Be Green, Keep Flying!

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Preambule
It is no secret that the number of passengers handled by the airline industry has increased in the past 50 years. Why has it grown so much? The first reason is, by far, the most important one. Propelled by globalisation, flying enables the freedom of movement in a reasonable time, traveling and exploring without any limits. Above all, it is a way to connect with people all around the world. These are the core reasons for the commercial aviation industry's existence. Global carrying capacity has increased due to the increase in low-cost carriers, growth of the global middle class, fulfilling the needs of many future explorers: whether it is for business purposes or leisure activities, it is usually the fastest way to get to places while still being affordable and safe. Travelling by plane has become, this past century, a hobby more than a necessity to move from a location A to a location B. Sharing the airspace is the first consequence of the continuing growth of air traffic, but other major issues are emerging such as satisfying the growing expectations of societies by becoming truly sustainable. On top of that, we are witnessing this year the biggest crisis the aerospace industry has ever faced: the COVID-19. These factors accelerate the opportunity to transform the industry and to renew itself to stay attractive and remain viable.

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Introduction

The need of a green movement To understand the foundations of the transformation of the aerospace industry, let's first focus on socio-ecological factors. It has been a trendy subject these past years, especially in Europe. If we take France as an example, a study [1] shows that environmental protection has become the top priority for French people (52%) ahead of social system's future (48%) and buying power (43%) when it had always been at the back before. Moreover, every category of population is now concerned about environmental issues, from the youth, which has always been a proactive supporter of the cause, to the elderly more recently but also to all kinds of socio-professional categories. This has been particularly visible in Europe with the green breakthrough at the European Parliament elections in 2019. Minimisation of plastic packaging, reusable products, reduction of meat consumption... Pro-environment actions are popping up now, but are climate change and environmental issues that new?

Along with the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, climate change and global warming awareness was born: this organisation warned that the increase in temperature is due to the greenhouse effect and extreme weather events can happen [2]. Ever since, the IPCC has published multiple assessment reports, each more alarming, indicating a clear human influence on global climate, an increase of greenhouse gas concentrations (Figure 1), rise of surface temperature over the 21st century... [3]

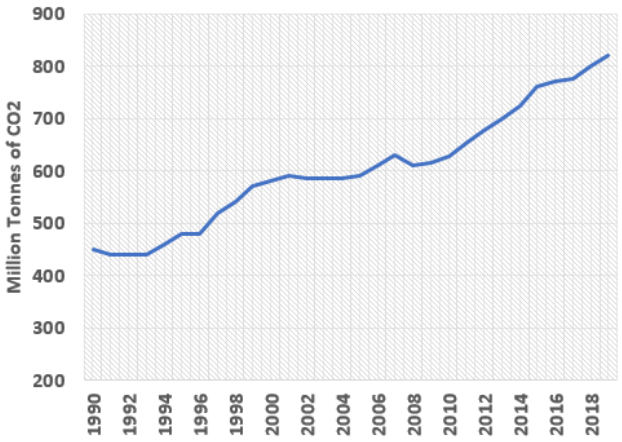

Figure 1. CO_2 emissions from the global fuel burn of commercial airlines [4]

Further, climatic events with environmental consequences

have been occurring more and more frequently: oppressive heatwaves, large temperature variations, hurricanes, ice melting... leading to increased rates of extinction in animals and plants in some regions. This has triggered the alarm for a serious need to rethink our way of consuming, as well as the politics to lead a new movement by installing new regulations.

Regarding aviation environmental impacts, CO_2 is the principal greenhouse gas and aviation represents 2% to 3% of the total annual global CO_2 emissions from human activities according to the IPCC. Aviation is "driven by long-term impact from CO_2 emissions and shorter-term impact from non-CO_2 emissions and effects, which include the emissions of water vapour, particles and nitrogen oxides (NOx)." [5] The scientific consensus on the emergency combined with the obvious impacts of CO_2 makes the aviation industry an interesting target to renew itself.

COVID-19: A justification for accelerating the transformation of the industry It is clear that the industry needs to be rebuilt. Up until now the transformation has been slow and the public opinion has not gotten better. The COVID-19 crisis has been the toughest the industry has ever faced. A crisis can be defined by its depth, duration and shape of recovery. On those three criteria, the severity of COVID-19 is unprecedented and has touched every member of the aerospace ecosystem [6]. Even though air cargo activities have been maintained (and even increased on particular routes to transport medical supplies and personal protective equipment), the drop of passenger traffic is estimated at 90% for April-May 2020 in comparison to 2019 at the same period [4]. There is no doubt: the COVID-19 crisis has fractured the industry.

New behaviours have emerged during quarantine all over the world to mitigate the spread of COVID-19. On the professional point of view, ways to adapt to restrictions in this new environment include teleworking and online meetings. Those services aren't new, but they have been highly democratised and have become the new norm in order to keep the economy together. Many of the white-collar populations used to travel for business, which has been completely challenged ever since. Is it really a necessity today? For sure, online meetings do not completely replace face-to-face communication as social and cultural interactions cannot be felt through a laptop screen. However, it has seriously developed the capabilities of adaptation of employees to reach goals even in times of crisis. Regarding leisure travel, mass tourism has been around for decades and has driven growth all over the world. This growth has also created negative environmental effects including overconsumption of natural resources and water pollution. New ways of tourism have emerged, such as sustainable and responsible tourism. All these new habits have a serious effect on the aviation industry because they make a real fracture with the old vision. However, this trend is to balance with the growing wish to fly further. To ensure that it subsists through and after this crisis, the focus on sustainability is a real opportunity for the aerospace industry to seize.

