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Green Aviation in the Age of Artificial Intelligence

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Abstract: The notion of Green Aviation is taking hold in the aviation community. Yet there is no clear definition (although some have attempted) to what it means or implies. In this article, we first bring into focus the contribution of the aviation sector to carbon emissions reduction and mitigation efforts to reduce that. We then propose our own definition of Green Aviation based on the total quality management framework and formulate a conceptual map allowing for the operationalization of the Green Aviation definition.

Keywords: Green Aviation, Environment, Climate, Carbon Neutral, Air Transportation

1.0 Introduction

The rapid advances in digital innovations and technologies continue to increase the rate of globalization development. Global transport reacts to globalization development by increasing the air travel demand. The tradeoff for this increased global connectivity is climate impact and organizational adaptation capabilities. This makes the sustainable development of the aviation industry more important and its transformation more urgent (Qiu et al., 2021, Hinnen et al., 2017, Kleiner, 2007). The exponential increase in air travel not only makes a significant impact on the climate via increased emissions but also on social ecosystem due to such interferences as noise pollution. For example, Correia et al. (2013) found that the impact of 10 decibels increase in noise levels from airports caused a 3.5% increase, on average, in hospitalization/death from cardiovascular disease. From a climate impact perspective, air transportation contributes the following: 13% of all transport carbon emissions; around 24% of nitrogen oxide emissions net effect (Lee et al., 2009); annual growth of 5%; and may surpass 7-times 1990 carbon emissions level by 2050 (International Air Transport Association, 2009). Considering these impacts on the climate and social ecosystems, focus on the sustainability of all stakeholders, who are all equally affected, including but not limited to the private sector, non-government organizations (NGO), the United Nations (UN), and cities becomes essential. This collective sustainable development ecosystem gives rise to the emergence of the notion of 'Green Aviation' (GA).

Therefore, GA can be viewed within the scope of a sustainability ecosystem entailing organizations, inter- and intra-interactions, processes, and people. In their article, Qiu et al. (2021) explains that 'green' refers to the environment characterized by friendly development, energy conservation, and protection to reduce negative influences (Hagmann et al., 2015). Subsequently, they refer to the 'Green Aviation Industry Sustainable Development' as a strategy centered around two parameters namely, environmental protection and rational utilization of resources (Vespermann and Wittmer, 2011), acknowledging it being influenced primarily by technological innovations, governmental climate mitigation policies, and organizational strategic planning (Zhang et al., 2020, Karagiannis et al., 2019, Perez-Valls et al., 2015).

If we consider environmental studies as the central theme of green aviation, then we can conclude that the body of knowledge in aviation environmental research has increased in the last 10 years, in the number of articles, number of journals, and diversity of topics, as confirmed by Chen (2017) and Qiu et al. (2021). A quick search using the Social Sciences Citation Index (SSCI) using the keywords 'Aviation' and 'Environment' in the title, results in 22 articles, most of which are in the areas of law, business environments, and pilots, with only 3 around environment. Rerunning the same keywords in the abstract, returns 453 articles, 79 in the transportation area. Further drilling down for relevancy to the environment, SSCI categories in environmental studies and green sustainable science and technology included 103 articles combined. By examining these 103 articles, only 5 were in the subject area of the environment. Finally, as a last attempt to search for publications related to the environment, we replaced the keyword 'Aviation' with 'Air Transportation'. No relevant articles were found. We found that the use of the keyword 'Climate' instead of 'Environment' produced better results with 31 articles, all of which were relevant, and most were in the areas of sustainable alternative fuels, carbon emissions, and policies/regulations. Therefore, we confirm Qiu et al. (2021) findings that the body of knowledge in the area of green aviation remains limited.

Hence, the purpose of this paper is to examine the concept of green aviation and propose a conceptual model that captures key factors and dimensions for the successful transformation of the aviation sector into a climate-friendly and sustainable zero-emissions ecosystem.

