old. Finally, in 2019, 1,500 yearly retirements were anticipated over the next 5 years [357].

9.3.2 Employment outlook

The health crisis obviously worsens the difficulties that the air industry is facing. Air France has thus announced in July 2020 that it intends to cut 16% of its workforce by 2022, half of these positions corresponding to departures not being replaced. This difficult decision would reduce the number of jobs in 2022 to 84% of the 2019 level, which consistently aligns with a forecast of traffic recovery by 2024.

Beyond 2022, the employment trajectory will depend on the sobriety scenario that we choose to implement, provided we collectively organize ourselves for that. Let's make this assumption for a moment. We would then only have a few years ahead of us to save employment in the long term, otherwise more job cuts will be inevitable towards 2050.

Finally, what will happen if the health crisis recovery takes longer than expected? Today's most pessimistic Eurocontrol[358] scenario envisions a return to 2019 levels only in 2029.

[358] https://www.eurocontrol.int/sites/default/files/2020-11/eurocontrol-five-year-forecast-europe-2020-2024.pdf

Will it then be necessary to rely on additional public aid? The French Government has already granted Air France with 7 billion Euros to overcome the crisis and there's no guarantee it will do it again in the future. The Norwegian Government has recently refused to provide further assistance to the airline company Norwegian that is facing difficulties [359]. Within a context of growing ecological pressure, this decision could inspire others.

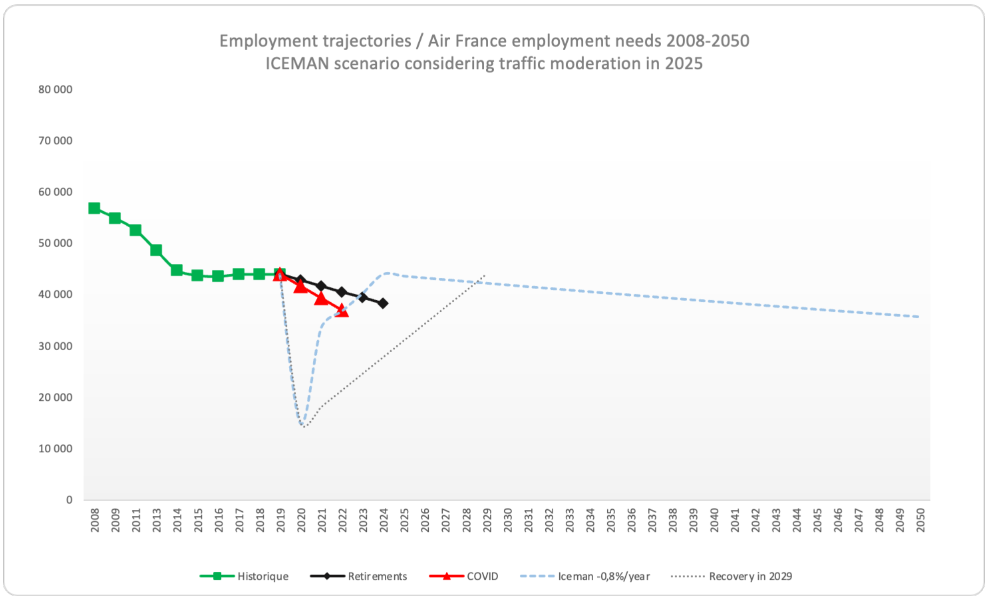

Figure 66 – Air France past and future employment trajectories

In summary:

- If traffic resumes in 2024 (optimistic scenario), we can hope that there won't be additional layoffs in the short term, other than those already announced. However, the problem of long-term employment remains and its preservation depends on traffic moderation that must be organized as quickly as possible, for example through an international agreement.
- If the traffic resumes in 2029, the problem then is the short-term management with a significant need for cash flow to ensure the industry's survival and commit as the earliest a concrete decarbonisation policy.

9.3.3 Geography, age and competences

58% of industry jobs are located in the Paris area, and this proportion rises to 70% if we include the Picardy region. This manpower concentration is particularly important for ground staff, three quarters of whom reside in the Hauts-de-France and Île-de-France regions, because of their proximity to the Paris area airports. Any reclassification or retraining effort will therefore have to be carried out in these regions as a priority.

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[359] https://www.latribune.fr/depeches/reuters/KBN27P0ZO/nouveau-coup-dur-pour-norwegian-air-qui-ne-recevra-plus-de-soutien-d-oslo.html

In France, almost one in three (32%) employees in the branch is over 50 years old. This is less true for women, and consequently in the cabin crew jobs and customer relations roles, the most feminized activity categories. To the contrary, the flight crew category has nearly one in two employees aged 50 or over, and two-thirds are aged over 45. The pyramid of jobs for employees over 59 years old helps identify the most affected people by the upcoming retirements: managers in the organization or A&F controlling managers, technical and commercial flight officers in civil aviation, as well as commercial and administration managers in passenger transportation and in tourism. These professions represent a third of employees over 59 years old. According to the FNAM [360], these positions being mostly management functions, and the related replacements could be ensured through internal mobility, thus limiting the need to attract external applicants to this sector undergoing reconversion. Questions will nevertheless arise about skills balance and proper transmission, if the workforce must be reduced over time and within the context of a potentially widespread health crisis. Possible departure, under short to medium term, of a large number of experienced employees (because of their age) would then weigh a risk of expertise impoverishment upon the industry, making long-term business continuity all the more difficult.

40% of workers have a job in which the transfer to other sectors of activity poses little problems: Sales and After-Sales, Support and Administration, Industrial Logistics, IS, HR, Finance and Accounting, Quality, Hygiene, Safety and Health.

On the contrary, 60% of the workforce initially has a job directly related to air transportation: Flight attendants, maintenance agents, ground crew, ground handling agents, traffic management, freight transport. Are these jobs limited to the aviation industry? If it is clear that there is nothing obvious about flight crews reconversion to another sector, they nonetheless represent only 7% of the workforce. The most represented job category is that of cabin crews which accounts for 22% of jobs in the sector. The cabin crew members fulfil a mission of safety and first aid on the one hand, and of customer relations on the other. If air transport logically represents the main employer in France for specific jobs such as flight attendants, to what extent could those work in another sector? The staff's habit of always working in different teams, with very erratic working hours and many trips away from their home are, in addition to life-support skills, indisputable assets for the tourism industry (local and low carbon of course!), personal assistance or other modes of transport for example [361].

9.3.4 Can the train save the plane?

Reclassifying air transport jobs into the railway industry, which is often seen as a natural solution to this matter, should be approached with caution.

Like the entire transport sector, the development of railways is conditioned by public financing of infrastructure. However, the investment that had allowed the rise of the train during the first half of the 20th century then dried up in favour of the private car. The recent refocusing of infrastructure programming on the conventional rail network, enacted in the 2019 French Mobility Orientation Law, will only enable the compensation for the accumulated delay - and not before many years.

[360] National Federation for the Merchent Aviation

[361] Although there is no guarantee that personnel leaving the airline industry for another sector will be ready to pursue this "agreed effort" of irregular working hours.

The number of SNCF[362] agents has thus decreased from 514,000 in 1938 to 142,000 [363] today. The long disinterest of the government for this transportation mode is not the only reason for this drop. For example, we know how to build infrastructures today that require less maintenance effort than in the past. Mechanization of labour has reduced the need for employment in the sector compared to the beginning of the century. The rise of the digital era has greatly weakened sales in shops and stations. Finally, a portion of the workforce is now employed in subsidiaries that do not operate on the railway in the French market [364]. At the same time, the offer is polarized towards long-distance mobility, with the development of high-speed train lines matching profitability requirements. Therefore, the transfer of jobs to the railway industry is, if anything, linked to the political choice to invest again in train [365].

Moreover, the technical or operating jobs of air and rail transport present significant differences. Flight crew members are not train drivers and it's not obvious they want to become one, due to the attachment they have to planes, but also due to questions of age or salary. Although the Swiss air transport unions have mentioned the possibility of encouraging pilots' reconversion to the railway industry (facing lack of candidates), this proposal did not bring the enthusiasm of the professional organizations at Air France [366]. Aircrafts and trains don't have much in common when it comes to maintenance. Runway agents, refuelers, luggage handlers, terminal or aircraft operators will not become overnight manoeuvre agents, network maintenance agents or switchmen without support or training, therefore without political will. And no need to mention that the job of an air traffic controller is very far from those of a rail traffic operator or regulator.

Finally, the possibility of transferring airfreight jobs (charterer, forklift operator, freight forwarder, customs agent, warehouse keeper, logistics manager, etc.) towards rail freight will, again, above all depend on governmental willingness to reinvest in this sector on a long-term basis, France lagging far behind the European average. Article 178 of the French Mobility Orientation Law required the government to build a freight plan for the end of 2020. To achieve this, the 4F Alliance (Fret Ferroviaire Français du Futur – French Rail Freight of the Future) was officially launched on June 8, 2020. The current plan presented by 4F on June 25, which amounts to 15 billion Euros of investments over 10 years, aims for a target of 18% market share for rail freight in 2030. This figure should be compared with the European average, which should reach 30% in 2030.

9.3.5 Assets' valuation

Beyond job reconversion, we defend the idea that the potential value of "non-human" assets in air transport must be questioned... in a context other than air transport. It is a topic as fascinating as it is complex, which deserves a full study and which goes well beyond the scope of this report. We do, however, offer two ideas that could be developed in further work: the reuse of transport data and the valuation of airport infrastructures.

Airline companies, whose current business model is based on extremely small margins, have developed automated learning and artificial intelligence techniques to optimize their operations [367].

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[362] "Société Nationale de Chemins de Fer », French National Railway Corporation

[363] https://www.liberation.fr/france/2019/10/23/sncf-les-effectifs-fondent-le-volume-de-transport-explose_1759047

[364] The only subsidiaries that operate trains are Thalys and Eurostar.

[365] This is actually one of the strong orientations of the French Economy Transformation Plan which aims to holistically articulate all levers for economy decarbonisation – including the

increased use of the train for long-distance mobility, among others – and therefore also the levers of transformation and job transfer.

[366] https://www.lepoint.fr/economie/des-pilotes-suisses-bientot-aux-commandes-de-trains-15-11-2020-2401119_28.php

These techniques require access to a large amount of data, such as those accumulated over time by major airline companies through their customer loyalty programs. This type of information is, for example, used to create highly customised offers [368]. If Big Data is now a strategic stake for value-sharing in the air transport, to what extent could this data be used in the future in a low-carbon activity? Could an airline company use its data to transform itself into the development of a local tourism offer, the launch of which could be facilitated by the priority usage of loyalty credits?

Airport infrastructures are another asset of the industry. They concentrate within a small territory, employment and activity rich areas. What will these areas become in a context of potential traffic decline? Today, some 200 airports are on the verge of bankruptcy simply because of the sanitary crisis [369]. The topic requires careful attention, especially considering that there are very few successful examples of airport reconversions [370]. From a topographical point of view, airports are open, flat lands, often close to metropolitan areas and served by a substantial road and public transport network, while being at a sufficient safety distance from homes. In addition, there are substantial logistical infrastructures. Would such a site be suitable for the settlement of new industries?

9.4 What future(s) for the aviation industry?

The French aviation industry was doing well until the health crisis. Since 1990, even though the French industry as a whole has lost 1.5 million jobs, the aviation industry created some. Globally, over the same period, the number of aircrafts produced each year has been multiplied by four. As far as manufacturing jobs are concerned, the aviation industry in France weighs as much as the automotive or the machinery and equipment manufacturing or twice as much as electrical equipment. The decline of the aviation industry would therefore accelerate the collapse of manufacturing capacity in France.

9.4.1 The aviation industry in the French economical landscape

The aeronautic sector represents nearly 200,000 direct jobs [371], including 160,000 in the great South-West area and 110,000 in the Occitanie region. It is a network made up of 376 companies including 176 small and medium-sized entreprises [372], mainly located in the South-West. The industry workforce is highly qualified, enforcing the highest quality standards, with numerous French engineers capable of innovation and significant economic value creation.