While many steps have been taken to reduce the carbon footprint of aviation, the industry has taken one step further, boosted by the French Government announcement: the investment of 15 billions of euros to develop a zero-emission aircraft by the end of 2035. This announcement is a way to accelerate a project which had already been going on, but had at the time a deadline in 2050. The Conseil pour la Recherche Aéronautique Civile (CORAC) benefits from this investment to develop new solutions, such as hydrogen powered aircrafts, biofuels etc. Down the road, the objective is to reach a gain of 30% of fuel consumption by 2035, while we only have an average gain of 1% per year today.

How will we make it to this objective? Disruptive innovations are certainly in the radar, but to ensure that the solutions offered by the aviation industry meet the expectations, we need to refer to the fundamental pillars of sustainable development: environment, economy and society. The entire industry needs naturally to work hand-in-hand to achieve this goal. However, they should not be the only ones: there is a need for a global movement at all stages, and different stakeholders can be associated with these challenges. Who are they and how can they contribute to the resurrection of the industry?

1. The role of institutions and politics

On January 1st, 1914, for the first time in history, a passenger paid for a ticket on the first airline. The price of the one-way ticket was $400 USD, for 23 minutes of flight. This was possible thanks in part to a contract between authorities and the founder of the airline. 1914 was also the beginning of World War I. During the war, governments massively invested in the aerospace industry, especially in defence, developing an air force capable of fighting against other countries. Emerging from the war, the desire and need to travel for leisure, work and to transport cargo to support globalisation have helped to democratise commercial and cargo aviation industries. Governments, through their political orientation, have provided a state action plan with focal points to lead the effort of the industry in the same direction. Today, institutions and politics at different scales have a role to play: lead the aerospace industry to a more sustainable future.

National and international politics and institutions such as the International Civil Aviation Organisation (ICAO), the International Air Transport Association (IATA) along with local civil aviation authorities understand the concerns of all stakeholders, including communities and NGOs. They are in charge of overseeing and regulating the industry. For example, if states want to develop greener aviation, they will have to start expanding the availability of clean electricity sources to power aviation activities. Governments, by bringing the whole coun-

try's industries together, are able to connect to guide them to common goals.

The establishment of structured cooperation processes among different countries could be guided by big institutions to ensure that measures are well implemented and that regulations are respected. Europe, as an international organisation, has proven its effectiveness fostering collaboration between countries.

1.1 European guidelines: a role model

Airbus, born from a European collaboration In July 1967, governments from the UK, Germany, France and the Netherlands combined forces for the joint development and production of an airplane, reinforcing European cooperation in the aviation industry and to end the disparity between all non-European programs which appeared in terminal decline: this marked the birth of Airbus. Today, Airbus controls approximately 50% of the global commercial aircraft market [7]. The rise of Airbus came from a collaboration between governments, institutions and companies from all countries, sharing their expertise freely and collaboratively. "Airbus's success lies in its political roots. While the original partners in the company recognised that the only way to compete was to consolidate national industries on a regional European basis, consolidation required negotiation and political finesse" [7].

The industry needs this kind of large-scale project where countries and companies work together to achieve a more sustainable aviation.

European perspectives today To take the lead, the European commission and its countries initiated major programs. For instance, the Single European Sky Program [8] led by the Single European Sky Air Traffic Management Research (SESAR) and Eurocontrol, aims to harmonise all European airspace. Improving Air Traffic Management (ATM) performance by modernising and aligning systems requires development and deployment of innovative technological and operational solutions, deployed digitally. This program is contributing to two of the commission's top priorities: the "European Green Deal" and a "Europe fit for the digital age".

The Clean Sky initiative (2008-2024) [9], led by the European Commission in agreement with the industry is another example proving the willingness of Europe to exploit European collaboration. Bringing together small and large companies and research centres drives innovation. Clean Sky 2 objectives are to reduce noise and greenhouse gas emissions by 20% to 30% compared to an aircraft entering into service in 2014. This partnership between public and private stakeholders develops innovative technologies such as lighter components, more aerodynamic structures, engine improvement including electrification and hybridisation. The European Commission's goals are very ambitious for this project: "By 2050, 75% of the world's fleet now in service (or on order) will be replaced by aircraft that can deploy Clean Sky 2 technologies" [10]. These projects and Europe's ability to handle a program such as Airbus provide a convincing argument that Europe should be taken as a model.

1.2 Defence: a specific case

References to authorities and large institutions cannot be made without acknowledging governments' defence policies. The top priorities of defence remain to protect the nation: protection, dissuasion and intervention. That is why the defence industry has always been closely linked with politics.

Defence has always been a driving force for innovation. Finding new and efficient solutions to protect a nation is critical to compete for military supremacy. Wars (especially First and Second World War) have boosted the aviation industry, putting it on the map of transportation democratisation. This great leverage of defence for innovation could be used for a greener aviation. However, this idea must be balanced with the core values of Air Forces, which is to preserve the superiority against enemies. Green aviation is, for sure, a meaningful objective for the military Air Force, as long as the operational power and efficiency is not threatened. If greener alternatives provide an equivalent or greater efficiency to current solutions, it would be a great step for aviation's path to ecological improvements. We recognise a strategic link between commercial and military aviation. Indeed, the more commercial aviation uses eco-friendly technologies or develops greener solutions, the more it will prove their efficiency. Ultimately, it will allow the military to consider implementing solutions to reduce their carbon footprint.