2.0 Defining Green Aviation

Before we delve directly into the sphere of green aviation, it would be worthwhile to briefly elaborate on the concept of 'green'. The term 'green' applied to aviation is a concept that has been used interchangeably with sustainability (eg. Baker, 2023). Some have even used it loosely to elaborate on the notion of sustainability, or net-zero greenhouse gas emissions. Yet, there does not seem to be any attempts to differentiate the meaning between the two, nor to provide definitions to help us better understand what they entail. Overall, it seems that the term 'green' is used to indicate a reduction of carbon emissions. Platzer (2023) associates 'green' with emission-free. However, the author does not further develop this notion of green and uses it to discuss the transition to a green global economy. In their industry information, Proponent (2017) explains that NASA perceives green aviation as an approach identified by the pursuit of enhanced aircraft efficiency via reduction of noise levels, greenhouse gas emissions, and lower carbon emissions.

In this paper, we view the term 'Green Aviation' (GA) through the lens of a Total Quality Management System (TQMS). The idea of a total quality system implies that all stakeholders engage, and that entails internal and external. In other words, this includes awareness, education, social responsibility, and talent management, among others. In addition, a total quality system also entails process, infrastructure, operations, management, strategy, and leadership. All this constitutes part of the organization. From an external perspective, a total quality system is centered around doing business with common shared values partners and with social responsibility in mind. Moreover, mechanisms that ensure not only continuous improvement, but its sustainability are necessary. Finally, climate success is an essential concept that must be adopted and represents the goal that the organization is embedded in its mission statement. The use of climate success instead of net-zero, or other similar terms, implies the flexibility for every organization to align its values with the rest of the world in what is considered as climate success. For example, that may be zero carbon emissions, net zero, or even the plan to establish a decarbonization strategy towards a goal or policy.

The above TQGAS entails three concepts that represent important components that need to be in place for GA to be realized. Organizational total quality system ❶ represents the organization's structure, governance, management, operations, culture, and performance. Continuous improvement ❷ implies that the organization has to have strategic and change management systems in place. Climate success ❸ indicates that the organization must have in place some understanding of the impact it needs to make regarding climate change. This definition can be used to develop a climate impact chain change model that defines the causal effects, namely: Awareness → knowledge → empowerment → change.

3.0 Aviation Climate Impact

Going back to 1987, the Montreal Protocol started a series of climate change initiatives whose aim was to address greenhouse gas (GHG) emissions. Moreover, the United Nation (UN) framework convention - UNFCC, the Kyoto Protocol (2005), the Paris Agreement (2015), and the United Nation's Sustainable Development Goals (Sachs et al., 2019) have all taken steps to establish frameworks and policies for carbon emission reduction. Today, climate change is viewed globally as a major challenge. The intensifying debate is an indication of ever-increasing global climate activities, whereby the center of the argument revolves around how to manage it. The lack of a timely global response has resulted in worldwide dissatisfaction with climate initiatives as the global temperature continues to increase with devastating environmental impacts that everyone is experiencing with severe, floods, hurricanes, fires, etc…

Recently, the International Civil Aviation Organization (ICAO) which was tasked by the 1997 Kyoto Protocol to prepare policy measures to reduce international aviation Green House Gas (GHG) emissions, has in 2016 at the A39-3 ICAO assembly, produced a carbon emission reduction scheme (see CORSIA, Carbon Offsetting and Reduction Scheme for International Aviation). There does not seem to be a consensus from the literature regarding the effectiveness of CORSIA's implementation such that researchers raise important challenging questions related to the viability of carbon emission reduction (Prussi et al., 2021, Sharma ae al., 2021).

It is therefore essential (can be even said to be existential) that the aviation sector transforms itself into a more climate-friendly industry via an innovative paradigm following a green strategy as a global conglomerate consisting of green organizations, operations, supply chain, services, focused on social responsibility, carbon-neutral growth plans, and shared green values. This cannot be stressed enough considering the following (Lyle, 2018, ICAO, 2020, Zhang et al., 2021, Fowlie et al., 2019, Wan and Zou, 2009Lu and Shong, 2012):