Airbus, with its 3 divisions (Commercial Aircraft, Defence & Space and Helicopters) employs 130,000 people, including 50,000 in France. Airbus Commercial Aircraft achieved 55 billion Euros turnover in 2019 [373] and delivered 863 aircrafts. Airbus's order book weighs 412 billion Euros. We can compare these figures to French exports in 2019, summing up to 508 billion Euros in goods and 251 billion Euros in services, representing a final trade deficit of -59 billion Euros, while aeronautics ended with a positive balance of 31 billion Euros [374].

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[367] See for example: Optimizing and Digitizing Operations with Artificial Intelligence, BCG Gamma,

https://www.bcg.com/industries/travel-tourism/airline-industry/optimizing-digitizing-airline-operations.

[368] https://www.latribune.fr/opinions/tribunes/les-compagnies-aeriennes-face-au-defi-du-big-data-587149.html

[369] https://www.lesechos.fr/industrie-services/tourisme-transport/deux-cents-aeroports-europeens-au-bord-de-la-faillite-1265698#xtor=CS1-3046

[370] Berlin-Tempelhof Airport is an example that has the particularity of being in the city centre: https://www.berlin.fr/aeroport-berlin-tempelhof

[371] https://ecomnews.fr/article/Aeronautique-15-000-postes-pourvoir-2019

[372] https://www.airemploi.org/sectors/industrie-aeronautique

[373] https://www.airbus.com/investors/financial-results-and-annual-reports.html

Airbus, France's leading principal, accounts for around a quarter of all jobs in the sector. The other major employers are Dassault Aviation, Thales and Safran. The rest of the sector is made up of a network of smaller (and often mono-sector) firms. Airbus shares the global commercial aviation market equally with Boeing (pending a rise of the Chinese manufacturer COMAC) in a duopolistic structure that has led over the years to a "mimetic conservatism", where everyone expects the other to make the first move towards innovation [375].

To date, the industry is globally sized according to the fleet growth perspectives, around 4% per year before the COVID crisis, which would have increased the global fleet from 23,000 aircrafts to 35,000 aircrafts over 10 years [376]. In 2019, the Airbus Global Market Forecast [377] predicted a production of more than 39,000 aircrafts over the 2019-2038 timeframe. In these prospective visions, the future production is only allocated for one third to fleet renewal, while the other two thirds are to support traffic growth. Questioning the growth hypothesis will consequently force the industry to lower its mass salary basis.

9.4.2 Squaring the fleet renewal circle

The global fleet now represents around 23,000 commercial aircraft with a worldwide production capacity (Airbus and Boeing combined) of around 1,600 units per year. As mentioned above, the vast majority of new aircrafts produced are to support the fleet growth (this being driven by traffic growth) rather than its renewal, the latter being one of the main levers for the sector to accelerate its decarbonisation by technological progress.

However, the COVID crisis might open up to a long period of industrial production slow-down. During part of 2020, Airbus has operated at less than 50% of its production capacity, while Boeing just got a new flying authorization for its 737 MAX. In terms of Asian competition, the Japanese company Mitsubishi recently announced the suspension of its SpaceJet program [378], and China's COMAC has to date only produced one type of aircraft out of the three in its production line, of which only around thirty units were delivered, exclusively to national companies [379].

This industry pause is by no means good news in the short term, as it translates into job cuts as well as a postponement of the decarbonisation process initiated by the deployment into the fleet of the most efficient aircraft series. In the longer term, all of our 2050 scenarios consider traffic reduction, and consequently fleet size reduction. To preserve employment in the industry, it would be necessary to act on the aircrafts' renewal rate. In two out of three scenarios, we make the assumption that the renewal rate will be increased to 15 years instead of 25 years today. This is obviously only possible if companies have sufficient cash flows, and these conditions are right now far from being met.

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[374] https://www.vie-publique.fr/en-bref/273282-le-commerce-exterieur-de-la-france-sameliore-en-2019

[375] It is thus quite remarkable that Airbus announced in the midst of a health crisis a hydrogen-powered aircraft program, a courageous decision that deserves to be saluted and which would perhaps make the American manufacturer react.

[376] https://www.rolandberger.com/en/Point-of-View/COVID-19-How-we-will-need-to-rethink-the-aerospace-industry.html

[377] https://www.airbus.com/aircraft/market/global-market-forecast.html

[378] https://www.lemonde.fr/economie/article/2020/10/28/mistubishi-suspend-son-projet-d-avion-de-ligne-spacejet_6057644_3234.html

[379] https://www.journal-aviation.com/actualites/44729-l-arj21-va-pouvoir-voler-pour-les-trois-grandes-compagnies-chinoises

IATA predicts that, in 2021, aircraft carriers will continue to experience an overall loss of 5 to 6 billion US Dollars per month and expects many company bankruptcies [380]. Should this assumption hold, the size of the world fleet would decrease. The surviving companies, presumably thanks to public finance, would then have to negotiate additional support to renew their aircrafts, and even more considering the second-hand market is likely to develop, boosted by bankruptcies and downsizing of certain companies. Support will be needed to encourage airlines to buy new and efficient aircrafts, rather than less recent and less expensive second-hand planes [381]. The support plan for the aeronautical industry, presented by the government last June, provides an aid of 7 billion Euros to Air France: This is the amount needed to renew only half of its A320 fleet with Neo-type aircrafts. It is therefore difficult to imagine how to prime the pump without a massive injection of cash or without a significant increase in ticket prices.

In the long term, the only possibility of maintaining a current annual rate of 1,600 aircraft would be, on the one hand to moderate the upturn in traffic in 2024, and on the other hand to renew the fleets in 10 years. A scenario that we have not detailed, and for good reason: This would multiply by 2.5 the costs of buying or renting aircrafts, and would require a complete revamp of the business model of aircraft maintenance operators. A virtually impossible mission under the current conditions.

Without an accelerated fleet renewal, we will not be able to quickly deploy less-emitting aircrafts, and the need for traffic reduction (which means a lower fleet size in the long term) will be more crucial for achieving the carbon budget. The ecological constraint forces us today to make a decisive choice for the future of the industry 30 years from now. Either we invest heavily to change the model of innovation funding and to support industrial activity, so that it fully serves the decarbonisation of the industry rather than its growth, or we engage into a long-term destructive spiral. It is an illusion to think that investing in the development of a new hydrogen aircraft, which should not materialize before 15 years, will solve this problem on its own, because only the design outlets will be mobilized during this period, not the production centres.

9.4.3 The vulnerability of a single-product mono-industry

The health crisis has revealed the vulnerabiliy of a hitherto robust industry. In just a few months, the airlines have increased postponements of aircraft deliveries and workforce reduction plans to save their cash. Airbus and Boeing have witnessed a real collapse in their activity, which made Airbus's CEO Guillaume Faury declare that the aerospace industry was going through the most serious crisis of its existence. "For the next two years, 2020-2021, we consider that production and deliveries will be 40% lower than what we initially expected. [...] We cannot dissociate ourselves from airlines' evolution", Faury said. In April 2020, the pandemic had already forced Airbus to reduce its production by 30%.

In order to get through the worst of the crisis and keep industrial know-how, a massive plan was put in place by the French State to support the French aeronautic industry. With the exception of support to the development of the hydrogen aircraft, this plan consists of on-demand support – through export credit to help companies purchase new aircrafts – and putting the rest of the production operations on standby via long-term partial unemployment and an investment fund to supplement equities to the companies facing difficulties in the subcontracting chain [382].

[380] https://www.deplacementspros.com/covid-19/de-nombreuses-compagnies-aeriennes-menacees-de-faillite-previent-liata

[381] Beyond the financial stakes, renewing at a higher frequency requires the availability of aeronautical materials (specifically metals) in sufficient quantity. This subject is not addressed in this report, but requires a full study!

[382] https://www.ladepeche.fr/2020/06/10/les-annonces-du-plan-de-soutien,8925542.php

This stand-by pursues the objective of optimally maintaining the ability to rebound very quickly, while maintaining the know-how and the industrial chain made up of small and medium-sized entreprises and mid-cap companies.

However, this support plan – although massive – is fundamentally fragile because it relies entirely on a short-term exit from the crisis. Yet, the recovery of global air traffic is not the responsibility of the European states alone, which cannot indefinitely support the sector whose growth is strongly driven by demand in Asia. A drastic drop in traffic could push companies to bankruptcy and therefore sell off their fleet, consequently competing with the new aircrafts' production for several years. Airbus is thus forced to adjust its size to the demand expected by the end of the crisis, and has therefore announced a job cut to be finalized before summer of 2021 [383]. This plan concerns 15,000 jobs worldwide (more than 10% of the workforce), including 5,000 in France of which 3,500 in Toulouse. These figures could in fact get much worse: in its worst-case scenario, the Roland Berger firm estimates that the demand for plane production by 2030 could drop to 10,000 units, down from 22,000 pre-COVID. This figure lies within our Iceman scenario family, whose worst-case scenario suggests a production drop of 60% by the year 2050, i.e. job losses of at least 20%, by extrapolating the ratios observed during the sanitary crisis.

In addition to the uncertainty associated with the resuming of air traffic and orders for new aircrafts, the European aviation industry could face a major political risk. Flying on a regular basis is a strong social marker, combined with a high climate impact, which makes it potentially explosive. Thus, the aeronautic industry could become a scapegoat in Europe if it does not fully engage in the energy transition. Already, a significant number of engineering students are worried about the future of the sector [384], which is a sign of questioning its attractiveness and a risk of losing future talents that needs to be taken seriously. If the plane-bashing dynamic were to gain momentum, the political support currently enjoyed by the industry could be put into question. This risk could even jeopardize its future if the financing of new programs were to be impacted or in the event of future crises...

We should keep in mind that the current crisis is, in principle, not an isolated phenomenon. New crises of comparable magnitude although possibly of different nature – e.g. climate, geopolitical, health, etc. even multifaceted – must be anticipated, as risk factors multiply, due to modification of ecosystems caused by global warming and loss of biodiversity in relation to human activities (cf. 4.2).

The resilience of the industry facing this risk is therefore essential. Consequently the support plan must be extended since this aspect is not considered. Today, Airbus revenues mainly come from the A320 product line, which is itself mainly related to civil aviation. Any industrial accident on this aircraft would have major economic consequences, as demonstrated by Boeing's setbacks with the 737 MAX. This aspect becomes a systemic problem when one considers the economic weight of aeronautics in the French Great-Western region, in particular in the Toulouse area. The latter, often praised as one of the world's aeronautics capitals, remains in a mono-industry situation and of extreme economic dependence upon the sector, to such an extent that local economic analysts and pundits allude to a possible "Detroit syndrome" [385].

[383] https://actu.fr/occitanie/toulouse_31555/toulouse-plan-social-chez-airbus-vers-licenciements-cascade-chez-sous-traitants_34711068.html

[384] https://www.lemonde.fr/idees/article/2020/05/29/aeronautique-la-transition-ecologique-impose-une-profonde-transformation-de-notre-industrie_6041127_3232.html?fbclid=IwAR3EYfkkn4IGX-IgADZBOvRg4F58q9DEZ_g7zlEeHYbzprNJ5sRjZ7XrORQ

[385] Vers une crise économique majeure dans Toulouse et sa région. Toulouse, le syndrome Détroit ? by local representatives of Copernic, Attac, the Université Populaire de Toulouse and Amis du Monde Diplomatique, April 22, 2020. Toulouse veut éviter le « syndrome Detroit », Matthieu Jublin, Alternatives Économiques, June 17, 2020.

Aeronautical suppliers are also not very diversified and, in the worst case, single-client dependent. By ripple effect, the entire supplier chain will be hit by a weakening of Airbus. After having invested to address the increase in production rates considered before the COVID crisis [386] in the perspective of future revenues, suppliers – especially tier 2 and 3 – as well as small and medium-sized entreprises, are today weakened. Maintenance operators are also affected, as well as engine manufacturers whose business model is partly based upon after-sales service.