Our point of view In a time of economical and price war, measures taken by the governments can have serious consequences on the countries. As an example, the French Government has established an "ecotax" where passengers would have to pay between 1.50€ to 18€ on all of their flights departing from France (connecting flights excluded). This measure, acknowledged as a step to challenge people's vision on the matter, is certainly a symbolic measure. However, it could be seen as a punishment more than a way to change people's behaviour: airlines and passengers are directly penalised nationally, reducing the national competitiveness of airlines, while other international airlines do not have to pay. Moreover, the tax is inconsistent throughout the process: the funds obtained are kept by tax entities instead of being directly used to invest in new technologies to reduce aviation's impact. In addition, it seems that consumers themselves are not aware of paying this tax and its usage, as it is not explicitly visible on the flight ticket. Finally, the last inconsistency that we have observed is that whatever the destination we are flying to, the tax remains the same. The non-proportionality between the tax cost and the distance makes it even less relevant. Other

countries, such as Sweden or Germany, have started to use ecotaxes, but the fact that there are only a few makes this a limited solution.

2. A synergy between OEMs and their supply chain

While domestic and international policies bring guidance to the aerospace industry, other stakeholders need to play a role alongside them to ensure that everyone goes in the same direction. Airlines, airports, Original Equipment Manufacturers (OEM) and their supply chain play a major role at their own scale. They need to create a sustainable aviation industry together, which need to reflect the 17 Sustainable Development Goals (SDGs) defined by the United Nations (Figure 2). Why is it so important to mention this? Simply because we would like to remind people that sustainable development does not only mean climate action, but it also covers plenty of other factors including "no poverty" and "industry innovation and infrastructure".

Figure 2. Some of the Sustainable Development Goals defined by the United Nations [11]

Based on Deloitte's 2017 study of the 100 major global aerospace and defence industries (OEMs only) [12], the global aerospace and defence industry revenue reached US$685.6 billion. The estimated GDP for the aerospace industry was 3.1% of the global economy and employed approximately 1,925,910 people worldwide. This justifies the weight and influence of the aerospace industry in the total economy, showing the crucial role it has to play to achieve goals in sustainable development. There is no doubt that the industry contributes to sustainable development in the factors previously mentioned ("no poverty", "industry innovation and infrastructure"). However, they also act on other factors, by implementing Corporate Social Responsibility (CSR) at the heart of their strategies, showing that becoming greener is a real challenge.

2.1 Airlines at the front line of customers

Airlines have started to develop more eco-responsible actions during recent years. It is indeed a strategic question, as the objective is to find an equilibrium between ensuring economic viability while including a green vision. For an airline, fuel price and consumption are major challenges because fuel accounts for about 30% of total expenses [13]. It is in their own interest to exploit new solutions to reduce it and digitalisation could be one of the solutions.

How can digitalisation be implemented in this context? With aircraft becmoing more autonomous, intelligent and connected, airlines could incorporate the latest hardware and software into their processes to become more efficient, generate more value and better serve its customers. One example is the modernisation of ATM: thanks to sensors and software, there is an uninterrupted flow of real-time information coming from aircraft, updating group operations (e.g. airlines, air traffic control) and pilots on the status of systems, equipment and current weather conditions, to adjust flight routes. Use of real-time data helps maximise fuel efficiency, minimise turbulence and even eliminate the wait for the gate after landing, the biggest fuel-consumption phase (Figure 3) because the plane usually has to move on the tarmac after landing, with engines still running (taxiing phase).

Maneuver	Duration [s]	Fuel consumption [kg]	CO emission [g]	NO_x emission [g]
Takeoff	42	103	21	2966
Climb	132	261	157	5872
Descent	240	162	259	1750
Taxiing	1560	353	6636	1659
Total	**1974**	**879**	**7073**	**12247**

Figure 3. Maneuvers duration, fuel consumption and emissions in the LTO cycle [14]

Solutions exist today: SkyBreathe® developed by Open Airlines and OptiFlight by Safety Line are the most used. Both solutions identify the most relevant saving opportunities and provide a series of recommendations for all stakeholders that could reduce the airline's fuel consumption up to 5%. To do so, big data algorithms, Artificial Intelligence (AI) and machine learning analyse billions of data and combine them with environmental data from actual flight conditions.

Pilots have also an important role to play in reducing the aircraft impact (e.g. fuel, noise pollution) and these software include the ability to teach and compare pilots behaviours for more efficient flying. "Pilots are much more aware of their fuel performance and how they can improve it. They feel engaged in the process." Frances Torres, Director Flight Operations Technical Support & Dispatch at Cebu Pacific. OptiFlight has already proved its effectiveness on Transavia France airline. According to Nathalie Stubler, President of Transavia France, the first test carried out on the fleet enabled a gain up to 90 kg of fuel per flight.

Aside from fuel efficiency, other ways to reduce airlines' environmental impact can be managed. Cabin waste (food, catering waste...) is a material expense, and more importantly adds weight to the aircraft, consuming valuable resources and undermining the sector's sustainability credibility. It has been specifically targeted in the SDGs to cut in-flight global waste by half by 2030. It is essential that airlines and their service providers work collaboratively with regulators to ensure that aviation makes a positive contribution to this SDG target.

While airlines still have a lot to do, it is important to mention that they have already made progress. For instance, more than 250,000 flights have been operated by 9 major airlines using biofuel (biofuel is a fuel that is made from living things or their waste and is less harmful to the environment than other types of fuel, more details on biofuel is mentioned in 2.3). The offsetting of CO_2 emissions is another example.

Airlines need to work closely with airports to ensure their strategies for a greener aviation can be realised. So, what are the roles and responsibilities of airports and what are the opportunities?