1. The aviation industry accounts for over 5% of the total greenhouse gases
2. Tourism contributes over 3% of total aviation emissions
3. Aircraft engines emit greenhouse gases (carbon dioxide (CO2), aerosols (sulfates and soot), nitrogen oxides (NOx), sulfur oxides (SOx), hydrocarbons (HC), carbon monoxide (CO), heat, soot, and other atmospheric particulate matter (APM – incompletely burned hydrocarbons, sulfur oxides, and black carbon)) in the layers between the stratosphere and troposphere
4. The GHGs aviation emissions contribute to global warming, affect ozone layer formation, alter radiative forces, and reduce methane levels
5. Aviation emissions can exceed ground transportation emissions in terms of impact on the environment by up to five times
6. CO2 contributes most to harmful gases
7. Advances related to increased efficiencies for the reduction of aviation emissions are small compared to growth in the air transportation industry
8. Forecasts show that the demand for aviation fuel will conservatively increase by 2% annually resulting in up to seven times more global carbon emissions by 2050 (as compared to 2019 levels).

Despite the various climate agreements, CO_2 levels continue to rise in the atmosphere at an alarming rate. An important challenge entails aviation in open seas and the airplane is flying across international space with no sovereign jurisdiction/borders. Another challenge is compliance and voluntary markets carbon offsetting (Zheng et al., 2019) – both being difficult and complex to manage. Volatility and sensitivity to market pricing due to uncertain and uncontrolled conditions are part of compliance markets. The other entails the purchasing of carbon credits to offset emitted GHGs from other sources. For example, CO_2e prices may vary from US$0.5 to US$50 per ton.

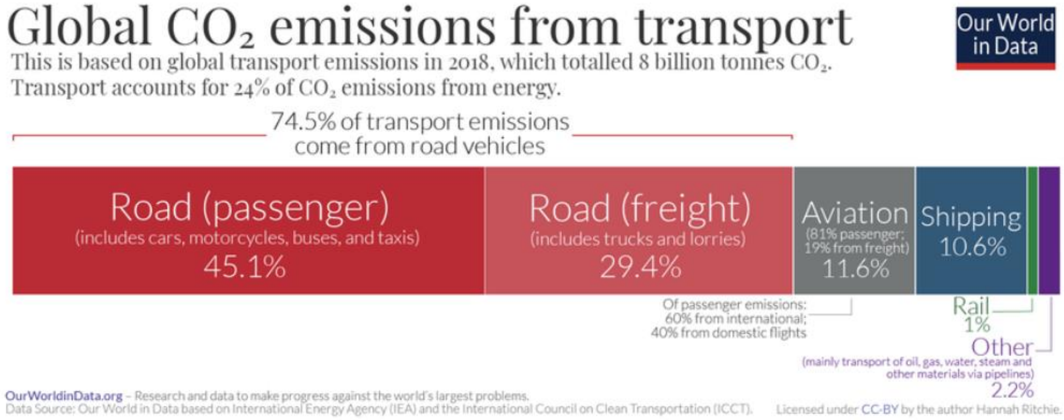

Figure 1. Aviation CO2 in perspective (Our World in Data).

As mentioned earlier, the global CO2 emissions of around 3% from aviation may seem small, but these emissions affect the climate more detrimentally due to the emissions being released into the atmosphere. Figure 2 shows the global CO2 emissions from the transport sector, reported by our world in data, contributed by cars and trucks (road), aviation (passenger and freight), shipping, Rail, and others. It is estimated that aviation is responsible for around 12% of those emissions, 81% of which are from passengers. Moreover, aviation emissions, also emit greenhouse gases which alter the atmospheric conditions in complex ways we still do not fully understand.

What we do know is that aircraft emissions

1. Change the concentration of other gases and pollutants in the atmosphere.
2. Short-term increase, and long-term decrease in ozone (O_3)
3. Decrease in methane (CH_4)
4. Introduction of water vapor, soot, sulfur aerosols, and water contrails into the atmosphere
5. Some effects cause warming, while others cooling.