9.4.4 How to manage tomorrow's risks?

Paradoxically, we show in this report that a sustained drop in traffic is positive in the long run as regards to carbon budget constraints. We are in fact facing a multidimensional complex problem, in which each risk is characterized by several themes that are deeply linked with one another:

- Timeframe,
- Geographic scale,
- Interdependent economic environments.

This report allows to make perceivable – meaning to measure, to quantify – the impact of the required energy transition onto the aeronautical industry, the latter which evolves between several scales:

- Global, because Airbus customers are spread around the globe,
- European, due to the localisation of most of the production in Europe
- Local, because the thousands of people in this industry live in well defined places.

Today, the energy transition is a must-do step for the European aeronautic industry. It is not pushed forward by global emission quotas, but through political debate both at the national and the European level. The direct risks, highlighted above, are a loss of attractiveness of the sector, and a gradual loss of political support. **Engaging even more in tackling climate issues is therefore essential for the European aviation industry**.

If our proposal n°0 (cf. §6) to include aeronautical carbon emissions into national carbon budgets was followed, there would still not be global quotas but national and multilateral choices because the distribution of carbon targets between industries within each country, or groups of countries, will be made under sovereign choices. As it is hardly conceivable that a majority of countries will allocate an increasing share of emissions to air transport, this would open up opportunities and a competitive advantage for the least emitting planes and the acceleration of fleet's renewal. As a reminder, both the ICEMAN and CHARLIE scenarios show that accelerating the renewal rate alone would enable increasing air traffic significantly (~ 10 to 15%) while almost doubling production by 2025 (see 9.2).

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[386] https://www.latribune.fr/entreprises-finance/services/transport-logistique/transport-aerien-dix-ans-au-mieux-pour-rattraper-la-courbe-de-croissance-d-avant-crise-844872.html

In the short term, this translates into accepting a long-lasting decrease in the orders, coming along with the impacts that we already observe (cf. 5.8). Once this is established, we must broaden our point of view and consider all the industrial and economic networks in which aeronautics plays a role in order to **improve the resilience of the sector and of local economies by diversifying the aviation industry.**

This would allow to secure aeronautical manufacturing, which will in any case not stop, but also to avoid the "Detroit syndrome" in several regions – of which Toulouse. The latter would only have harmful ripple effects on the local aeronautical industry: Loss of attractiveness, strikes, lower public investments, etc.

However, the current support plan provides little diversification (and at best for a limited period) and could even encourage the rise of "zombie" businesses [387]. This could consequently clamp down the investments that are necessary for the aeronautics' decarbonisation and thus erode our technological lead, whereas the priority is to make our industry more resilient considering that the aviation industry know-how is an opportunity for the European reindustrialisation.

9.4.5 Towards a new industrial adventure

Aeronautical skills are very diversified, whether in engineering or in manufacturing. The range of skills is extremely broad, like in metallurgy, mechanics, electricity, hydraulics, materials, systems, on-board electronics, aerodynamics or stress calculation. In each of these fields and know-how, Aeronautics achieves high levels of excellence and innovation capabilities, sustained by an exceptional quality control and deployed on very large production lines. It is a unique industrial tool in Europe. Given the risks mentioned above, as well as the impossibility to achieve carbon targets without moderating traffic, employment is ultimately at risk in the industry if it does not open-up to diversification. The long-term preservation of production tools, jobs and skills must be one of the primary concerns of an industrial strategy: If we anticipate today that it will be less needed tomorrow, couldn't we shift the industry and its know-how towards non-aeronautical production?

The example of Sud-Aviation

This is not a new idea. It's the same one that was acclaimed in 1960 by public authorities for saving 20,000 jobs at SEMM Sud-Aviation, the French historic manufacturer of the Caravelle. What was the context of this reconversion / diversification? At that time, France imported 100 to 150 billion Francs of equipment every year. These imports were necessary because the private industry sector was not interested in their manufacturing in France, for lack of profitability reasons. Sud-Aviation intended, with the support of the government, to play a pioneering role in manufacturing goods that were not produced in France anymore. Several options had been then studied, among them tools machineries for the automotive industry, camping trailers, seawater demineralization, isotope separation and even… a bridge over the English Channel. Eventually, at the end of the year 1960 the Managing Director announced the decision to manufacture camping trailers. With the Caravelair brand (a tribute to the Caravelle), the Saint-Nazaire plant followed the footsteps of other groups, which began diversifying earlier with the launch of Teleavia televisions and Frigeavia refrigerators.

[387] "Zombies" are companies whose economic model is not profitable and under the perfusion of public or private investment. No longer able to invest, they paralyse the economy by attracting capital that could be directed to more beneficial sectors. https://www.lesechos.fr/idees-debats/editos-analyses/les-entreprises-zombies-grandes-gagnantes-de-lepidemie-1265994

From this fascinating story four lessons can be learnt:

1. Sud-Aviation has not stopped the manufacturing of the Caravelle [388], but has saved jobs by developing its industrial tool, its employees' skills and the image of quality associated with the aeronautic industry to produce, locally and with a double requirement of durability and quality, goods that were previously imported and whose story still lives to this day [389].
2. Former aeronautical employees have remained proud of their production, synonymous with quality and technical innovation, transposing aeronautical excellence into retail products.
3. The diversification strategy did not impose itself immediately, but through trials and errors.
4. Government support played a key role.

Today, in a context of health crisis and while the preservation of long-term employment in the industry in its current form is incompatible with ecological objectives, while the European Union recovery plan intends to encourage the (re)localization of strategic industries, shouldn't we ask ourselves the question of using part of the aeronautical industrial structure to support a decarbonisation policy driven by the European Green Deal? The subject largely deserves a dedicated study, but we would like here to throw some open ideas that could lead to deeper thinking.

Encourage diversification

Although diversification has the double advantage of being able to cushion any prolonged future downturn production (whatever the reasons, climatic, energy or sanitary) and use governmental financial support as an opportunity to reposition the industry towards non-damaged and decarbonising activities, the likelihood that the sector will initiate this shift on its own is low. Large contractors are focused in the short term on maintaining skills across the entire value chain [390], and in the long term on technical decarbonisation of the aviation sector. It seems difficult for Airbus, after announcing a hydrogen aircraft for 2035 through the ZEROe program, which will require substantial funding [391] and increased international cooperation, to embark simultaneously on another industrial path. In addition, if the societal concern on climate impacts from air transport is growing in Europe, the awareness has not risen in the rest of the world. Aircraft manufacturers are therefore on the lookout for signs of recovery in the regions of the world that constitute their largest market, such as China, where traffic has already returned to pre-COVID levels [392]. Finally, in a duopolistic world (for now!), any openness to diversification could be interpreted by the market as a sign of weakness and create a transfer of business towards competition, current or future.

Ih terms of subcontracting, the chances of diversification are even slimmer. How can one imagine that SMEs, even very small businesses that, during the last decades, had major companies or higher-rank subcontractors as their sole clients, can shift overnight to other markets? While some companies will have the means to look for sources of growth or diversification by themselves, most of them remain mono-sectorial, hyper-specialized, without R&D, and suffering from a lack of competitiveness which, even before the crisis, had them at risk of relocation [393]. For an SME Managing Director, there is probably no other choice than to wait for the recovery and take advantage of the support plan to modernize itself [394].

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[388] Production of which continued until 1973.

[389] In particular through the Trigano brand, which purchased Caravelair in 1971.

[390] The skills in the sector are precious: We cannot allow ourselves to lose them. One of the objectives of the support plan presented in June by the government is precisely to secure the entire subcontracting chain in order to be able to bounce back in the best delays as soon as the health crisis has passed.

[391] Part of which would most certainly be public. See the SRIA budget: https://www.clean-aviation.eu/files/Clean_Aviation_SRIA%20_20200630.pdf

[392] https://www.lesechos.fr/industrie-services/air-defense/en-chine-le-trafic-aerien-a-retrouve-son-niveau-pre-covid-1265444

[393] https://www.usinenouvelle.com/article/sous-traitants-francais-de-l-aero-attention-danger.N690314

[394] In July 2020, the Occitanie region voted its own support plan for the aeronautics and space sector, endowed with 100 million Euros, which aims at promoting innovation and diversification of players in the sector, and announced in November 2020 the creation of the Aeronautic-Aerospace Stimulus Pass. Dedicated to SME and mid-cap companies with less than 500 employees, it will offer them, after carrying out a diagnosis that will have enabled them to identify the priority action levers, a support up to 60,000 Euros to finance "projects of diversification, consolidation, and improvement of their performances". Will this new system, which should remain in force at least until the end of the year 2021, be enough for the concerned companies to take the step of diversification? https://forumeco.fr/de-nouvelles-aid-for-the-aeronautic-sector/

Ultimately, the shareholders' voices remains. The largest shareholders of Airbus are France, Germany and Spain, which on the one hand only weigh 25% of capital, and on the other hand are aligned with the European strategy concerning the various support plans for strategic industries. All the other investors should therefore be collectively convinced about the risk of asset depreciation due to climate threat. This movement seems to be starting with certain investment funds that, as was recently the case for some major oil companies [395], plan to bring climate resolutions to shareholders' general assemblies[396].

Under these circumstances, we defend the idea that a diversification, even partial, of the sector will only be possible if public authorities encourage the conditions for a new industrial adventure, and make these conditions attractive enough for all stakeholders. What would be the criteria? What would make actors, who want to diversify, willing to be part of this new adventure?

- Diversification must be able to happen **quickly**, in order to limit as much as possible the restructuring plans due to the COVID crisis, to cushion the impact of job cuts, to avoid unemployment and/or loss of competencies and take over from the public aid as soon as possible.
- Diversification should be considered as an opportunity rather than a constraint, and the question of its **acceptability** by stakeholders is crucial:
    - At the **political** level, it must be a continuous part of current support plans and public recovery policies to come.
    - At the **societal** level, it must be seen as a response to the health crisis impact, preparing "the world after" within a process of ecological transition. In order to promote the resilience of territories, decentralisation must be a strength rather than a weakness.
    - At the **company** level, it must minimise changes in legal statuses and if possible business models for existing companies, promote (re)localisation and avoid as much as possible relocation of production sites and consequently workforce relocation.
- Finally, diversification must be **frugal**, avoiding waste of resources (raw materials, energy, human and industrial capital, public money) and being part of a decarbonisation pathway compatible with the Paris Agreement objectives.

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[395] https://follow-this.org/total-and-ca100-respond-to-climate-targets-resolution/

[396] https://www.lemonde.fr/economie/article/2020/12/13/le-fonds-activiste-tci-lance-la-chasse-au-greenwashing_6063206_3234.html

An industrial alliance for climate

How could such a diversification strategy be concretely implemented? Here, we are putting forward a proposal that stems from our previous findings and that would require an in-depth field study to cover all the implementation details. Once again, we do not pretend to offer a prospective vision for the transformation of the sector, but our intention is only to suggest an alternative industrial narrative for the sole purpose of opening the discussion.