2.2 Airports, more than an infrastructure

The total number of passengers has massively increased while airports have roughly kept the same number of runways and taxiways. It is a real problem for airports as they are trying to do more with the same infrastructure to avoid further constructions that could interfere with local residents. Like other players of the industry, airports need to work to improve aviation's reputation in relation to carbon reduction and environmental efficiency.

We know that aircraft in landing-take-off cycle is the biggest contributor of carbon emissions (Figure 3) but is it worth neglecting other sources? The entire airport supply chain emits carbon emissions (Figure 4), including passenger and staff transport throughout their journey in the airport. The use of electric or biofuel-used buses could help reduce the overall emissions.

Airports have worked to address their local impact. Since 2009 they have been working in a collaborative way with The

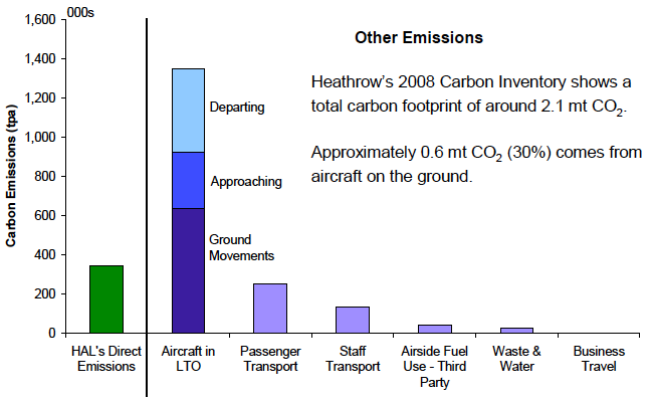

Figure 4. Heathrow Airport's Carbon Footprint 2008 [15]

Airport Carbon Accreditation, a global carbon management program for airports that independently assesses and recognises airports' overall efforts to manage and reduce their CO_2 emissions. There are many ways for an airport to address CO_2 emissions including: switching to a green energy source, better insulation and minimise its water consumption. Today there are 98 airports worldwide certified for mapping their carbon footprints [16]. This accreditation brings concrete solutions on the table and provides guidance to all airports.

Digitalisation can bring a real opportunity in this context and should be extended on a large scale. For example, Aéroport De Paris is using Airside Watch developed by Safety Line, which is processing all the radar data as well as using AI to optimise arrivals and departures of aircraft, minimising wait and corresponding fuel consumption. It also includes an environmental module allowing the airport to monitor its emissions, air quality and it can also manage where planes fly during take-off and landing to opitmise the flight path to reduce noise pollution for local residents. Another relevant example to highlight is the use of digitalisation by the UK's National Air Traffic Control to make a better use of airspace by rethinking routes to limit the number of aircrafts circling above airports waiting for a landing space. It can save up to 113,500 tonnes of CO_2 emissions [17] (the equivalent of approximately 46,000 round-trips of Paris-New York flights).

Digital solutions prove their effectiveness to answer today's challenges as they are easily and rapidly adaptable as well as scalable for different structures.

2.3 OEMs, engine of transformation

When thinking about a more sustainable aircraft, we first have in mind the technological progress because it brings the most impact. Nevertheless, it can also refer to a greener manufacturing and circular economy. For instance, ISO14001 is an environmental certification covering the whole production process: from production to the goods and services produced. Airbus was the first company to receive it in 2007 [18], followed by Boeing in 2009, showing that big leaders of the

industry put this matter at the forefront of their strategy.

Innovations driven by the industry have generated reductions of 15% to 20% in fuel consumption and CO_2 with each new generation of aircraft compared to the prior version [9]. These benefits are however limited: from the conception to an actual plane carrying passengers, all the way to the dismantling of the aircraft, the aviation industry is characterised by a very long product life-cycle. For example, Boeing 747 program started in 1965 and the airplane is still flying today! This can make it difficult for the industry to launch a new program using innovations randomly! Thus, building the next generation of greener aircraft takes time and requires close cooperation between small component suppliers and aircraft manufacturers. In this part, we will focus our study on new power sources and innovation propulsion systems as we are convinced that it will allow the industry to bring aerospace to the next step. The aerospace industry uses today Jet A fuel as a powered energy, which is a fossil fuel made with hydrocarbons, such as in oil. In a thermal aircraft engine, the combustion between hydrocarbons and oxygen emits CO_2 and water vapor, releasing considerable energy to power the aircraft. However, Jet A fuel has a major drawback: it takes greenhouse gases trapped for millions of years from the ground (oil), releasing those gasses into the atmosphere during the combustion process. The extreme heat in the engine also emits NOx.

The power source, and therefore the engines, are great opportunities to reduce the aircraft's environmental impact. Electricity as a power source could be a solution, in the same way as it is now applied to cars: batteries could power electronic engines. This solution can minimise the CO_2 impact and electronic engines are far more efficient than thermal ones (the engine efficiency is about 40% for a thermal engine against 80% for an electrical one [19]). However, it is well known that the weight of an airplane is proportionally linked to the aircraft's consumption: the lighter, the cheaper. As 1 kg of Jet A fuel [18] is equivalent to 25 kg of batteries, this solution is not conceivable with today's battery performance. Moreover, the battery making and recycling process is today questionable. The compromise could be Sustainable Aviation Fuel (SAF) or new propulsion technologies.

Biofuel, liquid hydrogen and synfuel Boeing operated the world's first 100% biofuel flight in 2018 with the ecoDemonstrator's FedEx Express 777 Freighter flight-test airplane. It demonstrated that biofuel can be used for powering current internal combustion engines. Biofuel is obtained from natural sources, is renewable and can recycle CO_2 from combustion through photosynthesis [21].