Lee et al. (2020) calculated the 'Radiative Forcing' which measures the difference between incoming energy and the energy radiated back to space. If more energy is absorbed than radiated, the atmosphere becomes warmer. When all effects are combined, they find that aviation accounts for approximately 3.5% of effective radiative forcing: that is, 3.5% of warming. It is worthwhile noting that although CO2 is being primarily considered for the reduction of aviation emissions, it accounts for less than half of this warming. Two-thirds (66%) is attributed to non-CO2 forcings, while Contrails – water vapor trails from aircraft exhausts – account for the largest share. Figure 1 presents the contribution of global aviation to anthropogenic climate forcing for the period 2000 – 2018. This figure depicts that in 2018, the global CO2 emissions from aviation were estimated at 1.04 billion tons of CO2, assuming 4-5% annual growth since 2010 when the emissions were calculated a just above 700M tons. Therefore, in 8 years, there was an increase of over 40% in aviation CO2 emissions.

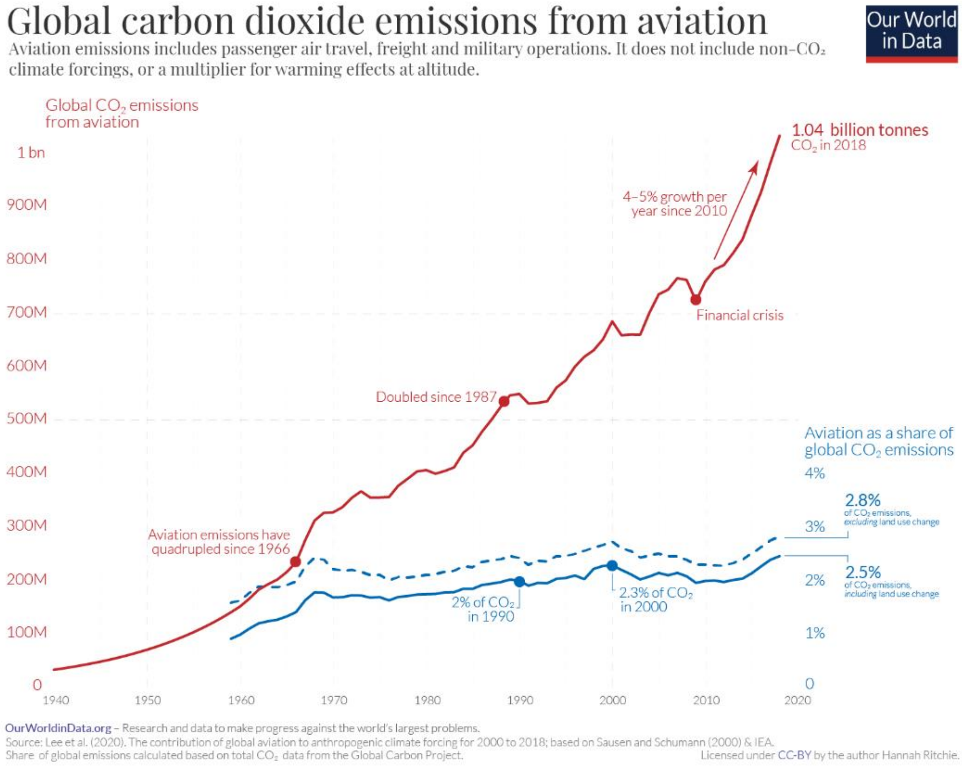

Figure 2. Aviation global CO2 emission from 2000 - 2018 (Our World in Data).

4.0 Key Mitigation Areas for Carbon Emission Reduction

The global trend for carbon emissions reduction is now the primary driver for governments to implement policies that are ushering in transformative innovations in various key areas across the aviation sector. This includes noticeable impact chains along the aviation supply chain, including the service sector. As such, policies have focused on setting a common environmental path toward carbon neutrality. This has influenced operations, technology, consumer behavior, geopolitical relations, global governance, and international collaborations. These key areas can be summarized as follows:

1. Airlines and aircraft manufacturers are incentivized to facilitate innovation and invest in cutting-edge technologies, fostering the development of fuel-efficient engines, lightweight materials, and innovative aerodynamic designs.
2. Funding for research and development has increased significantly to facilitate efforts in response to policies that drive the industry towards a future where sustainability and efficiency are at the forefront of aviation technology. Moreover, government funding and grants, often tied to environmental goals, play a pivotal role in driving research and development within the aviation industry. These funds support projects focused on developing new technologies, alternative fuels, and operational improvements.
3. Airlines are investing in SAF research, production, and integration into their operations. Consequently, the aviation industry is attempting to move away from its heavy reliance on traditional fossil fuels towards cleaner, renewable alternatives.
4. Airlines are continuously engaged in various methodologies to optimize their operational processes. Initiatives aimed at improving air traffic management, reducing taxiing times, optimizing flight routes, and enhancing ground operations become imperative.
5. Carbon Offsetting and Pricing: Carbon pricing mechanisms, such as emissions trading schemes and carbon taxes, are pivotal components of emission reduction policies. These mechanisms impose a financial cost on carbon emissions, compelling airlines to minimize their emissions to avoid economic penalties.
6. Efforts are being made to raise awareness about the environmental impact of aviation among consumers. Passengers become more conscious of their travel choices, and airlines respond by adopting greener practices to align with customer expectations. Awareness campaigns, driven by these policies, educate passengers about the

environmental consequences of air travel. Consequently, passengers become more conscious of their travel choices, often preferring airlines that actively participate in emission reduction initiatives. This shift in consumer preference encourages airlines to invest in greener practices, aligning their services with the expectations of environmentally conscious travelers.

5.0 Conceptual Model for Aviation Climate Change

From a high-level perspective (see Figure 3 below) it is important to establish a global forum, for the exchange of ideas, knowledge, and best practices, between Private Industry, Public Organizations (such as the United Nations), Governments, and Higher Education Institutions. All these stakeholders play an important primary role in enhancing awareness and providing accurate information regarding the aviation sector and climate change.

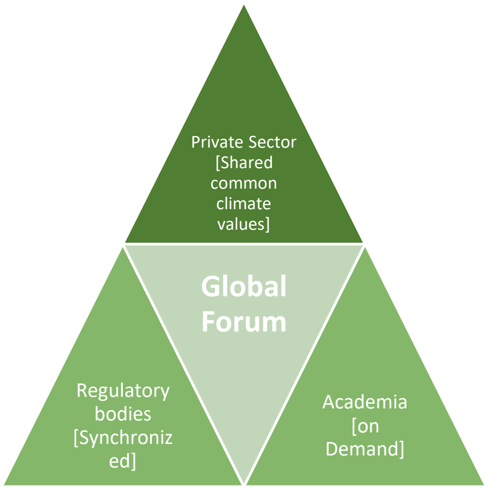

Figure 3. Global forum as a hub for aviation knowledge.

It is worthwhile noting that there is a serious global education and research gap in the world of aviation, and no one has yet addressed this issue. Moreover, climate change, in general, and carbon emissions reduction, in specific, increased this gap as the latest research has shown. There seems to be great interest from different stakeholders, but none have taken the necessary steps towards reducing that gap. As members of the three counterparts of the global forum, all stakeholders should take responsibility in engaging across the four aviation-climate-impact-chain (ACIC) shown in Figure 4 namely, awareness, knowledge creation, empowerment, and change.

Awareness: Review, update, and build a harmonious relationship between stakeholders, by collaborating and co-operating within common shared values and interests. These stakeholders, namely manufacturing, airlines, airports, training and educational institutions, associated organizations in the service sector, governments' aviation authorities, and the United Nation's aviation system stakeholders.

Knowledge Creation & Dissemination: The building of a network of global leading universities, and international expert panels, where universities will collaborate to offer unique non-competing courses leading to various types of Green Aviation Management degrees and training certificates. A newly created green aviation knowledge network will consist of strategically configured International Expert Panels (EP): regulatory, corporate; airline; airport; services; and education/training. All will be engaged in the future of global green aviation.

Empowerment: Empowerment of students and professionals should be a central focus which could be done through capacity building, capabilities development, consulting, mentorship, and other programs.

Change: Through empowerment, enhanced understanding of green aviation, harmonization of green aviation knowledge across geopolitical boundaries, and innovative creative thinking, decision-makers will be in a better position to balance aviation climate obligations, global aviation development and growth, and public perceptions and travel behavior.