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[393] https://www.usinenouvelle.com/article/sous-traitants-francais-de-l-aero-attention-danger.N690314

[394] The Occitanie region nevertheless voted in July 2020 its own plan to support the aeronautics and space sector, endowed with € 100 million, which aims to promote innovation and the diversification of players in the sector, and announced in November 2020 the creation of the Pass Relance Aéronautique-Aérospatial. SMEs and mid-cap companies with less than 500 employees will be offered an assistance grant (up to € 60,000 after a diagnosis to identify the priority levers for action) to finance "Projects to diversify, consolidate and improve their performance". Will this initiative, which should remain in use until the end of 2021 at a minimum, be enough for the companies concerned to take the step of diversification? https://forumeco.fr/de-nouvelles-aides-pour-la-filiere-aeronautique/

[395] https://follow-this.org/total-and-ca100-respond-to-climate-targets-resolution/

[396] https://www.lemonde.fr/economie/article/2020/12/13/le-fonds-activiste-tci-lance-la-chasse-au-greenwashing_6063206_

3234.html

Why wouldn't we then, propose to create an industrial Alliance responsible for implementing a strategy (national or supranational) for decarbonisation, and strengthening the resilience and competitiveness of the French industry? By replacing the major decision-makers, the Alliance would relieve companies wishing to join it from the burden of diversification and would allow small companies lacking R&D to benefit from remote and decentralised design offices. In addition, the Alliance would allow the pooling of underutilised industrial resources, in order to share the costs of transformation towards a more competitive industry and to quickly reconfigure the production lines in the event of contingencies. By putting aeronautical expertise at the service of the fight against climate change, the Alliance would position itself as a leading manufacturing player for the decarbonisation of France (or even better, of Europe) and would participate in the industrial (re)localisation efforts desired by the government. As a concrete implementation of the European Green Deal, the Alliance would thus respond to the dual challenge of increasing both the resilience and the competitiveness of European industry. The legal entity holding the Alliance could be an "Economic Interest Grouping", which was Airbus's structure at its very creation and which has precisely made it possible to strengthen European cooperation in the field of aviation and promote economical and technological progress in Europe[397]. This proposal coincides precisely with that of a column recently published by some of the sector's employees worried about its future[398]. It has the advantage of being able to be implemented quickly, of granting relative freedom to industry while preserving the role of the State in guaranteeing decarbonisation objectives.

The Alliance's missions could be numerous:

- Develop and conduct major equipment and service programs to decarbonise the economy and fight against climate change.
- Collect public & private funding and provide the guarantee that the funds are indeed used to serve a decarbonisation goal[399].
- Act as a major decision-maker for companies wishing to reconvert or diversify, offer a nursery-type ecosystem to young companies focused on decarbonisation.
- During times of crisis, use the skills of employees and the industrial tools at a standstill to redirect them towards sectors in demand[400].
- Conduct strategic relocation analyses, identify new products or new consumer expectations.

On the production side, there are plenty of options. For example, to what extent could the Alliance exploit the expertise and infrastructure of the aeronautics sector to contribute to the development of the hydrogen sector? Under what conditions can the production of liquid or high pressure hydrogen tanks, fuel cells, electrolysers, flow regulation and supply systems, coupling of battery systems, control and supervision systems guarantors of safety, be accessible to the aeronautical industry?

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[397] The Mission Statement of Airbus at its creation is thus explicit: "For the purpose of strengthening European cooperation in the field of aviation technology and thereby promoting economic and technological progress in Europe, to take appropriate measures for the joint development and production of an Airbus. " See Airbus History, Flight International, Reed Business Publishing, 1997.

[398] https://blogs.mediapart.fr/les-invites-de-mediapart/blog/080121/le-secteur-aeronautique-en-crise-peut-il-sauver-le-climat-

pour-un-airbus-du-climat

[399] The Alliance's industrial activity, contributing to the general decarbonisation of the economy, could be valued in injectable carbon credits in compensation systems such as CORSIA and therefore, ultimately, be part of a virtuous circle for air transport.

[400] This is the objective of the Passerelle Industrie scheme, implemented in the French Occitanie region by France Industrie, UIMM and Pôle emploi. In effect since October, it connects employees of companies experiencing downturns with companies from other sectors that have recruitment

or skills needs. https://www.franceindustrie.org/france-industrie-occitanie-lance-le-dispositif-passerelles-industries/

To what extent can the skills and logistics chains of aeronautics be used for the manufacture of wind turbines, especially off-shore? Their production requires skills in aerodynamics, structural calculations, composite materials; nothing insurmountable for industries in the sector, long accustomed to industrialisation, assembly and transport of very large components.

The idea of converting the sector towards low-carbon energy production is already underway, since Rolls Royce has just announced that it wants to create 6,000 jobs by 2030, thanks to the development of small nuclear reactors[401], including 80% that could be manufactured in the group's factories before being transferred to existing nuclear sites. The group even mentions 34,000 jobs by 2035 if the UK government makes a clear commitment to allow the construction of 16 SMRs[402]. However, this type of project seems to be better in the UK rather than in France: While France devotes a few tens of millions of euros from its recovery plan to the development of an SMR, the United Kingdom is likely to invest 2 billion pounds[403].

To what extent could the Alliance also manufacture energy-related capital goods for housing? The production of heat pumps, solar water heaters, thermodynamic tanks, geothermal elements (extraction and distribution) should not pose any particular difficulty to the aeronautical sector, which already uses hydraulic, heating and air conditioning systems in cabins, with significant thermal constraints.

Finally, to what extent could the Alliance encourage the development of a local sector for large-scale aircraft recycling, capable of enduring the pace of retiring of old aircrafts and redirecting materials to sectors other than aeronautics, and thus secure the supply to industries dependent on copper, aluminum, complex alloys, carbon composites?

Meeting these challenges requires, first of all, an adaptation of the industrial tool. By mobilising the underutilised productive resources of aeronautics (engineering, production, logistics, general resources), the Alliance should organise the modernisation of the sector, a transformation that the small players in the sector will be able to undertake all the more smoothly that will be accompanied by a "protective" structure. Adaptation of processes for more responsiveness (agility), homogenisation and harmonisation of the management of Alliance resources via a common information system as part of a digital independence strategy for Europe, adaptation of the industrial tool, manufacture of machine tools benefiting from the latest technological innovations[404] … These are large-scale projects that SMEs cannot carry out alone.

Moreover, one cannot ignore the question of which markets would the Alliance influence. Diversification or reconversion projects carried out by SMEs in the aeronautics sector, regional startup projects, production orders from other sectors less affected by the crisis (metal structures, industrial processes, household appliances, heat pumps, heating, railway industry), public orders for urban furniture, hospital equipment … There is certainly no shortage of ideas, but the Alliance will not see the daylight without the strong willingness of governments and local authorities.

[401] Small Modular Reactors (SMR)

[402] Small Modular Reactors. Small Modular Reactors see https://en.wikipedia.org/wiki/Small_modular_reactor

[403] https://www.usinenouvelle.com/article/rolls-royce-affirme-pouvoir-creer-6-000-emplois-au-royaume-uni-grace-aux-petits-

reacteurs-nucleaires.N1027454

[404] The aeronautical sector conceives and produces already its own toolware, and is experienced with diverse high-end machineries.

These will have a threefold role to play:

1. **Support for transformation.** The States could organize a general consultation, possibly coming along with public debates, with the whole sector, in order to assess the feasibility of the reconversion, to identify the actors likely to join the Alliance and to initiate a dynamic of industrial (re)construction. As a second step, the States could create a transformation finance fund and facilitate its access to Alliance member companies. At the same time, the States could offer enhanced support for airline employees who wish to retrain individually, for example by offering, as an alternative to partial unemployment, support for long-term training for employees leaving the sector.
2. **Stimulation of demand**, via a political agenda supporting strong demand in green sectors accessible to the Alliance. This support could be translated, by way of examples, by the immediate opening of numerous requests for proposal (floating or installed wind farms, development of a national network of transport and storage of hydrogen, for example) or strengthening of fiscal incentives for thermal renovation.
3. **Regulatory framework.** Finally, the State will have to promote an European approach, in compliance with Union rules, even if it means renegotiating with State members, while promoting strong regulations on the quality[405] and sustainability of the Alliance's production in order to promote the European industry.

9.5 Conclusion

This last chapter raises more questions than it brings answers, and would by itself require a full-fledged study. But, since we are dealing with the subject of sobriety in an industry as energy intensive as air transport, we could not elude the employment theme. Our position is therefore the following: for the aeronautics industry, diversifying now appears to be a reasoned policy of sustainable development, and this policy must anticipate the Governance issue, that is to say a way of opening a collective dialogue around the transformations of the industry. In the short term, the exceptional partial activity mechanisms (in France) will probably not be able to last if the traffic does not resume before 4 or 5 years. Working on a smart and large-scale reconversion of a portion of jobs in the sector is also a way of curbing the rise in unemployment, without sacrificing the aeronautics industry. On the contrary, it is about increasing its resilience and enabling it to secure its role in a low-carbon world. This position is defended by many employees in the sector and residents of the Occitanie region[406].

As part of the French decarbonization strategy, the employment outlook is guided by two tools, the National Low Carbon Strategy (SNBC) and the Pluriannual Energy Planning (PPE). Their reference scenario for the decarbonisation of France provides for a transfer of jobs from energy-intensive sectors to the sectors most likely to be decarbonised. There is no shortage of competent organisations to investigate this subject: France Stratégie, ADEME, CEREQ, the National Observatory of Jobs and Trades in the Green Economy will certainly be among the players in an in-depth reflection. a new endeavor must now begin, in partnership with the organizations involved and relying on methodological analysis instruments such as company monographs and site CVs, to support the sector on its journey towards the low-carbon world of tomorrow.

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[405] For example on the energy renovation of buildings, or on low-carbon urban transport without atmospheric pollution in Europe.

[406] As an example, we can cite the ICARE collective and the ATElier d'ECologie POLitique (ATECOPOL).

10. Going further

The subject of the sustainability of the aviation sector in a low-carbon world is extensive, and despite our intention to broadly cover the issue, there are still other areas of study and related questions that deserve further exploration. We could mention, among others:

- An examination of the economic impacts and financing assumptions for various scenarios.
- Prerequisites regarding the use of resources other than energy and fuels.
- The emissions impact of Hub & Spokes organizations as opposed to a point-to-point model.
- The increasing role of air freight and its alignment with the choices of our globalized societies.
- The possibility of carbon budgets allocated by country, contributing to the idea of a transition that is as acceptable as possible, finding the right balance between developed and developing countries, whose rates of air traffic growth differ significantly.
- ...

These various topics open up new avenues for reflection that can be the subject of further developments in this report.

11. Conclusion

Limiting our GHG emissions and adapting our societies to the consequences of climate change is a top priority. The scientific consensus, as embodied by the IPCC, defines the carbon budget as an essential metric to assess the necessary transformation efforts and our room for maneuver in achieving a specific climate objective.

Defining a sectoral carbon budget is, therefore, a political decision that precedes the development of GHG reduction pathways.

While technological innovation is vital for decarbonizing air transport, we cannot identify any robust '2°C' scenario or trajectory that would not require limiting the growth of air traffic. This limitation may be a result of voluntary steering or other factors.

Even in the most optimistic theoretical scenarios we have examined, which deliberately avoid constraints related to financial or energy externalities, significant risks to the supply of alternative fuels, or the availability of airport infrastructure, technological innovations arrive too late and ramp up too slowly in commercial fleets under pre-COVID traffic assumptions.

As a result, it becomes necessary to either expand the carbon budget or reduce air traffic. Since the overall carbon budget, encompassing all sectors, is non-negotiable, increasing the carbon budget for air transport would necessitate intersectoral negotiations and is subject to an uncertain outcome, as all sectors compete for access to low-carbon resources. This doesn't even account for a possible evaluation of aviation's significance compared to other essential services.

Therefore, the most pragmatic way forward is to incorporate a societal reflection on the essential role of aviation and the need for its increasingly sober transformation. This approach lays the groundwork for acceptable legislation and taxation, providing air transport with long-term prospects and allowing low carbon technological innovation to scale up.

The major challenge in this situation lies in financing. Massive investments to expedite the arrival and deployment of low-carbon innovations must occur concurrently with traffic containment to remain within the carbon budget, thereby reducing the income sources that previously prevailed. All of this is set against the backdrop of a health crisis that is currently absorbing public funds.

Governments acting as investment entities mean that citizens' priorities and budgetary trade-offs will determine the aviation industry's future. This is evident in the support plans for the aviation sector, where maintaining jobs, skills, and national sovereignty in aviation is considered a top priority in France and other countries.

However, the situation may evolve, and funding may prove insufficient to sustain both jobs and the carbon trajectory in a context of reduced air traffic, whether due to sustained or voluntary reductions. Therefore, it appears essential to anticipate the sector's contraction and explore all diversification avenues. The aeronautics industry can contribute to the comprehensive transformation of the sector, ensuring its long-term future, and can also offer its expertise, industrial capabilities, and pioneering spirit to advance global decarbonization of the economy.

