Submitted chapter to SUSTAINABLE ALTERNATIVES FOR AVIATION FUELS Book 2021 (Elservier)

Governance and policy developments for Sustainable Aviation Fuels

Marina Efthymiou, Dublin City University Business School Glasnevin, Dublin, 9, Ireland

Tim Ryley, Griffith Aviation, Griffith University, Brisbane, Australia

The environmental need for Sustainable Aviation Fuel governance and policy

The focus of this Chapter is on the governance and policy rather than technical aspects of developing Sustainable Aviation Fuels (SAF). It starts with an argument for the environmental need for SAF governance and policy. The subsequent section provides a policy framework for Sustainable Aviation Fuels, followed by some ongoing policy concerns and learnings from these developments. Finally, conclusions are provided.

This topic needs to be set in the broader context of **sustainable development**. Implicit in the sustainable development concept, is the requirement to meet “the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p.41). This future dimension approach aligns with the long-term planning and development of alternative aviation fuels. Sustainable development does have a core tension between economic and environmental goals, although the original concept also incorporates other elements such as population growth, poverty, technology and social organization. Sustainability solutions are also meant to incorporate three ‘pillars’, according to economic development, social development, and environmental protection aspects (UN General Assembly, 2005, p11). Using this **sustainability pillar framework**, aviation is arguably economically and socially sustainable, but it is the environmental sustainability challenge which is greatest and hence the focus of this Chapter.

The **environmental impacts of aviation** are listed in Table 1. Most of the focus on environmental sustainability concerns relates to the first impact in the Table of climate change. Yet when considering sustainable alternative aviation fuels, it partly the limited resource of oil as a major concern for the current fuel source. The other impacts listed in the Table show the wide range of over-lapping environmental impacts of aviation across the full range of spatial scales from local right up to global implications.

Environmental impact	Description
1. Climate change & air quality	Global (e.g. carbon dioxide) & local (e.g. carbon monoxide, nitrogen oxide) pollutants
2. Energy & mineral resources	Energy resources (mainly oil-based), infrastructure construction materials
3. Land resources	Infrastructure land
4. Water resources	Pollution (surface run-off, oil), change to water systems from infrastructure construction
5. Solid waste	Scrapped aircraft, waste oil / tyres
6. Biodiversity	Impact on wildlife habitats from infrastructure construction
7. Noise & vibration	Proximity airports, as well as access by connecting roads & railway lines
8. Built environment	Structural damage to infrastructure, property damage, building corrosion from local pollutants

9. Health	Death & injuries from accidents as well as local pollutants & noise disturbance

Table 1: Environmental impacts from aviation

There has always been a globally changing climate, but in recent times it has been possible to statistically link changes associated with the increased level of key greenhouse gas emissions to human activity. This is causing an increase in the earth's average temperature. Most scientists and the wider population would agree that there is the **climate change** phenomenon (*see IPCC, 2014)*.

Aviation is a major contributor to greenhouse gas emissions. Even though aviation-related emissions make up a small proportion of the global contribution to climate change, there is a major concern relating to the growth in air travel (Schafer & Waitz, 2014). The aviation sector will take an increasingly significant proportion of any carbon budget and is one of the hardest to reduce emissions at a time when a major reduction is required (Gossling & Humpe, 2020).

Much debate focuses on the scale of the problem and how to respond. This includes technological solutions and the implementation of alternative aviation fuels, one of a suite of **mitigation measures** to reduce environmental impacts. The focus on fuels is partly due to the lack of development possibilities with aircraft design over the timeframe required for environmental improvements. Aircraft have a very long lifespan and existing aviation infrastructures are very difficult to adapt and update.