Biofuel has a non-negligible disadvantage: it can use a lot of land and it can be water-consuming since it can be synthesised from feedstocks or crops. The industry will then have to ensure that the whole process of biofuel production has a better net environmental impact vs. Jet A fuel. Biofuel cannot be the only solution for a sustainable aviation fuel. Alternative fuels exist which do not require organic origins, such as hydrogen or synfuel, in particular Power-To-Liquid jet fuel.

The main advantage of Power-To-Liquid fuel over biofuel is the very low use of land and water resources. Even if water is part of the cycle, it uses approximately 1900 times less water than biofuel does [20]. Emissions over the entire lifecycle (direct and indirect emissions) of Power-To-Liquid production are estimated at $28gCO_2eq/MJ$, far lower than kerosene at $87gCO_2eq/MJ$ [20]. This statement is accurate if we consider renewable electricity as the power source (Figure 5).

Biofuel and synfuel both have a major advantage: they can be used in current aircraft engines so that aircraft architecture and fuel infrastructure remain the same. Therefore, they can be used for all aircraft segments (from regional to long range). However, these fuels still have an impact because the combustion in thermal engines still emits CO_2.

Hydrogen Hydrogen has been very popular in the news recently. Is it the best solution for aviation? Hydrogen, as a fuel, does not contain carbon. This helps to eliminate CO_2 emissions in flight. Hydrogen can be produced in every country, which is important for country's freedom.

Hydrogen has a 2.6 times gravimetric density compared to kerosene (energy per unit mass) [22]. However, hydrogen needs a volume that is 4 times greater than kerosene in order to store the same amount of energy. It also needs a complex and heavier fuel and storage system because liquid hydrogen needs to cool down to its boiling point of -253°C. Due to the volume constraint caused by liquid hydrogen, hydrogen powered aircraft are best for commuter, regional and short-range aircraft. Moreover, to take into consideration all of these constraints, the aircraft architecture will have to be reviewed: it is not possible to store hydrogen in the wing like kerosene, meaning that a new type of wing will have to be developed.

Hydrogen powered turbine engines have a disadvantage: they emit 2.5 times more water vapor mass than kerosene-burning engines for the same quantity of energy and NOx. The impact of NOx on the environment being still uncertain, it creates debates in the scientific community. Hydrogen can also be used as fuel cell to create electricity to power electric motors, which means no CO_2 or NOx emissions. However, airplane architecture will have to be completely updated. Figure 11 in Appendix is an example of the next generation of regional aircraft powered by hydrogen fuel cell and its benefits in terms ofcarbon footprint reduction

A hybrid concept (hydrogen combustion combined with fuel cell) could be suited on a short-medium-ranged aircraft. The fuel cell would be the power source for cruising while hydrogen turbines would provide the thrust required during take-off and landing. The hybrid technology adds complexity in the

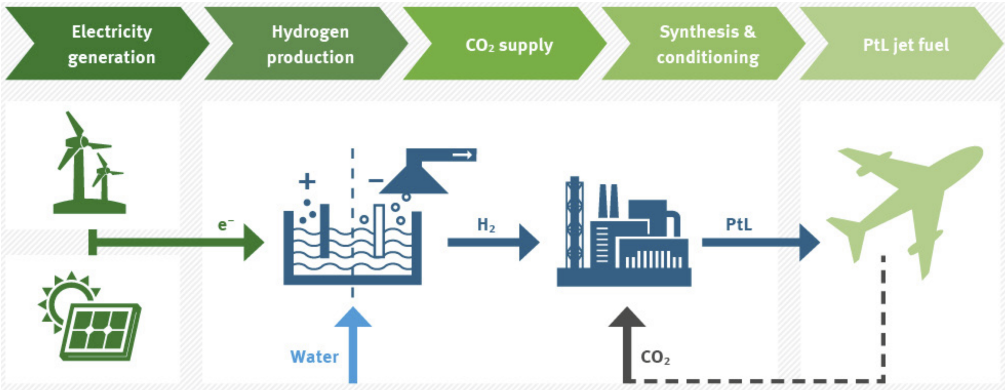

Figure 5. Generic diagram of Power-to-Liquids production [20]

design and certification of the propulsion system.

Is there one perfect solution? These new technologies and power sources can be compared in order to estimate their climate impact (Figure 6).

	Change of in-flight emissions and emission related effects			Climate impact reduction potential
	Direct CO2	NOx	Water vapor	
Power-To-Liquid fuel	-100%	-0%	-0%	-30-60%
Hydrogen turbine	-100%	-50-80%	+150%	-50-75%
Hydrogen fuel cell	-100%	-100%	+150%	-75-90%

Figure 6. Comparison of climate impact from H2 propulsion and synfuel - compared to kerosene-powered aircraft [9]

Hydrogen as a power source (hydrogen turbine or hydrogen fuel cell) has a huge potential to decrease climate impact. However, this is a long-term solution as hydrogen powered aircraft requires much more development in terms of economic production, distribution, storage on aircraft and at airports. New regulations are needed as well as stakeholders' approval to ensure safety. Biofuel and synfuel could be the ideal transition solution as they can be used in current aircraft with very limited updates. Biofuel and synfuel are the easiest short-term solution as the step from carbon fuel is much smaller.

Our point of view By summarising all the solutions for new power sources and their pros and cons, we thought it was relevant to present our hypothetical timeline (Figure 7) for these technologies to be implemented.