Air transport is an integral part of the modern world. It connects people, continues to inspire and foster growth. To move beyond stereotypes and vested interests and to assess the situation as clearly as possible, taking into account the constraints of climate change, is, in our view, the best way to serve it. This is the ambition of this report.

12. A word from the President of ISAE-SUPAERO

The report was sent for pre-reading to various stakeholders in the aviation sector for comments. ISAE-SUPAERO, represented by its President Olivier Lesbre, actively participated in the exercise. We express our sincere gratitude to him and are pleased to present his contribution:

"The impact of air travel on global warming has been prominently featured in the media for several years, often relying more on simple ideas or moral convictions than on scientific analysis. In recent months, with the aeronautics crisis triggered by Covid, the debate on the ecological transition of air transport has intensified and deepened, taking a more pragmatic turn, thanks to the growing mobilization of engineers on the subject. As a leading school of aeronautical engineers, ISAE-SUPAERO welcomes this.

The essay 'Flying in 2050' is a case in point. It was written at the initiative of the SUPAERO-DECARBO collective, which, for two years, has brought together alumni and students of the Institute who are mobilizing to reduce the impact of the aeronautics sector on the climate. It draws on available scientific knowledge to make proposals on the future of the aviation sector that are compatible with the Paris climate agreements.

As the essay clearly shows, many uncertainties hang over the forecasts related to the evolution of emissions, leading the authors to make assumptions and identify choices that will be important for the future. Two of them merit particular discussion:

The first concerns the share of the 'human carbon budget' that can be devoted to aviation (or, in other words, to long-distance travel) between 2020 and 2050. This essay chooses to set it equal to aviation's share of 2019 global emissions, recognizing that this is an arbitrary choice. This is indeed a crucial choice for the conclusions of this work, and it is a politically motivated decision. However, most economists consider that this is not the most effective way to reduce overall emissions. To be as effective as possible, one should first tackle the sectors where it is easiest, such as the production of electricity, which mechanically leads to an increase in the relative share of sectors where it is more difficult, such as aviation.

The second concerns the pace of technological progress. The natural tendency is to extrapolate it from the past. However, the speed at which the first anti-Covid vaccines were developed has vividly shown that this rate accelerates sharply when the international community of competent scientists and engineers focuses on an urgent problem.

The Institute is optimistic that the same phenomenon is occurring for the decarbonization of our societies in general and of air transport in particular. It is resolutely committed to this direction, by training engineers capable of leading the ecological transition of the sector in all its complexity, by putting the subject at the heart of its research activities, and by contributing to the public debate.

In conclusion, the Institute welcomes this contribution from some of its students and alumni to a rational and structured public debate. The viewpoint expressed is well-argued, but, like all forward-looking work, it is based on assumptions, some of which are questionable and still need to be fully discussed. There is no doubt that this work will help enhance the quality of the debate on the future of air transport!

PS: The Institute has just posted an online open tool that allows everyone to simulate the impact on global warming of various hypotheses regarding the evolution of aviation. This tool should naturally be of interest to readers of this report and is available at aeromaps.isae-supaero.fr."

13. Appendices

13. 1. Appendix 1: Preconceptions about alternative fuels

13.1.1 "Biofuels compete with the food production industry and require deforestation": TRUE and FALSE (depending on the type of biofuel).

There are different types of biofuels categorized according to their manufacturing process and the raw material used. So-called first-generation biofuels are those produced from vegetable and grain oils. Therefore, they require a large agricultural area which may involve deforestation and are in direct competition with the food industry. These are the most developed and marketed today, and their percentage of use is regulated: for transport in Europe (RED II regulation), it must be less than 7% in 2020, a rate which will be reduced to 3.6% in 2030[407]. The ICAO target of a 63% CO2 reduction through the use of 100% SAF[408] is calculated based on second-generation biofuels.

So-called second-generation biofuels are derived from other raw materials, products based on cellulosic material: dedicated energy crops (the entire plant is used, so the necessary surface area is smaller), agricultural or forestry waste, municipal organic waste, or animal fats. These do not compete directly with food since the raw material is not edible and limits land use, implying a low need for deforestation. Once the areas necessary for housing, agriculture, and unusable areas have been removed, there would remain on earth by 2050, 1.41 GHa (or 10%) of arable land for non-agricultural expansion such as bioenergy[409].

Third-generation biofuels, currently exclusively at the research stage, are produced from microorganisms by photosynthesis or fermentation (yeasts and algae). At a stage of development that is still not marketable, they would make it possible to drastically reduce the agricultural land needed despite very high water consumption, thus making them subject to controversy. Their environment (temperature, light, resources) must also be controlled, which requires significant energy expenditure[410].

13.1.2 "Biofuels have a worse carbon impact than kerosene": FALSE for the most part

In order to correctly evaluate the carbon impact of a fuel, it is necessary to determine the carbon fluxes during each stage of the fuel's life cycle: from its extraction/planting to its combustion. Therefore, the carbon impact comes from the carbon emitted during other stages of its life: potentially deforestation, processing and transport.

Biofuels with a high carbon impact are those that have been produced on land resulting from deforestation and particularly the deforestation of primary forests which are the greatest carbon sinks.

[407] International Council on Clean Transportation, The European Commission's renewable energy proposal for 230, January 2017

[408] ICAO, Sustainable Aviation Fuels Guide, December 2018

[409] Sustainable Aviation Fuels Guide, ICAO, 2018

[410] The industrialization Possibility of Micro Algae Fuel in China, accessible via https://www.bio.org/sites/default/files/legacy/bioorg/docs/TUES_PLAZABC_The%20Industrialization%20Possibility%20of%20Microalgae%20Fuel%20In%20China%20-Yang.pdf Zongxin Yang

E.g.: for a biofuel derived from palm oil, while its cumulative CO2 emissions linked to cultivation, transport and industry are reduced by 66% compared to kerosene emissions (30gCO2 / MJ against 87gCO2 / MJ for kerosene[411]), taking into account the change in land use increases this number to 105.3gCO2 / MJ, i.e. 21% higher emissions compared to those of kerosene.

These effects of deforestation can be applied to all first generation biofuels and to energy crops when deforestation occurs. However, the surface area requirement is much lower for second generation biofuels.

Agricultural/forestry waste and animal fats are by-products and do not require a direct change in land use (residues emit 8 to 11gCO2/MJ over their entire life cycle, i.e. eight times less than kerosene): as a consequence , no deforestation is necessary.

Therefore, this assertion is false if the cultivation of biofuels is regulated and second generation biofuels are used.

13.1.3 "The "non-CO2" emissions of biofuels are worse than those of kerosene": WE DON'T KNOW[411-1]

During combustion, whether it be kerosene or biofuels, fuels emit more than just CO2 into the atmosphere (see 5.7.2)

A study by MIT[412] sought to quantify the impacts of "non-CO2" emissions that occur during the combustion of alternative fuels. Over a 100-year timeframe, the study shows that the climate impacts of non-CO2 products emitted during aircraft combustion are equivalent to emitting 78.1 gCO2e/MJ (for comparison: 73.2 gCO2/MJ are emitted directly).

Compared to conventional kerosene, the use of a biofuel eliminates sulphates and increases water vapor, leading to warming. At the same time, it reduces NOx and soot, resulting in cooling.

However, considering periods between 100 years and 500 years, the reduction in Nox actually leads to a slight warming effect. The study thus shows that the climate impacts of the non-CO2 products from aircraft combustion using biofuel are equivalent to emitting 85.7 gCO2e / MJ. According to the results of this study, the non-CO2 emissions from biofuels would be nearly 10% higher than those from kerosene, in grams of CO2 equivalents. However, other studies are ongoing on this subject and may bring new conclusions.

13.1.4 "Biofuels will never be available in sufficient quantity to supply the aviation sector": Probably

Given the aviation energy demand projected for 2050 in the 2019 ICAO report413, it appears that aviation would require four times more energy than what first-generation biofuels could potentially provide within existing agricultural areas. Consequently, these biofuels may not be available in sufficient quantity to meet the aviation sector's needs.

[411-1] When this report was released on March 3, 2021, the rating was 'Rather True' and was based on the text and references of this paragraph, unmodified to that date. On June 17, 2021, NASA and DLR published a study (https://www.nature.com/articles/s43247-021-00174-y) showing that low-aromatic SAFs significantly reduce the radiative forcing effect of contrails. As of today, it is therefore difficult to take a position on the overall effect of SAFs (contrails and other effects) on 'non-CO2,' which is why we changed the rating to 'We don't know.' However, this NASA-DLR study is nonetheless very promising.

[411] European Commission, Sustainability and Deployment Strategies for SAF. Communication paper (deliverable D1.1.4), Feb 2019 - Table 3

[412] Russell W. Stratton, Philip J. Wolfe, and James I. Hileman, Impact of Aviation Non-CO2 Combustion Effects on the Environmental Feasibility of Alternative Jet Fuels, 2011

[413] ICAO, ICAO global environmental trends – present and future aircraft noise and emissions, July 2019

Second-generation biofuels have the potential to meet the energy demands of the aviation industry in 2050. According to the IPCC P2 scenario (90Mha of cultivable areas), aeronautics would utilize nearly 60% of the available energy, increasing to 85% in scenario P1 (20Mha of arable land). The projected aviation energy demand for 2050 aligns with the capacity that second-generation biofuels could provide.

It's crucial to emphasize that this energy resource will not be exclusive to aviation but will be shared across the entire energy sector. Raw materials not used directly or indirectly in the food industry can serve various energy sectors, including heating, transport, or electricity. Considering the anticipated growth in air traffic and overall energy demand, there needs to be a trade-off in resource utilization. This involves distributing the resource among different modes of transport, making the use of 100% biofuel for aviation in 2050 unlikely. This underscores the importance of simultaneously developing various alternative fuels such as PtL or Hydrogen.

13.1.5 "All current airplanes can fly with 100% alternative fuels": FALSE

Whether a fuel can be used in an engine depends on the characteristics of the engine. Certain alternative fuels, called "drop-in", can be incorporated "as is" in planes, without having to make technological modifications to existing planes and airport infrastructures. This is the case for mixtures of kerosene - synthetic fuels (Power-to liquids) but also of mixtures of biofuels - kerosene.

Thus, the rate of incorporation of an alternative fuel depends on its properties. Currently, the maximum incorporation rate for drop-in fuels is 50%. The need for mixing with kerosene stems among other things from the current technology of engine seals. Certain chemical compounds must be kept in the final mixture to avoid sealing problems (aromatic compounds) that are absent from most drop-in alternative fuels.

As for hydrogen, its use requires a structural modification of current aircraft for storage issues in particular.

Therefore, current planes cannot fly with 100% alternative fuels. A modification of the aircraft / engine pairing, or of the composition of alternative fuels, is necessary to achieve this objective.

Thus, a biofuel incorporation rate of 100% could be considered by coupling pyrolyzed oils, containing many aromatics, with other alternative fuels that do not contain them. A technological improvement could also make it possible to use fuels containing less aromatic compounds, and therefore, to increase their incorporation rate.

These constraints are part of the elements structuring the aircraft roadmap proposed in 7.2.2.2

13.1.6 "If alternative fuels are not marketed, it is because they are too expensive to produce": TRUE and FALSE

Alternative fuels are indeed more expensive to produce than kerosene [414] [415] [416] [417] [418] [419]. The costs range between \$1.02/L and \$4.17/L, depending on the type of fuel, compared to the current \$0.47/L for kerosene (McKinsey[420]). These estimated costs consider raw materials, investment expenses, and necessary operating expenses.

However, a survey by IRENA of major alternative fuel investors in Europe, Brazil, China, and North America indicates that production costs are not the primary obstacle to the development of these fuels. The main hindrance is uncertain and unstable regulation[421]. Having a favorable, long-term regulatory environment would reassure investors and industry players.