Governance of Sustainable Alternative Fuels

The 1999 report "Aviation and the Global Atmosphere" published by the Intergovernmental Panel on Climate Change (IPCC) is an important milestone for governance and policy formation of climate change mitigation. The report found that aviation's impact will be far greater in 2050 unless new technologies and operational modes are developed. In 1983, the **International Civil Aviation Organization (ICAO)** established the Committee on Aviation Environmental Protection (CAEP). CAEP assists ICAO in formulating new policies and adopting new international Standards and Recommended Practices (SARPs) relating to aircraft noise and emissions and includes an Alternative Fuels Task Force (AFTF) that provides technical input. ICAO resolution A38-18 on climate change recognizes the role and importance of alternative fuels and the needs for coordinated policies and sustainability criteria. In 2016, the ICAO Assembly adopted Resolution A39-2: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change. ICAO set a 2% annual fuel efficiency improvement through 2050 and carbon-neutral growth from 2020 onwards goals (Figure 1). A basket of measures that includes SAF can assist aviation to reach these two global goals.

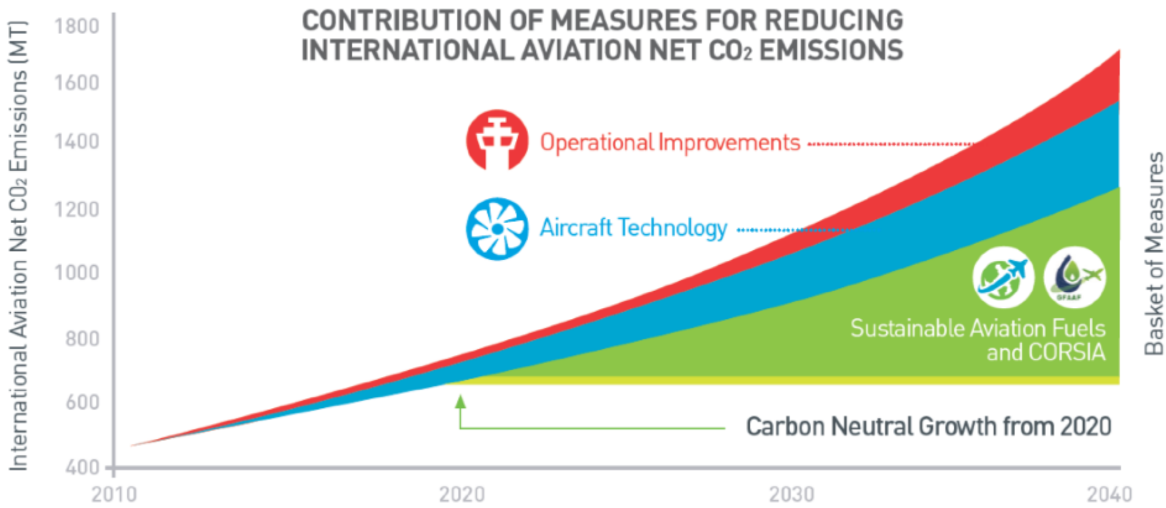

Figure 1: Contribution of measures for reducing international aviation net CO_2 emissions (ICAO, 2019a)

The most significant in terms of effect and scale in terms of an environment-related project is ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a market-based measure. With CORSIA, aircraft operators should comply with emissions commitments by offsetting emissions through "offset credits" from crediting mechanisms and "allowances" from emissions trading schemes. Aircraft operators can claim emission reductions from the use of biofuels only when the fuel complies with the ICAO sustainability criteria and is categorised as SAF (ICAO, 2019).

The **European Commission** has a long-established trading scheme. The European Union Emissions Trading Scheme (EU ETS) is one of the main instruments used by the EU to reach the statutory reduction of GHG targets. In 2008, the European Parliament and the Council adopted a new law, Directive 2008/101/EC, amending the EU ETS (Directive 2003/87/EC) to include aviation activities. In a similar manner to CORSIA, the EU ETS provides an economic incentive to aircraft operators to use SAF by attributing them zero emissions under the scheme and thereby reducing the number of ETS allowances it has to purchase. The EU recognises that while SAF use is still limited, the contribution of SAF to decarbonising aviation is important. From 2013 to 2020, a total budget of €464 million has been provided to R&D to study advanced biofuels and other renewable sources, of which €25 million has been specifically allocated to SAF (EASA, 2019). EU has a target of 40% SAF by 2050.

