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EXECUTIVE SUMMARY

This report corresponds to D7.2 Report on description of aviation emissions impact on the environment. The work reported is related to WP7.1 Scientific description of the impact of aviation emissions to climate change.

WP7.1 is organized in three different tasks:

- Task 7.1.1 State-of-the-art review on aviation environment impact
- Task 7.1.2 The spatial and temporal distribution characteristics of aviation emissions
- Task 7.1.3 Aviation emissions impact on the environment

Deliverable D7.1 included the work performed in Task 7.1.1 and Task 7.1.2. The work performed in Task 7.1.3 is part of D7.2 Report on description of aviation emissions impact on the environment.

The information contained in this report provides a general description of aviation emissions impact on the environment, in the context of the environmental impact of air transport which includes local and global effects. The status of the present aviation emissions regulatory work and future perspectives, together with the main aviation emissions control systems are also part of this report.

These results, together with the investigations on the previous tasks of WP7.1, related to the State-of-the-art review on aviation environment impact, and the spatial and temporal distribution characteristics of aviation emissions, will provide the necessary inputs to continue the work in this MWP7 and begin the next WP7.2 Development of an evaluation methodology for environmental impact, which is the work planned for the next 12 months.

No major issues or deviations are to be reported.

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1. INTRODUCTION

This report corresponds to D7.2 Description of aviation emissions impact on the environment. The work reported is related to WP7.1 Scientific description of the impact of aviation emissions to climate change.

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2. WORK PERFORMED

2.1. ENVIRONMENTAL IMPACT OF AIR TRANSPORT

The interest on the environmental impact of civil aviation started in the middle 60s with the introduction of the first commercial jets. The noise around the airports increased in a substantial manner and incentivize the research on technical and regulatory solutions. First noise certification regulation was developed in United States by the Federal Aviation Administration (FAA). The Federal Aviation Regulation (FAR) Part 36 entered into force in 1969, followed by other rule with similar content but global reach: the International Civil Aviation Organization (ICAO) Annex 16 Volume I in 1971. Both regulations were updated, and gradually brought together, with an increased stringency entering into force in 1977, another in 2006 and the last one until now in 2020.

Despite all the benefits of air transport to our societies, its environmental impact is becoming a concern from different perspectives. Airports need an exclusive area for their operations, producing noise impact on surrounding neighbourhood. The fuel utilization by aircraft has different environmental impacts, as well: local air quality and contribution to climate change. Manufacturing and operation of commercial aircraft use some non-renewable and hazardous materials.

From a broader perspective, the environmental impacts of air transport are traditionally classified according to their reach in local and global effects. Local effects are restricted to the airport area, while global effects have a worldwide scope. The main impacts may roughly classified as:

- Local effects
    - Noise

    - Local Air Quality
    - Land and Space use
- Global effects
    - Non-renewable materials consumption
    - Climate Change contribution

Local effects

Concerning local effects, aircraft noise is by far the impact causing more complaints from affected communities. For instance, European airports receive one local air quality complaint per each 300 noise complaints. Engine noise is dominant under the takeoff and initial climb path and along the sides of the runway as well. Climb gradient is the key element for the noise impact. In approach and landing engine and airframe noise are comparable. They depend on the aircraft configuration.

ICAO requires an acoustic certification before granting the Type Certification to new aircraft types. The applicable regulation is in Annex 16, Part 1, to the Chicago Convention. The regulation stringency is increased as the acoustic technology advances in order to ensure the application of the best available technology. Certification levels for new types are presently included in Chapter 14 of that part of the Annex.

The use of land and space is related to the following elements:

- Land and infrastructures (airports and air navigation control centres)
- Air space for flight airways, distributed according to the local air navigation service provider capabilities
- A frequency band of the radioelectric spectrum for communications and ATC services

This effect is relatively modest compared to other transport modes. Airports (including the airport ramp, runways and the aeronautical and environmental domains) take about 1% of the overall land used for transport infrastructure. Competition for air space is comparatively lower. There are protected areas due to military use, security, or wildlife care. The present Air Navigation System is based in airways, but may evolve towards free flight with satellite guidance as new satellite constellations (Europe, China) join existing GPS and GLONASS.

Civil aviation uses a number of exclusive frequencies in the radioelectric space for voice communications and data transmission (according to ICAO-ICU agreements). In terms of allocation, civil aviation communications are divided in two groups: those needing high integrity and fast response (by safety reasons) and those corresponding to administrative issues or passenger service. Some frequency bands (VHF COM) might become saturated in the near future.