Having a new fuel available at a reasonable price will be essential for the democratisation of new fuels. A 2019 study from the International Council of Green Aviation mentioned that alternative jet fuel production costs are two to eight times higher than the price of petroleum fuel [23]. Considerable work will have to be performed by the industry to decrease these costs while taking into consideration the green aspects

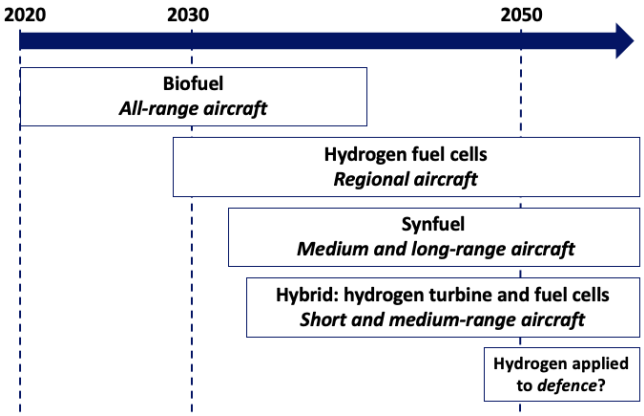

Figure 7. New power sources technologies' implementation timeline, Source: Personal interpretation

of its production. Governments, companies and future generations will have to work together to design an international fuel network allowing all airlines to be refueled at a reasonable price in every country. The fuel used must therefore meet international specifications. If the aerospace industry developed biofuel, liquid hydrogen or synfuel, it would have to ensure that the supply chain can provide it worldwide. Global development is a key enabling requirement.

Developing new power sources and propulsion systems are one of the paths to be taken to reduce aviation's impact but many other paths exist and should not be overlooked: reducing the aircraft's weight with innovative materials such as composite materials or decreasing drag by improving aircraft's aerodynamics. While these paths show strong evolutions of the industry and are necessary for short-term impact, we believe new power sources and propulsion systems are what will revolutionise the industry on the long-term.

The lifecycle of an aircraft wouldn't be complete without its maintenance. By improving the maintenance services, aircraft will of course enjoy a fuller lifespan, which will increase the efficiency of aircrafts (and so reduce fuel consumption) and minimising the number of equipment checks and replaced

[24]. It can be improved by using predictive maintenance with digital twins combined with of course big data. Moreover, additive manufacturing is another technology which allows to print on-demand components. Therefore, it can possibly reduce the overall supply chain's carbon footprint and avoid the waste of materials.

Finally, we can't talk about the aerospace industry without mentioning the sub-tier suppliers and new entrants. The role of stakeholders mentioned earlier is to provide a clear roadmap to ensure all sub-tiers will have time to adapt and develop technologies in the framework of the industry's needs. COVID-19 has had a domino effect on the industry: the lower in the chain, the more it was impacted. It is today a matter of surviving the crisis for those small businesses. The whole industry needs to support them to ensure that the expertise provided by these smaller companies will remain safe. It can be applied by investing in R&D to support green initiatives while ensuring the sustainability of the company and its collective knowledge. Sub-tiers and new entrants can also be a source of innovation. High competencies in their areas of expertise gives them the ability to push their concepts even further.

3. A step as individuals

What would the aerospace industry be without the people actually flying? Consumers as individuals are the essence of the transformation! If we notice an increase in commercial air traffic, it is because the consumers felt the need for flying. If we notice today a transition to greener aviation, it is because the consumers' behaviours are changing. It raises some questions of how consumers' behaviour will impact the transformation of the industry. Moreover, we can question ourselves into thinking that the behaviour might be heterogeneous according to cultures, socio-professional categories…

3.1 A wake-up call: is it so obvious for everyone?

The powerful step up of a new pro-environmental behaviour is something obvious in certain cases, for instance for French students like us, as we are constantly concerned with environmental impact questions. Whether at school or in the media, we see the cultural transformation and new ways of consumerism. Is it equally obvious for everyone though? Carbon footprint awareness could be a question of perception. It could be the subjective way of seeing your reality and everyday life. Other factors might play including quality of life and culture.

Sensitivity to environment, a social question? Disparities exist today over the globe in terms of ecological awareness of individuals and actions to undertake at a higher scale. To understand the phenomenon, the Environmental Performance Index (EPI) [25], developed by Yale University, is a helpful indicator which ranks 180 countries according to 32 specific indicators across 11 categories. Among them are: carbon gas emissions, forest preservation but also criteria related to actions taken by the country such as awareness campaigns, preventive measures etc... It provides an idea of the ecological performance of a country, and its "efforts to meet the targets of the UN Sustainable Development Goals" and to "move society toward a sustainable future". It represents efforts made at the level of a country, which could be correlated with the population's own efforts. Conclusions of this study (Figure 8) show that:

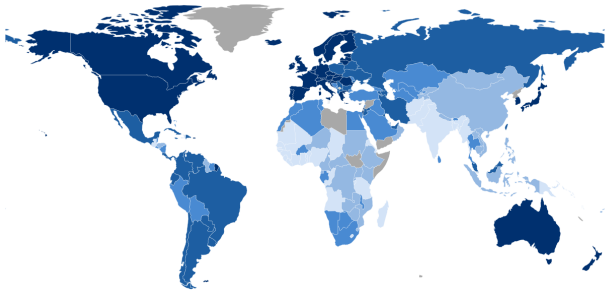

Figure 8. EPI score over the globe, from the highest score (dark blue) to the lowest one (light blue) [25]