Similarly, uncertainties about the price of alternative fuels should be compared with the high volatility of kerosene prices[422].

13.1.7 "The use of hydrogen is emission-free": FALSE

The use of hydrogen as an aircraft fuel only makes sense if it is produced with low carbon energy, especially renewable energy. Generating it using fossil fuels would be totally counterproductive since it decreases the overall efficiency in a chain involving fossil combustion. CO2 emissions would then be increased throughout the process.

It should also be noted that the use of renewable energy for the production of hydrogen (and synfuels) implies a very large increase in output from these sources on the planet. Flying, for example, 40% of aircraft on LH2 in 2050 would require up to 1500 GW of installed power, which is 60% of the current capacity (3 times more for synfuels capturing CO2 from the air). All of this, knowing that major network modifications would be necessary, and that the airline industry is not the only sector wishing to use this type of fuel.

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[414] J. A. Hayward, D. A. O'Connell, R. John Raison, The economics of producing sustainable aviation fuel : a regional case study in Queensland, Australia, 2015

[415] Ramboll, Sustainable Aviation Biofuel Status 2017, 2017

[416] E. C. Wormslev, J. L. Pedersen, C. Eriksen,Sustainable jet fuel for aviation - Nordic perspectives on the use of advanced sustainable jet fuel for aviation, 2016

[417] H. F. A. Elhaj, A. Lang, The worldwide production of bio-jet fuels - The current developments regarding technologies and feedstocks, and innovative new RD developments, October 2014

[418] N. Pavlenko, S. Searle, A. Christensen, The cost of supporting alternative jet fuels in the European Union, March 2019

[419] IATA 2014 Report on Alternative Fuels

[420] A. Dichter, K. Henderson, R Rediel, D. Riefer, How airlines can chart a path to zero-carbon flying, McKinsey Company, 2020

[421] D. Gielen, S. Oksanen, Advanced Aviation Biofuels : ready for take-off ?, 2019

[422] L'Union Européenne risque de subir des contraintes fortes sur les approvisionnements pétroliers d'ici à 2030, The Shift Project, 2020

[423] Clean Sky 2, Hydrogen-powered aviation, A fact-based study of hydrogen technology, economics, and climate impact by 2050, May 2020

Therefore, it is necessary for us to consider the entire production chain to assess the emission reductions induced using hydrogen. By also considering the non-CO_2 effects (notably, hydrogen releases 2.5 times more water than kerosene during its combustion but 70% less NOx), the direct combustion of H2 would reduce emissions from 50% to 75%, and the use of fuel cells would reduce emissions from 75% to 90% (due to the reduction of condensation trails linked to the management of rejected products) [424].

The emissions and externalities associated with the production of hydrogen are included in the calculations of the 'Convergent scenarios' in 7.2.3.

13.1.8 "Green production of hydrogen would allow air traffic without environmental impact": FALSE

If the use of hydrogen eliminates CO_2 emissions generated by air traffic combustion, it is still necessary to consider non-CO_2 emissions. There are many uncertainties on this subject, but they could represent 2 to 8 times the effects of CO_2. The table below summarizes the evolution of emissions compared to kerosene[425].

- The use of a fuel cell does not generate NOx (affecting the ozone layer), while the direct combustion of hydrogen significantly reduces NOx emissions compared to kerosene.
- Whether from the direct combustion of hydrogen or from the fuel cell, water vapor emissions are multiplied by a coefficient of 2.55 compared to kerosene (the capture of water vapor emissions via fuel cell technology is, however, technologically possible, but it implies weight concerns).
- Condensation trails appear at high altitudes when the air is extremely cold (-40°C) with hot exhaust gases. The effect of condensation trails, in the case of the fuel cell, is considered to be weaker since it would be possible to collect the water vapor and condense it.

Table 20 - Trends in non-CO_2 emissions for hydrogen technologies

	CO2	NOx	Water Vapor	Condensation trails
Direct combustion of hydrogen	0			

[424] Clean Sky 2, Hydrogen-powered aviation, A fact-based study of hydrogen technology, economics, and climate impact by 2050, May 2020

[425] Clean Sky 2, Hydrogen-powered aviation, A fact-based study of hydrogen technology, economics, and climate impact by 2050, May 2020

13.2 Appendix 2: Additional information on SETI, SETO, and STAR Technologies

13.2.1: Operational constraints

Operational constraint and externalities	Applies to…		
	SETI	SETO	STAR
It is necessary to keep the APU running to provide enough air to start the 2nd engine, but also as a backup generator for the primary generator. This reduces the fuel efficiency benefit, which is included in the calculations.	x	x	x
During taxiing, the engine powering the hydraulic circuit, which drives the brakes and the front wheel, must be kept running. Therefore, the pilots should	x	x	x

carefully consider which engine to keep on to ensure the necessary hydraulic systems are operational.			
Some engines require a minimum cooldown delay after landing, so the use of SETI would not be operational for them.	x		x
Once shut down, the engine cannot be started right before take-off as it needs 5 minutes before it is usable (more or less, the actual time depends on the engine type). • 1min to start a warm LEAP engine (the SETO will not apply to the first flight with a cold engine). Start-up must be made in a straight line. • 3min of engine warm-up. • 1min to do the checklist before the take-off.		x	x

Therefore, the SETO is limited to long enough taxiing which depends on the distance between the parking area and the landing runway (i.e., the size of the airport).			
In case of a heavy load (cargo, passengers, etc.), a slow down or sharp turn maneuver may be impossible (problem of differential thrust as well). Heavy cargo can also be problematic on slippery taxiways. In general, it is not easy to precisely control the trajectory (parking exit) if the surroundings are cluttered.		x	
To exit the parking area, it may be necessary to move the throttle lever past idle. Precautions should be taken to avoid excessive engine blast (risk of damage to the surroundings) and blowing debris (FOD risk).		x	

- 13.2.2: Technical risks

Risks and externalities	Applies to...		
	SETI	SETO	STAR
Risk of an undetected leak (either fuel or hydraulic) because there is no supervision at the end of the runway. This could be checked by the control tower with cameras installed at the beginning of the runway. Therefore, the SETO would not be mandatory for the first flight of the day since leaks generally occur when the engine is cold.		x	x
D&C (Delay & Cancellation) impact exists due to the risk of the plane having to drive back to the boarding gate if the 2nd engine does not start once the end of the runway is reached (very low probability though). Moreover, such a procedure can also be caused by a breakdown of the 2nd engine or of the connected systems, including generators and different transfers (APU, GNE1, GEN2) which occur during or right after the engine start-up.		x	x

Positive externality: Early wear from the brakes, caused by idle ground thrust deemed too high on recent engines with a high bypass ratio (BPR), is problematic, especially after landing, when the plane is lighter and has already heated its brakes. The SETI-SETO and STAR can solve this issue.

13.2.3: Considerations on STAR

There are already technologies developed by companies like TLD in France (with 3 production sites) that have created traction systems for short distances to move the plane away from the gate and bring it back. For about a decade, the Taxibot system has been trying to offer a towing solution for longer distances, controllable from the aircraft cockpit. This system has been tested in operations at Schiphol (AMS) and Frankfurt (FRA) and is currently in use at the New Delhi (DEL) airport.

In mainland France, where electricity is decarbonized, this system needs to be electric for significant benefits; otherwise, greenhouse gas emissions related to electricity production must be deducted from the calculation.

Lastly, air traffic controllers would also see their role modified by the addition of ground tractor traffic management, just as the ground traffic rules would be modified to maintain the necessary safety.

The STAR system costs more than a conventional pushback but allows for fuel savings. The manufacturer's promise is to balance the savings and additional costs so that there is no impact on passenger prices. It will be necessary to ensure coordination between airlines (ticket prices) and airports (fees) to ensure that this balance occurs from the passenger's perspective.

13.3 Appendix 3: Overview of the airline industry in 2020, impacts of the COVID-19 crisis.

Situations related to some companies mentioned in chapter "5.8 Overview of the airline industry in 2020, impacts of the COVID-19 crisis" are further explained below, along with associated sources.

13.3.1: Afore-mentioned airline.

Norwegian had to file for bankruptcy protection after the Norwegian government refused to help following a second request for support in November 2020[426]. The airline is now refocusing on intra-European and Scandinavian networks with a reduced fleet, but significant uncertainties persist regarding its financial sustainability. In 2020, Norwegian reduced its workforce by 8,000 people, and an additional 2,000 redundancies are expected in 2021, along with more base closures, particularly in France.

Virgin Atlantic, which transatlantic traffic represented 70% of its business, reduced its workforce by 50% (4,700 job cuts out of 10,000 staff), reduced its fleet by 20% and refocused its activities on the Heathrow airport by closing its Gatwick base. A recapitalisation plan of £1.2 billion over 18 months was deemed sufficient, at the end of 2020, to enable it to get through 2021, despite the expected decrease in operated flights[427].

IAG (parent company of British Airways) recorded a loss of 5.6 billion euros over the first nine months of 2020, with a 66% revenue drop compared to the same period in 2019. In an effort to reduce its debt, the IAG group raised 2.7 billion euros in September 2020 and laid off thousands of workers (British Airways implemented 10,000 job cuts out of a pre-crisis workforce of 42,000 between March and October)[428].

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[426]Le Monde, 20th May 2020. L'Etat chinois entre au capital de Norwegian ; Les Echos, 28th August 2020, Norwegian ne passera pas l'hiver sans une nouvelle aide financière ; Les Echos, 9th November 2020, La Norvège lâche la compagnie aérienne Norwegian ; Les Echos, 1st January 2021, Norwegian dit adieu à ses vols low cost long-courrier.

[427]Les Echos, 5th May 2020, Coronavirus : Richard Branson rogne les effectifs de Virgin Atlantic ; Virgin Atlantic, 14th July 2020, A Solvent Recapitalisation of Virgin Atlantic ; Les Echos, 15th July 2020,

Richard Branson parvient à renflouer Virgin Atlantic sans l'aide de Londres ; Les Echos, 4th September 2020, Virgin Atlantic va finalement supprimer la moitié de ses effectifs

[428]Courrier international, 29th avr. 2020, Transports. Plombée par la chute du trafic aérien, British Airways va licencier 12 000 personnes ; Les Echos, 12th October 2020, British Airways s'offre une crise de gouvernance en pleine crise sanitaire ; IAG Group, 30th October 2020, Ninemonths Results Announcement ;

Air Canada, WestJet: In Canada, national airlines have not yet received any financial state support. Negotiations have been at a standstill since November, with the Canadian government requiring from companies to provide a total refund for all flights cancelled at the start of the crisis. However, companies argue that refunding is impossible without state assistance. Air Canada, in particular, is significantly weakened (net loss of just under 3.5 billion Canadian dollars over the first 9 months of 2020, 20,000 job cuts, and 2.6 billion Canadian dollars in tickets refunds) and its future depends on this financial support[429].

Lufthansa group (Lufthansa, Austrian Airlines, Swiss and Brussels Airlines): At the beginning of 2021, Lufthansa continued to incur losses, with its CEO stating that the company was losing "1 million euros every two hours"[430]. In the first nine months of 2020, Lufthansa incurred a net loss amounting to 5.6 billion euros., with revenue reaching 11 billion euros (compared to 28 billion over the same period in 2019). The company's cash position remained strong, primarily due to the 9 billion rescue plan granted by Germany, Switzerland, Austria, and Belgium. However, losses are expected to increase in Q4, driven by a traffic downturn and exceptional charges related to redundancy plans. The company plans to gradually cut 29,000 jobs, including 9,000 in Germany. The company has reduced its offering down to 25% of its current capacity, which will also be gradually decreased. The fleet will be scaled down to 610 planes in 2025, aligning with the strategy announced by its CEO: "Lufthansa will emerge from this crisis leaner and smaller".