Local air quality in the airport area is regulated by the general air quality law of each country or region and it should include the impact of every activity within the airport area (Figure 1). The European Union has a general rule establishing pollutants limits, but each Member State or local Administration may apply more stringent values.

The two major products of fuel combustion are carbon dioxide, CO_2 and water, H2O. Other products of fuel combustion are nitrogen oxides, NOx, sulphur dioxide, SO2, carbon monoxide, CO, unburnt hydrocarbons, UHC and Soot (Figure 2). Although the amount of species produced in the combustion of 1 ton kerosene depends on parameters such as the aircraft operating conditions, altitude, humidity and temperature, the following figures can be taken as good approximations:

- CO_2 3.15 ton
- H2O 1.239 ton

- NOx 6 - 20 kg
- SO2 1 kg
- CO 0.7 - 2.5 kg
- UHC 0.1 - 0.7 kg
- Soot 0.02 kg

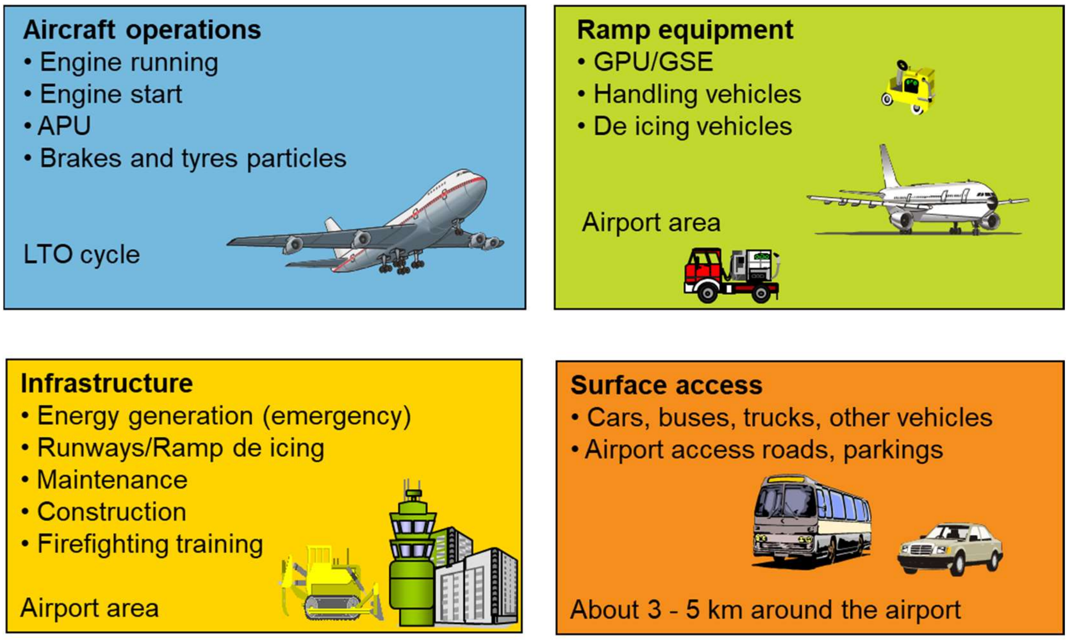

Figure 1. Main emission sources within the airport area (Source: own elaboration).

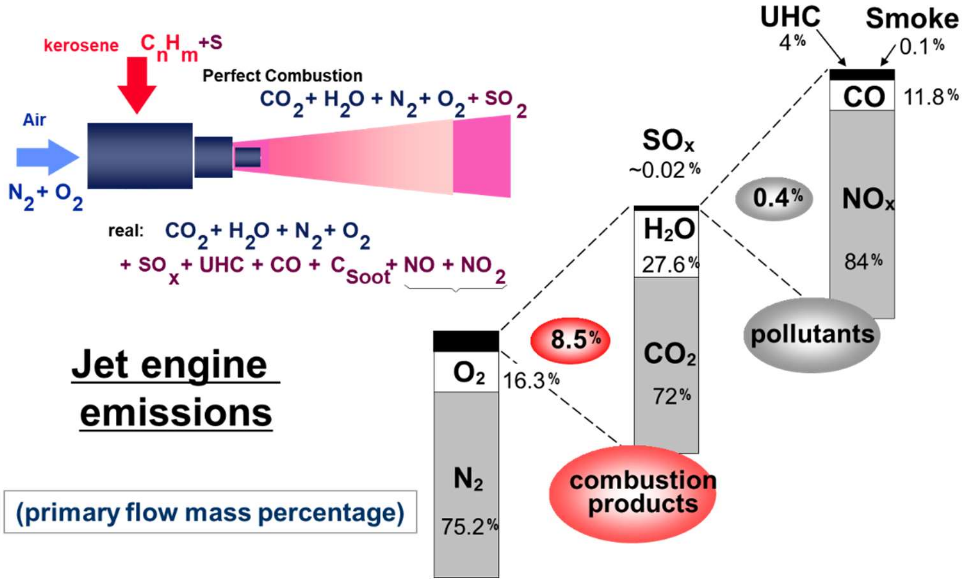

Figure 2. Jet engine emissions (Source: IPCC report).