A significant issue with the governance of biofuels is that while the scientific understanding of the negative effects of biofuels is increasing, stricter sustainability criteria have been imposed. This leads to high levels of uncertainty and investment risk for biofuel producers. Moreover, there is no standardisation for the biofuel's sustainability criteria. In the case of SAF, where the majority of aircraft operators need to comply with CORSIA, ICAO sustainability requirements provide some guidance to SAF users and producers.

In 2009, the **International Air Transport Association (IATA)**, as the trade association for the world's airlines, has set three environmental targets: a) an average improvement in fuel efficiency of 1.5% per year from 2009 to 2020, b) a cap on net aviation CO2 emissions from 2020 (carbon-neutral growth) and c) a reduction in net aviation CO2 emissions of 50% by 2050, relative to 2005 levels. In order to reach the 2050 target, SAF are required. The main role of IATA in relation to SAF is recommending and influencing policy, as well as providing expert input through relevant working groups.

Policy framework of Sustainable Aviation Fuels

Fossil fuels are an exhaustible source of energy for aircraft and fuel is a significant cost for commercial aviation that represents 30% of their total operating cost. Airlines respond to the increasing public and political pressure to reduce their emissions by investing in fuel-efficient technologies and operational practices (Efthymiou, 2021; Efthymiou and Papatheodorou, 2020). Frequently, they follow fuel-hedging strategies or, in some rare cases, invest in vertical integration by buying oil refineries (e.g. Delta airlines). With biofuels being significantly more expensive than fossil fuels (2-3 times more)[1], airlines have no significant financial incentive to use them and trigger the supply of SAF. Yet, some carriers like Lufthansa and KLM have used biofuels as part of specific projects that aim to SAF. Policy frameworks can drive the production and use of biofuels due to the lack of economic incentives for the aircraft operators and encourage a more sustainable path for aviation.

Climate change and environmental degradation have been acknowledged as threats by regulators who have implemented several regulations for airlines like the Emissions Trading Scheme (Efthymiou, 2021; Efthymiou and Papatheodorou, 2019) and service providers like the Single European Sky (Efthymiou and Papatheodorou, 2018). Governments are committed to sustainability targets. Therefore, they need to encourage initiatives that reduce carbon emissions. The European Green Deal for example aims to boost the efficient use of resources by moving to a circular economy and to restore biodiversity and cut pollution. The decarbonisation of air transport is a central element in the agenda, with sustainable alternative fuels playing a key role.

Countries have set indicative targets for the share of renewable fuels in their total fuel consumption. Many biofuels policies have been developed and implemented to encourage the supply and demand for biofuels. Many of the policies are not specific to aviation or even exclude aviation. Yet these policies influence SAF as they encourage biofuel production and biofuel R&D overall. Across developed and developing counties there have been goals to implement biofuel policies for energy supply diversity (e.g. Malaysia's Fuel Diversification Policy), environmental improvement, creation of new outlets or demand for agricultural products, regional development and enhanced economic activity (e.g. South Korea) reasons (OECD, 2008). There are a variety of supply-side (e.g. subsidies to SAF producers) and demand-side (e.g. SAF mandates) policy tools that can support the 'missing SAF market' issue. Ebadian et al. (2020) categorise the policies to technology-push and market-pull types of policies.

Policy intervention in the case of biofuels is justified based on the welfare maximization argument where the government intervenes to correct market failure (e.g. an externality) and improve allocative efficiency. Biofuels without regulatory support would remain an underinvested private sector with lacking skills and capacity as well as high uncertainty. From a political economy point of view, public intervention is a rent-seeking behaviour of politicians and bureaucrats. In any case, public intervention should aim to correct the market failure in the most effective and efficient way. Considering that environmental externalities are diverse and not easily quantified, policies are often complex and can even fail. Few of the most popular instruments are command and control regulations, economic incentives and disincentives (e.g. Pigouvian taxes) and Market Based Measures (Efthymiou, 2021; Efthymiou and Papatheodorou, 2020).