- "Good policy results are associated with wealth (GDP per capita), meaning that economic prosperity makes it possible for nations to invest in policies and programs that lead to desirable outcomes." [25] Thus, developed and rich countries are at the top of the ranking.
- Priority is given to economic prosperity in the developing countries, showing that environmental issues are in the background. China (ranked at #120) and India (ranked at #168) are perfect examples of this situation. Knowing that China has become the country producing the most tourists worldwide, with the largest international tourism expenditure [26], it justifies that statement and shows that climate change and actions to reduce it is definitely not a priority.
- Some countries, like Nepal and Afghanistan, face challenges such as civil unrest, for which "their low scores can almost all be attributed to weak governance." [25]

Therefore, we can say that yes, it might be a social question to be sensitive to environmental issues because people with higher socio-economic status could afford alternative solutions for the environment while it might not be a priority for those with fewer resources. Low-cost carriers' worldwide market share has increased from 15.7% in 2006 to 31% in 2019 [27]. This has helped people with fewer financial resources to travel and discover the world. Thus, low-cost carriers' prices have been a factor of increase of air traffic. Is it compatible to travel with low-cost airlines while reducing carbon footprint? One could question this, because the price structure is not oriented to reduce its carbon emissions, or to invest in greener fuel (which we have seen can be very pricy so would inflate prices).

However, the correlation between environmental commitment and level of development of countries can have its limits. The Unites States of America, for example, is only ranked at the #24 of the EPI while still being a major power in the world. It can be justified by the fact that ecological decisions are not part of their political program, and maybe culture has its part in this.

A cultural approach The behaviour of people can be shaped by "institutional features, environment-related legislation, and cultural and psychological aspects" [28]. Some countries have very permissive legislation about ecology towards their citizens, therefore citizens are not really encouraged to have an environmental-friendly attitude. Those from countries with more ecological-minded legislation will more likely adopt eco-habits in their everyday life. The level of public knowledge is also a significant factor. Indeed, raising awareness on the effects of climate change can consequently lead to a positive attitude towards ecology (as it is seen in Northern European countries in contrast with China where there is rarely any awareness campaign).

Moreover, national culture is another important factor playing in the consumers' attitude. In particular, "highly individualistic societies exert the lower levels of public concern on the environmental impacts" [29]. If we take the example of China, "materialism, individualism growth and decline of collectivist values" [30] are minimising citizens' actions for the environment as a collective action.

Differences between countries and their level of acceptance is a significant challenge to overcome to make a real change in the industry by bringing people and companies together. Moreover, the industry faces strong negative opinions, especially in the media, when the facts and figures show otherwise.

3.2 Changing the vision of the industry

The reality of the aerospace industry's efforts Generally speaking, the aviation industry does not appear as a green transportation mode. It is understandable and can be justified through numerous statistics of aviation's impact on the environment that we can find online. It is usually the image conveyed by the media, and it is a thought well-rooted in people's minds. However, it is necessary to put some numbers in perspective at a higher scale (Figure 9). If we compare with other transportation modes, aviation is responsible for "12% of CO_2 emissions from all transports sources, compared to 74% from road transports" [13], as well as having a high rate of occupancy at an average of 82% [13], which is a lot more than the other forms of transports. Air transportation is the most convenient mode of transportation for high-value commodities (time-sensitive or perishable) and for long distances. Thus, around "80% of aviation CO_2 emissions are emitted from flights over 1,500km, for which there is no practical alternative mode of transport." [13] Therefore, air transportation should not be compared to road or train transportation as they are complementary modes of transport, not competitors.

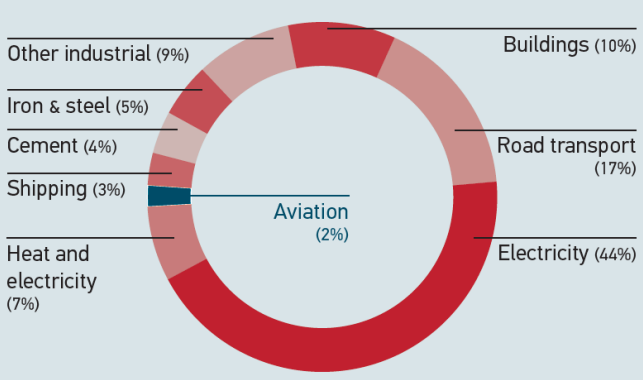

Figure 9. Proportion of aviation global energy-related CO_2 emissions (land use change emissions from agriculture or forestry excluded)[13]

Furthermore, it is important to highlight aviation's efforts throughout the years, showing a real responsibility towards carbon footprints' reduction. It has made significant gains in fuel efficiency (around 2.3% per year since 2009) driven by innovation and operations improvements, allowing a CO_2 reduction of 50% compared to a similar flight back in 1990 [31]! Moreover, jet aircraft are "over 80% more fuel efficient per seat kilometer than the first jets in the 1960s." How come these information do not reach the population and change their minds about aviation? It shows somehow that even if the innovations have been achieved, communication is key by telling stories to recall people the essence of aviation and its benefits.

Educating people, a start "Flygskam"... If this does not ring a bell, it is a popular trend on social media in Sweden created in late 2018, literally meaning the shame of flying. It is a way to point a finger at the people abusing of traveling and generating CO_2 emissions. It has had a serious effect across Europe, especially in Sweden, native country of Greta Thunberg, where passenger air traffic on domestic flights has declined by 10% from 2017 to 2019 [32]. This growing flight-shaming has nourished the image made up by people that flying is bad and made them forget the real use of aviation: sharing liberty, interests and adventures. Instead, it has only made people go against each other, blaming one another for their own personal choices. Media-bashing plays a part as well in the change of people's opinions about aviation. Media tend to present statistics about aviation without putting numbers in perspective, or mentioning the benefits of aviation... which lead to influence the moral and social norms against the core desire of air travel.