As for noise, ICAO requires a certification of the pollutants emissions before granting the Type Certification to new aircraft types. The applicable regulation is given in Annex 16, Part 2. The list of the pollutants regulated by ICAO and their respective environmental effects are shown in Table 1.

The initial 1980 certification limits were the following:

- Smoke number limit is defined as the lowest of:
    - $SN \leq 83.6 \times (F_{00})^{-0.274}$
    - $SN \leq 50$
- For the other pollutants, the limits are based on the allowed emitted mass during the LTO cycle:
    - HC (g/LTO) = $19.6 \times F_{00}$
    - CO (g/LTO) = $118 \times F_{00}$
    - NOx (g/LTO) = $(40 + 2\ OPR) \times F_{00}$

Being

F_{00} the maximum certified engine thrust

OPR the engine Overall Pressure ration

The Landing and Take-off (LTO) cycle includes the air operations under 3000 ft (915 m), see Figure 3, with the Take-off, Climb, Approach and Taxi phases described in Table 2 in terms of engine thrust and duration.

Table 1. Pollutants regulated in Annex 16, Part 2. (Source: own elaboration)

Pollutant	**Flight phase**	**Environmental effects**
Unburnt Hydrocarbons (HC)	Low power	Photochemical reaction (incomplete combustion), toxic, odour
Carbon monoxide (CO)	Low power	Toxic (incomplete combustion)
Nitrogen oxides (NOx)	High power	Photochemical reactions (smog), acid rain, toxic, ozone creation
Soot (C)	High power	Visibility, condensation trails (contrails)
Non-volatile Particulate Matter (nvPM)	Whole flight	Toxic, condensation trails (contrails)

LTO cycle emissions are basically dependent on the engine design. These emissions follow the ICAO Annex 16 Part II stringency evolution. The limits for soot, unburnt hydrocarbons and carbon monoxide have not been changed since the initial values, as technological advances have shown great improvements, leaving actual values far away from the regulatory limits.

However, high By-Pass ratio engines could have problems with NOx compliance. In 2004 ICAO approved CAEP/6 proposal to reduce 12% the limits for new certified engines after 01/01/2009. Later, in 2010 ICAO Assembly approved a further reduction of 15% for OPR ≥ 30 engines and 5-15% for OPR < 30 engines, certified after 01/01/2013. As NOx creation is a function of combustion chamber temperature, mixing quality and particle residence time, more efficient engines increase chamber temperature and have a trend to increase NOx, unless the other elements compensate that problem. ICAO increasing stringency tries to keep pressure on manufacturers to continue the improvement in this contaminant.

Table 2. LTO cycle (Landing Take off), air operations under 3000 ft (915 m) (Source: own elaboration)

OPERATING PHASE	THRUST	TIME(minutes)
Take off	100 % F_{00}	0.7
Climb	85 % F_{00}	2.2
Approach	30 % F_{00}	4.0
Taxi / ralenti	7 % F_{00}	26.0

ICAO adopted in 2020 a new standard on non-volatile solid particles (nvPM), including visible (smoke) and non-visible ones. In 2003 SAE emissions committee approved the measurement technical procedure for solid particles down to 10 nanometres. Applicable to engine designs of rated thrust greater than 26.7 kN, the new non-volatile Particulate Matter (nvPM) mass and number engine emission standard will govern both new and in-production engines from 2023 onwards.