Several initiatives and policies of the federal government promote alternative fuels. The main regulatory framework in the US is the Energy Policy Act that introduced the Renewable Fuel Standard (RFS) and the Farm Bill. The policy schemes are concentrated in fossil fuel/biofuel blend mandates, tax credits for producers and suppliers, financial help for new and expansion of existing biofuel supply and production facilities, reduction of import duties for some kind of biofuels, incentives to manufactures for production and sale of alternative fuel vehicles and funding for R&D (Noh et al., 2016). RFS for example, requires U.S. transportation fuel to contain a minimum volume of renewable fuel. The RFS is a market-based compliance system in which involved parties have to submit credits (Renewable Identification Numbers known as RINs) to cover their obligations. The statute focuses on

[1] A typical price for fossil-based aviation fuel would be €600/tonne, the price of aviation biofuel produced from used cooking oil can be in the range of €950-€1,015/tonne (EASA, 2019)

four renewable fuel categories—conventional biofuel, advanced biofuel, cellulosic biofuel, and biomass-based diesel—each with its own target volume (Renewable Volume Obligation) legislated by the Energy Independence and Security Act of 2007 (EISA). The Biorefinery Assistance Program, established within the Farm Bill, provides a loan guarantee for companies that turn waste into renewable jet fuel.

The most important legislative measures related to biofuels in Europe are the Renewable Energy Directive (RED), the Energy Taxation Directive and the Directive on the Quality of Petrol and Diesel Fuels (FQD). RED (2009/28/EC) requires that 20% of the EU's energy needs should come from renewable sources by 2020, and includes a target for the transport sector of 10% from biofuels while it considers sustainability criteria. EU member states adopt individual targets following current shares and other indicators (such as GDP) and SAF contribute to achieving these targets. A specific multiplier of 1.2 is to be applied to the quantity of SAF supplied, in calculating its contribution towards renewable energy targets (EASA, 2019). The revised Renewable Energy Directive 2018/2001/EU, commonly known as RED II has a new target of at least 32% renewable energy in the EU by 2030 and ranges from a low of 10% in Malta to a high of 49% in Sweden. RED II has also enhanced the sustainability and GHG criteria for produced and consumed bioliquids in the EU. Transport must comply with these criteria for them to count towards the overall 14% target and to be eligible for financial support by the authorities.

There are also transport dedicated policy initiatives and regulations like the Directive 2003/30/EC (EU, 2003), on the promotion of the use of biofuels or other renewable fuels for transport. The European Union has launched the 'Initiative Towards Sustainable Kerosene for Aviation' (ITAKA) to produce sustainable bio-jet-fuel at a large enough scale to test its use in normal flight operations. The 'Aviation Initiative for Renewable Energy' in Germany (AIREG) and 'Bioqueroseno' in Spain, are also pursuing the development of a sustainable bio-jet fuel industry. The European Advanced Biofuels Flightpath (EABF) initiative, introduced in 2011 and part of the EU strategic energy technology plan, aimed to establish a functioning supply chain for bio-kerosene and achieve 2 million tons of sustainable biofuels to be used in aviation by 2020. EABF among others focuses on the establishment of financing structures, certification frameworks and acceleration of targeted research and innovation.

Considering the lack of economic viability of biofuels due to high production cost, supply-side policies can encourage the production of biofuels. **Subsidies** to the energy sector is a very common practice. The world's total, direct energy sector subsidies (including those to fossil fuels, renewables and nuclear power) are estimated to have been at least USD 634 billion in 2017 with the cost of unpriced externalities and the direct subsidies to fossil fuels exceeding the subsidies for renewable energy by a factor of 19 (Taylor, 2020). Direct subsidies for biofuels were only 6% (USD 38 billion) of the total amount and mainly came from the European Union (USD 11.4 billion) and the United States (USD 14.1 billion).

Biofuel supply subsidies can be direct and indirect or can be direct subsidies per output of biomass (e.g. a subsidy to a farmer according to the volume of production) or can be general input subsidies that may not be direct subsidies for the production, but have an indirect effect on the production costs of biomass (e.g. subsidy on fertilisers). Therefore, subsidies can take many forms, for example, free access to water or subsidized irrigation water, crop subsidies, labour subsidies, below-market access to public lands, load guarantees and investment incentives. IATA (2015) suggests that economic instruments are beneficial for starting a market, but become expensive in sustaining the market.