Air France-KLM[431]: The French and Dutch governments have committed to providing loans of 7 billion euros and 3 billion euros to Air France and KLM, respectively, since the onset of the crisis. Despite this, additional cash injections will be necessary for the group to weather the crisis in 2021. The crisis has accelerated the implementation of measures that were consistently postponed by previous management, including significant cost reductions on short-haul flights, which were structurally loss-making, especially within the HOP! branch operating regional flights that are challenging to make profitable. This includes the planned loss of 1,000 jobs (40% of pre-crisis staff). Across the entire group, 7,500 jobs will be cut, primarily through voluntary redundancies and non-replacement. The head of Air France-KLM has maintained a maximum number of flights to take immediate advantage of a possible traffic upturn. However, since autumn 2020, this strategy has been undermined by the crisis' extension: turnover dropped by 70% in the third quarter, although cargo operations were maintained, along with flights when their operating costs could be covered. The company has had to seek new funding sources and negotiate a long-term partial unemployment agreement with the French state. A recapitalization of Air France by the French state is even being considered.

RyanAir will face "the most challenging year" in its 35 year-history" in fiscal year 2020 according to its CEO, with an estimated loss of around 900 million euros on March 31st, 2021, and 3,000 redundancies[432]. Its balance sheet (3.5 billion euros cash at the end of 2020) and the 600-million British government-backed loan (678 million euros) give it confidence in its ability to recover in 2021.

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[429]Air Canada, 9th November 2020, Air Canada annonce ses résultats pour le troisième trimestre de 2020 ; Les Echos, 30th January 2021, Au Canada, les compagnies aériennes attendent désespérément l'aide de l'État

[430]Les Echos, 21st September 2020, Lufthansa contraint de réduire davantage la voilure ; Les Echos, 5th Novemebr 2020, Covid : Lufthansa se met en quasi-hibernation ; Les Echos, 7th December 2020, Lufthansa s'accorde avec les syndicats sur la suppression de 29.000 postes ; Les Echos, 21th January 2021, Lufthansa perd encore un million d'euros toutes les deux heures

[431]Le Monde, 3rd July 2020, Air France annonce 7 580 suppressions de postes ; Les Echos, 13th September 2020, « Nous ferons ce qui est nécessaire pour garantir la survie d'Air France » affirme Bruno Le Maire ; Le Monde, 31st July 2020, Air France-KLM : l'État n'écarte pas une recapitalisation ; Les Echos, Fin du suspense chez KLM avec l'accord des pilotes au gel des salaires ; Le Monde, 17th November 2020, Air France-KLM recherche 6 milliards d'euros supplémentaires pour assurer son avenir ; Les Echos, 22nd December 2020, Air France boucle le douloureux plan de restructuration de sa filiale Hop! ; Les Echos, 27th January 2021, Chez Air France, le cargo prend sa revanche

[432]Le Parisien, 1st May 2020, Coronavirus : le groupe Ryanair prévoit 3 000 suppressions d'emplois ; Les Echos, 1st February 2021, Le Covid commence à peser sur les comptes de Ryanair

EasyJet recorded its first losses since it started in 1996 (1.27 billion pounds, i.e., 1.41 billion euros) and saw its turnover drop by 53%. At the end of September, the company still had a 2.3-billion-pound cash position, after raising funds by 2.4 billion pounds (2.7 billion euros). Coupled with a reduction in its supply by 20% of its capacity until the end of March 2021, this gives it the possibility to cope with the ongoing traffic reduction. 4,500 posts have been lost out of a 15,000-strong workforce[433].

Wizz Air, the ultra-low-cost Hungarian company that was the first on the Central European market before the crisis, is an exception and is taking advantage of the situation to keep growing. After laying off 1,000 employees from its pre-crisis workforce of 4,500 and cutting wages by 14% on average, the company opened nine bases and 200 new routes in Q2 2020, diversified its offer, expanded its network, confirmed the growth of its fleet, and opened a base in Abu Dhabi in December 2020. It is well positioned for the medium term, although the sustainability of its growth is not guaranteed[434].

13.3.2: Aforementioned industrial companies

Airbus announced measures in March 2020 to adapt the company to the new situation: it increased its available liquidity (through credit lines), utilized partial activity schemes and implemented cost reduction plan mechanisms[435]. The aircraft production rate was reduced by 40%, resulting in 48 airplanes from April 2020[436]. Subsequently, 15,000 job cuts were announced at the end of June 2020, representing 11% of its staff, and will be added to the initial measures by August 2021[437]. The first nine months of 2020 reveal the significant financial impact of the crisis on the aircraft manufacturer, with a 35% revenue drop compared to the same period in 2019 and a net loss of just under 2.7 billion euros[438]. Despite the severity of the crisis, the aircraft manufacturer managed to deliver 566 aircraft including 82 wide-body aircraft (a 34% drop compared to 2019), recorded 383 orders and faced 115 cancellations[439]. Its backlog stood at 7,184 aircraft at the end of 2020. The aircraft manufacturer plans an increase in production rate starting from H2 2021[440], going from 40 A320 per month at the beginning of the year to 45 in Q4. In France, after negotiation and requesting available government measures to support employment (long-term partial activity scheme (APLD), CORAC funding, etc.), job cuts have almost been halved (2,157 instead of the 4,248 initially announced) and will be done without mandatory leave. However, job losses could still be high in other countries affected by this redundancy scheme (mainly Germany, Spain, and the United Kingdom), as the total objective of staff reduction has not been modified[441].

Boeing witnessed a 24% drop in 2020, totalling $58.2 billion. The net loss amounted to $11.9 billion[442]. Since March 2020, the aircraft manufacturer has been implementing a “transformation

[433]Les Echos, 28th May 2020, Coronavirus : easyJet va supprimer 30 % de ses effectifs ; Challenges, 28th May 2020, EasyJet compte supprimer 30% de ses effectifs, soit 4.500 emplois ; Les Echos, 7th September 2020, EasyJet réduit son offre en France au terme d'un été décevant ; Les Echos, 8th October 2020, Pertes historiques pour easyJet, qui réduit encore la voilure ; Le Journal de l’Aviation, 8th October 2020, EasyJet subit la première perte annuelle de son histoire en raison de la pandémie

[434]Les Echos, 9th March 2017, Wizz Air veut devenir encore plus low cost que Ryanair ; Les Echos, 24th August 2020, La low-cost hongroise Wizz Air progresse à la faveur de la crise ; Les Echos, 8th December 2020, Wizz Air, cette compagnie aérienne qui se joue du Covid

[435]Airbus, 23rd March 2020, Airbus announces measures to bolster liquidity and balance sheet in response to COVID-19, Le Monde, 29th April 2020. Coronavirus : Airbus et l’aéronautique s’enfoncent dans la crise ;

[436]Les Echos, 7th September 2020, Airbus a bien ajusté sa production d'avions à la demande

[437]Airbus, 29th June 2020, Airbus plans to further adapt to COVID-19 environment ; Le Monde, 30th June 2020, Airbus va supprimer environ 15 000 postes dans le monde, dont 5 000 en France

[438]Airbus, 29th October 2020, Airbus reports Nine-Month (9m) 2020 results;

[439]Airbus, 8th January 2021, Airbus 2020 deliveries demonstrate resilience ; Les Echos, 8th January 2021, Les livraisons d'Airbus font de la résistance face au Covid-19 ; Le Monde, 14th January 2021, Malgré la violence de la crise, Airbus limite la casse

[440]Les Echos, 21st January 2021, Airbus : la production repartira à la hausse dès l'été prochain

[441]Les Echos, 23rd December2020, Airbus en passe de boucler son plan social sans départ contraint

[442]Boeing, 27th January 2021, Boeing Reports Fourth-Quarter Results

plan" to adapt to the new situation[443]: a reduction of production rates (already heavily challenged by the ban on the 737 MAX), consolidation of 787 production lines on one site, optimization of its supply chain, improvement of its operational excellence… The product portfolio and the investments have also undergone thorough streamlining and reorganization to adapt to market developments and refocus on its core business (see the example of the 747 in chapter 5.8.3 above and the cancellation of the Embraer commercial airplane branch purchase in April 2020[444]). Boeing has initiated the reduction of close to 30,000 jobs out of a workforce of 161,000 employees at the end of 2019[445]. By the end of 2020, Boeing had delivered 157 aircraft (including 114 wide-body aircraft), fewer than the total deliveries in 2019, which were already well below those of 2018 (806 deliveries). Additionally, the aircraft manufacturer experienced several order cancellations, especially for the 737 MAX (758 cancellations since the FAA requested its grounding in March 2019) [446]. However, its backlog still accounts for around 5,000 airplanes and the end of the year showed encouraging signs, with the 737 MAX back in the air[447], and a significant increase in orders and deliveries (Ryanair and Alaska Airlines with 75 and 23 airplanes, respectively).

The aviation division of General Electric (United States) reported a turnover of just over $16 billion and a profit of $681 million for the first nine months of 2020, reflecting a decline of 32% and 86%, respectively, compared to the same period in 2019. In May 2020, in response to the crisis, the department reinforced the initial cost-cutting measures taken in March. Consequently, the cutting of 10,000 jobs was announced, in addition to the 2,800 positions already axed in Mars 2020. In total, 25% of the entire division's job positions will have been lost[448].

Rolls-Royce Holdings PLC, until recently, accounted for around 0.6% of the United Kingdom's GDP and 2% of the country's exports and relying on a network of 2,800 subcontractors. For H1 2020, the Civil Aerospace division has reported a 37% drop in revenue compared to the first semester of 2019 (2.5 billion pounds) and incurred losses of £1.8 billion. With an expertise primarily focused on high-power aircraft engines, the company has been significantly affected by the sharp decline in long-haul traffic and the anticipated withdrawal of wide-body airplanes, given its business model based on power-by-the-hour service agreements. Therefore, the division expected a 45% decrease in 2020 in incomes related to long-term service agreements based on engine flying hours and 250 engine deliveries. Since May 2020, Rolls-Royce has implemented a strict reorganization program to secure its funds: a 5 billion pounds fund raised through secured loans, shares and bonds issues, disposal of assets deemed non-strategic estimated at 2 billion pounds (nuclear department, ITP Aero, and Bergen Engines branches), a slowdown of production rates, production transfer between facilities and the shutdown of several facilities in the United Kingdom and Singapore. Regarding employment, Rolls Royce is cutting 9,000 jobs, including 8,000 in the Civil Aerospace division alone, from a workforce of over 42,000 workers before the crisis[449].

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[443]Boeing, 28th October 2020, Third-Quarter 2020 Performance Review

[444]Les Echos, 27th April 2020, Sans Embraer, Boeing renonce à refaire jeu égal avec Airbus

[445]Les Echos, 29th April 2020, Boeing va supprimer 10 % de ses effectifs et réduire durablement sa production ; La Tribune, 30th April 2020. Aéronautique : en pleine crise, Boeing supprime 16.000 postes ; Les Echos, 28th October 2020, Boeing annonce 7.000 suppressions de postes supplémentaires

[446] Les Echos, 12th January 2021, Boeing se console d'un bilan 2020 désastreux avec le retour du MAX ; Boeing, Orders & Deliveries

[447]Le Monde, 20th January 2021, Le Boeing 737 MAX pourra retrouver le ciel européen à partir de « la semaine prochaine »

[448]GE Aviation, 4th May 2020, An Update on COVID-19 GE Aviation Business Impact ; Les Échos, 5th May 2020. General Electric veut supprimer 10.000 emplois supplémentaires dans l'aviation ; General Electric, 28th October 2020, GE annouces third quarter 2020 results - Building momentum amidst still-difficult environment

[449]Rolls Royce, 27th August 2020, Rolls-Royce Holdings PLC -2020 Half Year Result (Presentation) ; Les Echos, 27th August 2020, Le motoriste Rolls-Royce dévoile une perte presque égale à son chiffre d'affaires ; Les Echos, 1st October 2020, Rolls-Royce dévoile son plan de sauvetage à 7 milliards de livres ; Le Monde, 24th November. 2020, Rolls-Royce, un joyau britannique en péril ; Rolls-Royce, 11th December 2020, Rolls-Royce Holdings PLC Trading update

Safran, an engine and equipment manufacturer, reported in October 2020 a yearly revenue forecast of 16 billion euros, down 35% compared to 2019, but expects a 10% of operating margin and a positive cash flow in H2, in line with the set objectives and the reduction of the amount of credit lines taken out when the crisis started. However, on civil aircraft engine activities, Safran has posted a revenue drop of around 42%[450]. These results, an exception in the sector, can be explained by the strict cost-cutting plan implemented by Safran as early as March 2020: a 40%

reduction in raw material purchases and in subcontractor expenses, a 74% cut in investments, a 33% reduction in research and development costs, and the cancellation of the 2019 dividend payment (1 billion euros). The group reduced its staff by 16% (20% including temporary contracts), mainly abroad: nearly 17,000 employees have been made redundant in Morocco[451], Mexico and the United States. Safran has, however, pledged not to make any redundancies in France between now and the end of 2021, after signing a Long-Term Partial Agreement (APLD) and a business transformation plan with the trade unions in early July 2020. These agreements include incentives for voluntary departure or retirement, but 3,000 jobs will eventually be lost.