Our point of view Through it all, we believe that educating people and spreading the real values and aims of aviation is what will make them change their minds and anchor in the societies once and for all. Through school, cultural education and activities or initiations, students can fully absorb the

knowledge and values of aviation. Moreover, what better way to tackle a challenge than by using current tools? We have mentioned it before, but digitalisation really is the engine for transformation. It is known that people like tracking things, putting numbers and statistics on everything. There is a culture of knowing the origins of products and the use of it ever since digitalisation enabled it. In the aviation sector, a similar approach could be used and could help educating people: as passengers ourselves, we would like to see our real impact on the environment on each flight. As a suggestion, we could see a mobile application created, coordinated between airports, airlines and manufacturers, where we could have, of course, on-time flight information, but also a carbon footprint section. It could provide information on what impact our flight is going to have at the passenger level, a comparative study compared to other modes of transportation, and its impact on the whole ecosystem, showing raw data. Finally, it could also suggest new one-click solutions to offset the carbon emissions made by the passenger, in partnership with associations. That way, it will highly enhance the customer experience which is very valuable nowadays, but it will also bring transparency to customers, allowing them to sit back, relax and enjoy their flight.

Conclusion

When we first discovered the subject of this competition, we thought: "Okay, what does it mean to be green? What does it mean to keep flying?" The first step for us was to put down on paper everything that came through our minds related to this sentence. Once everything was written, we realised that there were tons of paths or subjects we could cover, endless possibilities to associate ideas. However, two major ideas struck us the most. First, identifying the stakeholders in this issue would help to identify the key statements of a greener aviation: institutions and politics, airlines, airports, aircraft manufacturers and its supply chain, but also and most importantly the individuals themselves (Figure 10). Second, considering a greener aviation does not only mean reducing carbon emissions, but seeing the industry as a whole ecosystem and working on the pillars of sustainable development.

The motivation of the younger generation supported by the experienced ones can open up to new aerospace revolutions in the interest of all human beings and ecological and economical preservation. The "clean plane" is a building block in the construction of a resilient carbon-neutral world. It includes operational performance improvement, implementing new technologies, development of sustainable sources of energy. Working as a whole and bringing our forces together will make us "be green and keep flying"!

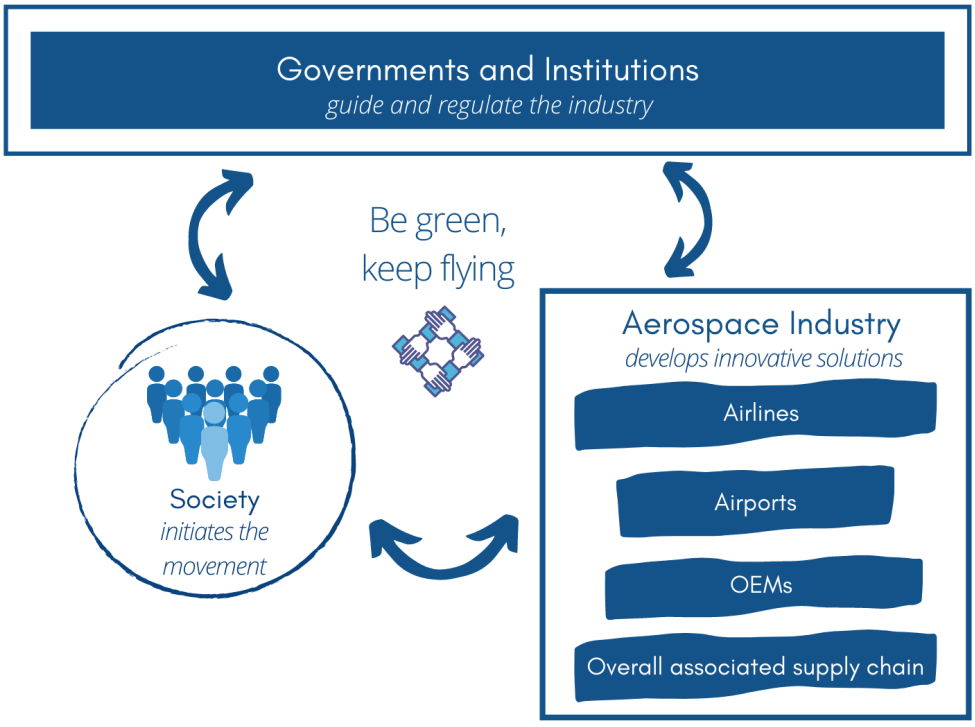

Figure 10. Stakeholders' collaboration to "Be Green and Keep Flying" as a global project

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Appendix

Regional aircraft powered by fuel cells

Revolutionary aircraft

Design mission: 80 PAX, 1,000 km range, cruise speed Mach 0.44

- **Highly efficient** wing
- **2 LH_2 tanks** behind PAX cabin - added weight: 2 tons
- **Distributed propulsion** using electric motors for thrust

Energy demand[1]	-8%
CO_2 reduction	100%
Climate impact reduction	80-90%
Additional cost	5-15% CASK[2]
Entry into service	10-15 years
Propulsion power	Fuel cell system
MTOW[3]	+10%

1. Major assumptions: 30% gravimetric index of LH_2 tank, 90% useable LH_2 fuel, FCS mass 1.75 kW/kg (incl. cooling) and 59% peak efficiency (LHV), e-motors and PMAD with 97%
2. Cost per available seat kilometer
3. Maximum take off weight

Figure 11. Regional aircraft powered by fuel cells [9]