Technology-push policies encourage early-stage technology development such as R&D, demonstration and commercialization of SAF, whereas market-pull policies support low-risk pre-commercial and commercial biofuel technologies (Ebadian et al., 2020). It is essential to push **funding on research on technology**. A good example of a supply-side policy to biofuels production is the Biomass Crop Assistance Program (BCAP) in the US. The BCAP provides three types of payments to producers of dedicated energy crops. It provides feedstock establishment payments that lower the planting cost by 50%, annual land rental payments for up to five years and matching payments of up to \$45 Mg^{-1} of feedstock partially covering the cost of collecting, harvesting, storing and transporting biomass to a biorefinery for up to two years. The BCAP financing lowered the expected cost and investment risk for the biofuel industry program and motivated farmers to switch to lignocellulosic biomass (LCB) crops. Denmark has allocated €14 million as deficit guarantee for new biorefineries (Ebadian et al., 2020).

The supply-side policies aimed at the reduction of the supply cost including the cost of infrastructure. This can be in the form of **capital grants** partly financing a renewable fuel installation. A system of guaranteed loans underwritten by authorities or capital allowances is another option. Load guarantee programs have primarily funded biofuels in the later stages of development and demonstration, whereas grants are mainly used for SAF technologies at the pilot and demonstration phases. A tender selection process that grants a license can reduce the risk for the firms while ensuring some robustness in the funding process. Commercialisation of the biofuels should rely on technology-neutral financing to encourage competition for funds between different technologies and innovative projects. Public-private partnerships to commercialize the production of biofuels may be a way forward. International collaboration is also common. In 2011, the US and Brazil signed a Memorandum of Understanding to cooperate on the development of renewable aviation biofuels

The **distribution** of biofuels is also of importance. The aviation industry wants to use the same distribution systems as fossil fuels, yet distribution remains challenging as it needs technical capacity and core skills for deploying and handling SAF. International agreements are key to delivering biofuels to big international hub airports. The most challenging part of this process is the transportation from the refinery to the airport, but also the handling at the airport environment. Existing supply systems have supplied biofuel to airlines (e.g. at Oslo Gardermoen Airport and San Francisco International Airport). SAF distribution can be encouraged by funding schemes.

A **guaranteed price for biofuel** produced is less used. The most well-known example is that of Indonesia. As part of the National Biofuel Policy, the state-owned oil company Pertamnina sold 5% biofuel blends to local markets at the same price as fossil fuel. The key policy instruments increasing the consumption of SAF are **blending mandates** and **tax exemptions**. Brazil has tax incentives for biofuel producers, blenders and users. Noh et al. (2016) suggest that tax exemptions are easier to be applied to production and distribution rather than consumption and that blending mandates in aviation can be applied by using tradable certificates like for example the RINs[2] in the US. The Malaysian government introduced the Pioneer Status of Investment Tax Allowance (ITA) under the Promotion of Investments Act of 1986, whereby a company with pioneer status is granted tax exemption on at least 70% of the income derived from the biodiesel production for 5 years.

Low-carbon fuel standards (LCFS), initially implemented in California in 2011 and later to other states in the US, require a 10% reduction in the carbon intensity of transportation fuels by 2020 and a 20% reduction by 2030. This policy includes both fossil fuels and biofuels. Fuels that can be produced at a lower carbon intensity compared to their petroleum-based counterparts generate higher carbon credits and therefore they reward efficiency and encourage on-going innovation in biofuels.

Fuel blending mandates are a very common policy implemented at both the national/federal and state/provincial level aiming to encourage both SAF supply and demand. Ebadian et al. (2020) determined that increasing blending mandates in Brazil, Canada, Japan, the Netherlands, South Korea, Sweden and the US are increasing the production and use of biofuels, whereas mandates that remained stable in Austria, Denmark, Germany and South Korea led to a fairly flat biofuels production

[2] Renewable Identification Number is a numeric code assigned to a biofuel package, identifying its vintage, volume and fuel classification.

and use. They argue that the lack of blending mandates for biodiesel in Japan and ethanol in South Korea is to blame for the slow market development.