Latécoère, an expert in aerostructure and interconnection systems products, recorded a loss of 94 million euros in the first half of 2020. In 2020, the company began selling real-estate assets and implemented a redundancy scheme involving the loss of 475 jobs out of 1,504 in France and the shutdown of some sites (such as Latélec in Blagnac), where consequences could still be mitigated with the negotiation of a collective performance agreement ("APC" in French). In early February, the company announced a reduction in the number of job cuts to 246 instead of the initially planned 345 in its aerostructure branch and the cancellation of the redundancy scheme for its Interconnections branch (preserving 130 jobs)[452].

Figeac Aero, an expert in industrialization and production of parts and aerostructures, forecasts a nearly 58% decrease in revenue for 2020 compared to 2019, resulting in a net loss of 51 million euros. Two redundancy schemes have been initiated, in Figeac (initially 320 positions finally scaled down to 220) and in Méaulte (20 jobs), with 742 jobs cut abroad[451]. Nevertheless, the company is encouraged by positive signs for 2021, as they secured a 3.6-million-euro support from the state, associated with production and information systems optimization projects, the award of important contracts and a willingness to diversify its activity into energy and industrial services[453].

Mécachrome, an expert in precision mechanics, has announced its intention to cut 300 jobs, close the MKAD factory in Ariège (joint venture with Aubert & Duval, see below) and to reorganize part of its activities in France, particularly affecting the Centre-Val de Loire region[454].

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[450] Safran, 30th October 2020, Safran en ligne avec ses objectifs 2020 ; Safran, 30th October 2020, Chiffre d'affaires du T3 2020 ; Les Echos, 8th December 2020, Comment Safran résiste au mal de l'air ; Le Monde, 22nd December 2020, Pour l'aéronautique, le patron de Safran « espère un retour au niveau d'avant-crise début 2024 »

[451] Le Monde, 17th November. 2020, Au Maroc, un « trou d'air » nommé coronavirus dans le secteur aéronautique

[452] Latécoère, 17th September 2020, Latécoère publie ses résultats du premier semestre 2020 ; Les Echos, 25th September 2020, Latécoère prévoit de supprimer un tiers de ses effectifs en France ; Les Echos, 15 October 2020, En difficulté, Latécoère cède du foncier ; Touleco, 3rd December 2020, Aéronautique. Les salariés de Latelec et Cauquil en grève ; La Dépêche, 18th December 2020,

Latécoère : 114 postes en voie d'être "sauvés" dont 38 à Gimont ; Le Journal de l'Aviation, 5th February. 2021, Latécoère supprime moins de postes que prévu en France

[453] Les Echos, 13th July 2020, Figeac Aero prépare un plan social « significatif » ; Les Echos, 27th August 2020, Aéronautique : Figeac Aéro supprime 320 postes au siège ; La Dépêche, 17th December 2020, Lot : le groupe Figeac Aéro reprend des couleurs après une année noire ; Le Journal de l'Aviation, 17th December 2020, Figeac Aéro, « extrêmement touché » par la crise, voit la reprise arriver ; Figeac Aero, 2nd February. 2021, Figeac Aéro prépare l'avenir

[454] Les Echos, 29th September 2020, Aéronautique : plus de 300 postes supprimés chez Mecachrome ; France 3 Occitanie, 15th September 2020, Ariège : le sous-traitant aéronautique MKAD pourrait fermer, 45 emplois sont menacés

SKF, a Swedish company specializing in ball bearing production, announced the cutting of 123 jobs at its Lons-le-Saunier and Valence factories, and around thirty jobs at the Valenciennes factory, where it manufactures parts for Safran's LEAP engine[455].

Aubert & Duval has been an expert in high-performance metallurgical materials for more than a hundred years. Such expertise is crucial for the aviation branch (70% of its business) but also for the France defense and nuclear industry. The company recorded a revenue of 81 million euros in Q3 2020, down 31%. As a result, the company started an APC in July 2020, then implemented an APLD for its 7 French sites. During the first quarter of 2021, internal training and mobility are planned and voluntary leaves and seniority measures will be negotiated, leading to the cutting of 380 jobs out of the 3,700 in France. Eramet has been considering the sale of its subsidiary since the end of June 2020. Safran has shown interest in taking it over[456], which would enable the company to stay French, but a buy-out by one of its two main foreign competitors remains a possibility.

Sogeclair Aerospace SAS, the French branch from the engineering group Sogeclair introduced a redundancy scheme involving 245 people out of its 580 French employees[457].

Assistance Aéronautique Aérospatiale (AAA) signed a redundancy scheme in October, cutting 567 jobs out of its 1,587 French employees[157].

Akka Technologies finally announced in December that it was cutting 900 jobs in France[458] after initially considering an APLD agreement.

Expleo is considering the use of APLD measures to mitigate the number of job losses outlined in a redundancy scheme which aims to cut 1,538 of the 4,919 jobs in France, including half of the 1,300-strong workforce in Toulouse[157, 458].

Altran (Capgemini) wishes to establish a legally independent structure, consolidating 2,000 engineers in Blagnac, and to negotiate a collective performance agreement associated with salary cuts[458].

Alten Sud-Ouest laid off 321 people between late April and late July 2020 using the employee mobility clause[459].

Air France-KLM Industries, one of the key stakeholders in the MRO sector, has reported a nearly 35% drop in revenue for the first nine months of 2020, with operating losses of 366 million euros[460].

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[455]Le Journal de l'Aviation, 15th September 2020, SKF prévoit la suppression d'une centaine de postes sur son site de Lons-le-Saunier ; Les Echos, 20th November 2020, Le suédois SKF supprime 400 postes en France ; Le Monde, 14th December 2020, Dans le Jura, le tissu industriel souffre mais ne rompt pas

[456]France 3 Occitanie, 1st July 2020, A l'heure où Airbus annonce un plan social historique, le sous-traitant ariégeois Aubert & Duval pourrait être vendu ; Aubert & Duval, 3rd July 2020, Aubert & Duval annonce un premier accord collectif pour adapter son organisation à la crise du marché aéronautique ; Les Echos, 7th December 2020, Aubert & Duval engage un plan de 380 départs volontaires ; Les Echos, 8th September 2020, La vente d'Aubert & Duval alerte le ministère de la Défense ; Les Echos, 2nd November 2020, Safran confirme son intérêt pour Aubert & Duval

[457] L'Usine Nouvelle, 24 juin 2020, La société toulousaine Sogeclair Aerospace annonce un projet de PSE

[458]Les Echos, 17th November 2020, Chômage partiel longue durée et baisse des salaires, le deal d'Akka pour sauver 1.100 emplois ; Les Echos, 18th December 2020, Akka Technologies prévoit 900 suppressions d'emplois

[459] Le Monde, 8th December 2020, Covid-19 : les ingénieurs de l'aéronautique, entre désespoir et colère

[460] Air France KLM Group, 30th October 2020, Résultats du 3ème trimestre 2020

13.3.3: Aforementioned airport companies

The company operating London Gatwick airport, managed by the Vinci group, had lost 80% of its activity by the end of August 2020. Additionally, some airlines decided to shift their flights to their base airport, like British Airways on London Heathrow, thereby increasing operating losses for Gatwick airport. Consequently, its operating company has announced 600 job cuts, representing a quarter of its workforce[461].

Heathrow airport launched a savings program[462] and announced in 2020 that its Terminal 4 would remain closed until the end of 2021. The start of construction work for the airport expansion, finally approved in mid-December 2020 by the United Kingdom Supreme Court, was delayed by two years. The construction of a third runway, planned with a budget of 14 billion pounds, was initially scheduled to start in 2022 and last four years.

ADP is anticipating a 2.5 billion euros shortfall for 2020, with a net loss of 543 million euros over the first semester. In November 2020, air traffic plummeted by 90% due to France's second lockdown. Throughout the year, air traffic slumped by nearly 70% (71% for Roissy-Charles De Gaulle, 66% for Orly airport) [463]. When the crisis began, the company was forced to implement adaptation measures. Financially speaking, ADP secured a 2.5 billion euros loan and the group's investments were halved, with large capacity expansion projects postponed. Only those projects that were already well underway[166] will be completed (Orly airport Terminal 4, Roissy-Charles De Gaulle Terminal 1 commercial zone expansion as well as junction and rehabilitation work from Terminal 2B to 2D). The construction project of Roissy-Charles De Gaulle Terminal 4 was cancelled by the French government due to the deteriorating outlook for air traffic over the next few years and in alignment with the government's environmental objectives[464]. Regarding employment, an agreement was signed in December 2020 to organize 1,150 voluntary leaves (700 of which will not be replaced) out of the whole 6,250 ADP workers. It was also promised that no dismissal procedures would bne implemented until January 1st 2022[465]. This strategy might be complemented in early 2021,by additional economic measures, a long-term partial activity agreement, and salary reductions.

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[461] Les Echos, 26th August 2020, L'aéroport de Londres-Gatwick va supprimer un quart de ses emplois

[462] Le Monde, 16th December 2020, Aéroport d'Heathrow : feu vert de la Cour suprême britannique au projet d'extension

[463] Le Journal de l'Aviation, 17th December 2020, Les Aéroports de Paris accusent une baisse de trafic de près de 90% en novembre ; Le Monde, 18th January. 2021, Covid-19 : les aéroports parisiens très sévèrement touchés par la pandémie en 2020

[464] Les Echos, 2nd September 2020, Roissy : le début des travaux du terminal 4 repoussés d'un an ou deux ; Le Monde, 9th July 2020, Pour l'autorité environnementale, le projet de nouveau terminal à Roissy est à revoir de fond en comble ; Les Echos, 28th July 2020, Le gouvernement appelle à une révision du projet d'extension de Roissy ; Le Monde, 4th February 2021, Jugé « obsolète », le projet de nouveau terminal à l'aéroport de Roissy abandonné par le gouvernement

[465] Le Monde, 26th August 2020, Restructuration de Groupe ADP : la CGT et la CGC refusent le rythme imposé par la direction ; Le Monde, 9th December 2020, Les syndicats d'ADP signent un accord pour 1 150 départs volontaires ; Les Echos, 9th December 2020, Feu vert aux départs volontaires chez ADP

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About The Shift Project

The Shift Project is a think tank working for a carbon-free economy. As an association under the French law of 1901, recognized as being in the public interest and guided by the highest standards of scientific rigor, our mission is to enlighten and influence decision-makers. **https://theshiftproject.org/**

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SUPAERO-DECARBO is a collective of more than 100 former and current students of the ISAE-SUPAERO school, more than half of whom work in the aeronautical industry or air transport. Passionate about aviation and intimately concerned by the issue of climate change and its consequences for life on earth, they are keen to introduce a scientifically supported discourse on the true contribution of the aviation sector to climate change, allowing us to consider aviation's future on a sound basis in a low-carbon world.

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