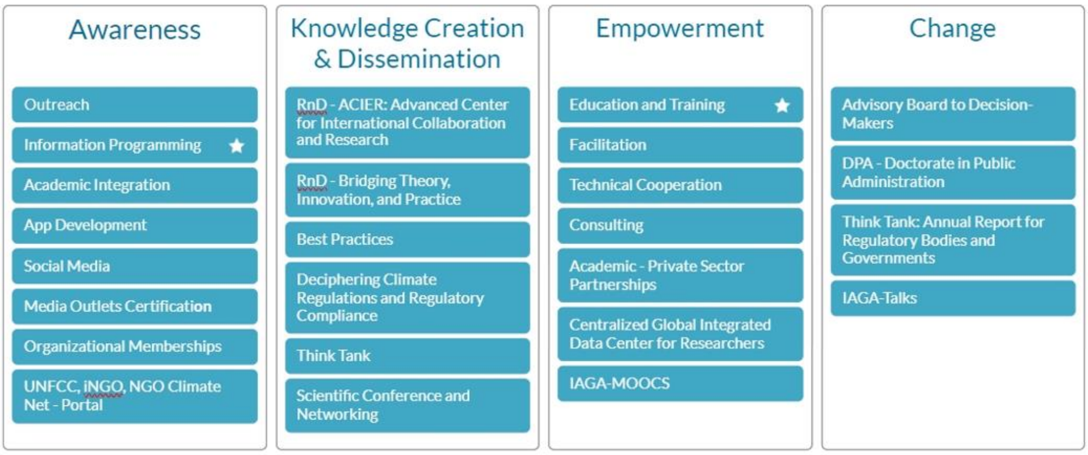

Figure 4. Conceptual model for the global forum of the Aviation Climate Impact Chain (left to right).

6.0 Discussion & Conclusions

Aviation's contribution to climate change may be perceived to be relatively less important compared to other sectors. One may even think that aviation emissions are currently a relatively small proportion compared to other areas of transportation. However, aviation emissions do not occur at ground level but rather in the atmosphere, which makes them unique in terms of the significance of climate impact. Aviation emissions stem predominantly from the combustion of aviation fuel in aircraft engines. The staggering scale of aviation emissions necessitates urgent action.

Experience so far has shown that it is particularly challenging to decarbonize the aviation sector. Decarbonizing other sectors such as power and road transportation is currently being scaled as some solutions (adequate or not is up for debate) have been adopted and are in place. However, solutions to tackle aviation decarbonization are yet to be determined. The proposals today are still under development with no clear indication of effectiveness and time.

The horizon contains several innovative solutions but the time for realization of these solutions is not clear. This is due to the fact that these innovative solutions cannot keep pace with demand such as that of passenger traffic in the travel sector which is growing at 7% or more a year. Thanks to COVID-19, the nature of the business not only has changed but continues to change in an accelerated fashion. Global air transportation has become very networked, and increasingly connected.

Yet, looking at current trends, we can safely say that the aviation industry is in its infancy in terms of global connectivity, and its growth is becoming exponential, such that it is playing an important role in changing the notion of globalization, and geopolitical relations. However, its success comes with significant environmental costs. This study investigates the intricate web of aviation-related carbon emissions, examining their sources, impacts, challenges, and most importantly, potential solutions, and proposes a conceptual map that we believe is fundamental in increasing success towards green aviation (carbon neutral).

Addressing aviation emissions requires a multifaceted multidisciplinary approach. Sustainable Aviation Fuels (SAFs) present a promising alternative, derived from renewable sources. Continued investment in technological innovations, such as electric and hydrogen-powered aircraft, holds the key to a greener future. Operational efficiencies, including optimized flight routes and advanced air traffic management systems, can reduce emissions substantially. Policy interventions, such as stringent emission standards and carbon pricing mechanisms, provide economic incentives for airlines to adopt cleaner technologies. Education and advocacy efforts can raise awareness, influencing both consumer behavior and corporate practices.

Mitigating aviation emissions demands immediate and concerted efforts from all stakeholders involved. The challenges are significant, but the urgency of the climate crisis leaves no room for complacency. By investing in sustainable technologies, implementing effective policies, and fostering a collective sense of responsibility, the aviation industry can navigate the complexities of its carbon emissions and transition toward a more sustainable future. This, we believe, can be facilitated by the Aviation Climate Impact Chain concept proposed.

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