Several countries have now introduced blending mandates for aviation fuels at the supplier level. Canada has a federal mandate of 5% for ethanol and 2% biodiesel, whereas British Columbia, Alberta, Saskatchewan, Manitoba and Ontario have established a blending requirement of 5%–8.5% for ethanol and 2%–4% for biodiesel. According to Ebadian et al. (2020) the use of ethanol and biodiesel has increased at an annual rate of 30% and 10%, respectively since 2010. Finland has set a 30% blending mandate for SAF by 2035. France has a target of 2% by 2025, 5% by 2030 and 50% by 2050. The Norwegian government set a 0.5% blending mandate that will increase to up to 30% by 2030. While blending mandates are widely used, they are not enough to grow or maintain biofuel markets due to lack of or high cost of feedstock, shortage of infrastructure and sustainability concerns according to Ebadian et al. (2020). Mandates are largely based on the volume or energy content of biofuel rather than the decarbonisation potential. Table 2 summarises the strengths and limitations of the various policy instruments.

Policy instrument	**Strengths**	**Limitations**
Biofuel blending mandates	- Effective for developing a biofuel market at the early stages - Effective in establishing biofuels markets and in shielding biofuels from low oil prices - Greater certainty of increased development - Broadly effective to support relatively mature technologies, as they create a demand for biofuels, which is typically met with commercial conversion technologies such as conventional ethanol or biodiesel	- Need to balance costs of infrastructure while demand is low in the early stages - Need suitable governance to ensure compliance - Not necessarily as useful in expanding /maintaining markets - Not necessarily successful for meeting GHG reduction targets - Limited in their capacity to pull early-stage technologies into the market, since these are often not yet fully commercially viable, or are typically more expensive to be produced commercially - struggling to compete against first-generation conventional biofuels
Excise duty reductions/ exemptions	- Increases the competitiveness of biofuels with fossil fuels, especially at early stages of development, if fossil and renewable fuels are taxed differently - Can also be considered for the production of biomass such as dedicated biomass crops (e.g. switchgrass) to ensure sufficient feedstock for the production of conventional and advanced biofuels and ultimately the achievement of mandates for use - Broadly effective to support relatively mature technologies, as they create a demand for biofuels, which is typically met with commercial conversion	- As fuel excise rates vary, this may not be a strong enough driver to foster the biofuels market as a stand-alone policy - Limited in their capacity to pull early-stage technologies into the market, since these are often not commercially viable, or are typically more expensive to be produced commercially - struggling to compete against first-generation conventional biofuels

	technologies such as conventional ethanol or biodiesel	
Research, development and demonstration funding and financial de-risking measures	- Necessary to support early market technology development and initial commercial projects with longer-term market potential but high investment risk - Successful in de-risking technology and catalysing private investment for subsequent stages, somewhat sparing public budgets as technologies advance into commercial stages	- Financial risks associated with potential project failures

Table 2: Strengths and limitations of selective biofuels policies (Ebadian et al., 2020: 9)

Policy concerns and learnings

Policies are frequently accused by environmental groups of not being **ambitious** enough and properly implemented. **Political feasibility** is a common concern for regulatory authorities. In policies that address a global concern collaboration is needed and many times the decision-makers of the various countries may have diffident beliefs, targets and priorities. CORSIA for example has been characterised of having a low ambition and being too compromised. Reaching an agreement among 193 member states for CORSIA is an important step towards decarbonising air transport.

Moreover, the initial policy frameworks and regulations did not consider some shortcomings related to the development of biofuels mainly due to the lack of scientific understanding. Firstly, regulations ignored the effect of biofuels on food production. Biofuels competed with **food production** in terms of land. Farmers switched to biofuels resulting in an increase in food prices. For example, BCAP subsidies may lead more food cropland to be converted for biofuel crops, creating the unintended consequence of land competition for food versus fuel use affecting the food supplies and prices globally. With certain regions facing issues with limited or lack of arable land, biofuel production can have a significant effect on food production capability. Thus, subsidies for biofuels need to comply with strict sustainability principles as they may unintentionally encourage land-use changes.

Indirect environmental effects related to the biofuel production is of concern to the regulators (Noh et al., 2016). The use of nitrogen fertilisers to increase the produced quantities of biofuels is connected to N_2O emissions. Indirect Land Use Change (ILUC) is also another acknowledged significant issue with negative effects on the environment. While the scientific understanding of biofuels and their effects is achieved, regulators amend the regulation to incorporate sustainability criteria. The European Commission for example includes ILUC emission in the assessments of the GHG effect of biofuels. RED II sets limits on high ILUC-risk biofuels with a significant expansion in land with high carbon stock. Member states cannot reach the targets by using these biofuels, but they can still use biofuels certified as low ILUC-risk. CORSIA eligible fuels (CEF) include Sustainable Aviation Fuels (SAF) and Lower Carbon Aviation Fuels (LCF). CORSIA has defined sustainability criteria for CEF based on two themes, GHGs and Carbon stock (see Table 3).

Theme	Principle	Criteria
Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
Carbon stock	Principle: CORSIA eligible fuel should not	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January

	be made from biomass obtained from land with high carbon stock.	2008 that was a primary forest, wetlands, or peatlands and/or contributes to the degradation of the carbon stock in primary forests, wetlands, or peatlands as these lands all have high carbon stocks
		Criterion 2: In the event of land-use conversion after 1 January 2008, as defined based on IPCC land categories, direct land-use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land-use change (ILUC) value, the DLUC value shall replace the default ILUC value.

Table 3: CORSIA sustainability criteria for eligible fuels (ICAO, 2019b)

Policies should focus on global measures rather than local measures to avoid **carbon leakage**. Carbon leakage is the increase in CO_2 emissions outside of countries with domestic policy mitigation divided by the reduction of emissions of these countries (Babiker, 2005). For instance, the increase in local prices of fuel resulting from mitigation policies can lead to a shift of production to areas with less stringent mitigation rules (or no rules at all), which increases emissions in these regions and therefore carbon leakage. For example, the decline in global demand for fossil fuels and the consequent reduction in the prices of fossil fuels can lead to an increased consumption of fossil fuels in countries that have not taken steps to mitigate and, therefore, a risk of carbon leakage. However, the investment attitude in many developing countries may be such that they are not ready yet to benefit from such a leakage.

Policies aiming at reducing GHG emissions are well intended, but in many cases can result in unintended and undesirable consequences. A subsidy for biomass for example can lead to a reduced consumer price for biofuel and consequently an increase to biofuel consumption, but not necessarily to fuel substitution. Non-global level pressure to limit the demand of fossil fuel without a pressure to reduce the supply of fossil fuel, will result to a reduction of fossil fuel prices to increase the demand from countries that have no GHG reduction targets and therefore can lead to an increase of extraction volume. This can also cause an inter-temporal effect where contemporary fossil fuel supplies increase the oil extraction levels in anticipation of the future impact on demand. In summary, the supply-side effect of fossil fuel suppliers may dominate the substitution effect from fossil fuels to biofuels. This does not lead to a GHG emissions reduction and may contribute to accelerating global carbon emissions. This effect on green demand-side policies is commonly known as the '**Green Paradox'**, initially introduced by Sinn (2012) and later investigated by various researchers. Several parameters influence 'green paradox' with the most important being the imperfect competition in the fossil fuels market, political feasibility and the timing of policy implementation.

Conclusions

Sustainable Aviation Fuels (SAF) are identified as the only low-carbon fuels available for aviation in the short to mid-term, with other solutions like cryogenic hydrogen fuel and electric-power aircraft unlikely to be commercially ready before 2030. The first commercial flights using SAF were performed in 2011, and since 2016 regular SAF supply has been introduced at various airports (e.g. Oslo, Los Angeles and Stockholm). More than 250.000 flights have used various amounts of blend-in SAF and more than 40 commercial airlines have used certified SAF.

By 2050, improved operations, aircraft technology, and use of SAF will allow CO_2 emissions reductions of 9%, 25%, and 41% respectively according to ICAO. Governance structures are starting to be implemented to assist biofuel development, together with appropriate funding mechanisms, but the usual question remains as to whether they are fast enough to meet environmental requirements. Aircraft operators in response to environmental market-based measure obligations (i.e. CORSIA and EU-ETS) aim to use SAF to reach their targets. Yet, until concerns related to cost, sustainability and a balance between biofuel are addressed, aviation SAF will not gain a significant share of the fuel market. Ebadian et al. (2020) suggest that biofuels policies have enhanced SAF market growth. They also argue that both technology-push and demand-pull policies are fundamental in increasing the rate of introduction and diffusion of new environmental technologies. Similarly, the policies can support SAF development and use.

Individual environmental policies have been criticised about their efficiency, effectiveness and occasionally their political feasibility and ambition. Considering the advantages and shortcomings of individual policies, policy combinations can correct the inefficiencies in sustainability behaviours (Efthymiou and Papatheodorou, 2020). Therefore, mixed policy approach is the best way forward for SAF deployment and scaling up.

References

1. Babiker, M. H. (2005). Climate change policy, market structure, and carbon leakage. *Journal of international Economics*, *65*(2), 421-445.
2. EASA (2019) European Aviation Environmental Report 2019. Cologne: EASA.
3. Ebadian, M., van Dyk, S., McMillan, J. D., & Saddler, J. (2020). Biofuels policies that have encouraged their production and use: An international perspective. *Energy Policy*, *147*, 111906.
4. Efthymiou M. (2021) The fundamentals of environmental regulation of aviation: a focus on EU emissions trading scheme. Aeron Aero Open Access J., 5(1):9–16. DOI: 10.15406/aaoaj.2021.05.00122
5. Efthymiou, M., & Papatheodorou, A. (2018). Environmental considerations in the single European sky: A Delphi approach. *Transportation Research Part A: Policy and Practice*, *118*, 556-566.
6. Efthymiou, M., & Papatheodorou, A. (2019). EU Emissions Trading scheme in aviation: Policy analysis and suggestions. *Journal of Cleaner Production*, *237*, 117734.
7. Efthymiou, M., & Papatheodorou, A. (2020). Environmental Policies in European Aviation: A Stakeholder Management Perspective. In Walker, T., Bergantino A. S., Sprung – Much, N. and Loiacono, L. (eds) *Sustainable Aviation* (pp. 101-125). Springer Nature/Palgrave Macmillan, Cham.
8. Gossling, S., & Humpe, A. (2020). The global scale, distribution and growth of aviation: Implications for climate change. Global Environmental Change, 65, 102194.
9. IATA (2015) IATA Sustainable Aviation Fuel Roadmap. Montreal: IATA. Available online at: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/safr-1-2015.pdf [Accessed 23/11/2020].
10. ICAO (2019a). Destination Green: The next chapter – 2019 Environmental Report Aviation and Environment. Montreal: ICAO. Available online at: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf [Accessed 19/11/2020].
11. ICAO (2019b). *CORSIA Sustainability Criteria for CORSIA Eligible Fuels*. Montreal: ICAO. Available online at: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf [Accessed 19/11/2020].
12. IPCC (2014). Climate Change 2014. IPCC 5th Assessment Synthesis Report. Available online at: https://ar5-syr.ipcc.ch/ [Accessed 9/12/2020]
13. Noh, H. M., Benito, A., & Alonso, G. (2016). Study of the current incentive rules and mechanisms to promote biofuel use in the EU and their possible application to the civil aviation sector. *Transportation Research Part D: Transport and Environment*, *46*, 298-316.
14. OECD (2008). *Biofuel support policies: An economic assessment*. Paris: Organisation for Economic Co-operation and Development.

15. Schafer, A.W., & Waitz, I.A. (2014). Air transportation and the environment. *Transport Policy*, 34, 1–4.
16. Sinn, H. W. (2012). *The green paradox: a supply-side approach to global warming*. MIT press.
17. Taylor, M. (2020). *Energy subsidies: Evolution in the global energy transformation to 2050*. Abu Dhabi: International Renewable Energy Agency.
18. United Nations General Assembly. (2005). *2005 World Summit Outcome*. New York.
19. World Commission on Environment and Development. (1987) *Our Common Future.* Bruntland Report.