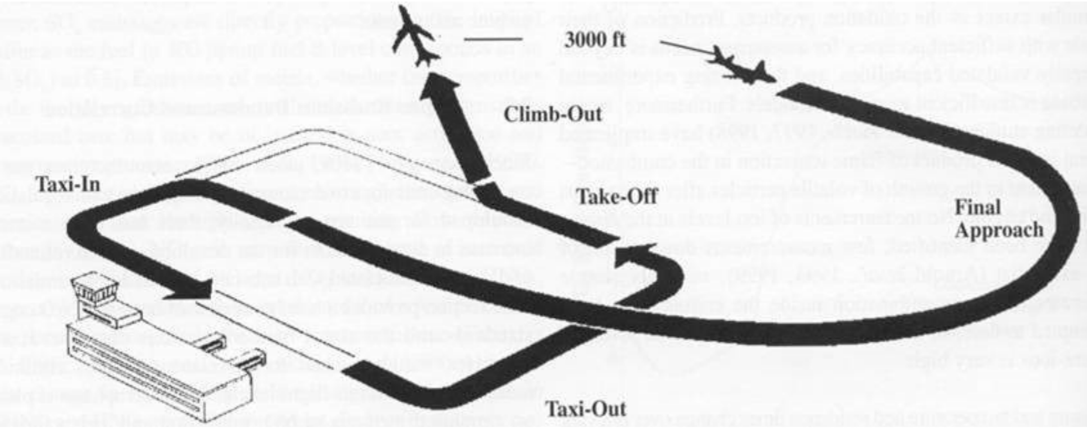

Figure 3. LTO cycle. (Source: ICAO)

Local Air Quality in the airport area complies with general national standards. Some large airports may have little margins if ground sources are important. Pollutant dispersion in open space makes difficult to identify the source of each one. Theoretical models are still in very primitive phases. Air quality has been a limitative factor for some airport developments, as the third London Heathrow runway, still in discussion. The main problem would be NOx concentration.

Global effects

Although fuel distilled from fossil fuel is the most characteristic non-renewable material used by air transport, it is not the only one. Other non-renewable materials consumed by the industry are:

- Some scarce metals, in particular Titanium
- Some substances still in use although their production is already forbidden, like some CFCs, in particular Halon for on board fire extinguishing.

Fuel consumption has a higher or lower, but always important, impact on airlines operating costs, depending on oil price. This consumption depends on multiple technical and operating factors. The climate change irruption has made it a high priority.

Natural phenomena have always contributed to climate change. Climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations. Recent climate changes, however, cannot be explained by natural causes alone. Anthropogenic climate change is defined as "A climate change directly or indirectly chargeable to human actions that modify the composition of the global atmosphere added to the natural climate variability observed during comparable time periods" (UNFCC). Human activities that contribute to climate change are basically industry, agriculture, and transport.

The combustion of hydrocarbon is the chief source of man-made CO_2 which is a significant greenhouse gas (GHG). Other products of the combustion have also environmental effects and an indirect contribution to the climate change, but they are not regulated in Annex 16 Part 2 (Table 3). ICAO included in this Annex 16 a new Part 3 regulating the maximum levels of CO_2 emissions for new civil aircraft types. The selected metric is the following:

$$(1/SAR)_{AVG}/RGF^{0,24}$$

where:

$(1/SAR)_{AVG}$ is the Specific Air Range average of three aircraft weights, representing the situation at the beginning, in the middle and at the end of a typical cruise

RGF is a factor representing the floor surface devoted to carry payload

The certification procedures were approved by ICAO General Assembly in 2013, while the maximum levels and the application date were established in the 2016 ICAO Assembly.

Table 3. Substances unregulated in Annex 16, Part 2 (Source: own elaboration)

SUBSTANCE	FLIGHT PHASE	ENVIRONMENTAL EFFECTS
Sulphur Oxides (SOx)	Whole flight	Photochemical reactions, odour, greenhouse effect
Nitrogen oxides (NOx) out of LTO cycle	Climb / cruise / descent	Photochemical reactions, ozone creation, methane depletion
Water vapor (H_2O)	Whole flight	Condensation trails (contrails), cirrus clouds formation

The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC).

ICAO asked in 1997 for an IPCC Special Report (1999), that was a compendium of all the available knowledge at that time. It contains:

- Atmospheric Sciences
- Aeronautic Technology
- Socioeconomic effects and reduction possibilities

- Scenarios of the possible aviation effects until 2050

Basic consequences of climate change are that Earth atmosphere and oceans are warming; snow and ice are diminishing, especially in Arctic areas; sea level is rising from 1.5 to 3 mm per year; each of the most recent decades have been successively warmer than any preceding decade since 1850. According to IPCC, increase in global average temperature should not exceed 2 °C above pre-industrial level, in order to prevent a catastrophic evolution. IPCC calls therefore for urgent and more decisive action, like the Paris Treaty (2015) ratification.

To explain climate change the concept of Radiative Forcing is introduced. The difference between radiant energy received by the Earth and the energy radiated back to space is called Radiative Forcing (positive forcing warms the system). The effects of men activities on the Radiant energy balance are called anthropogenic radiative forcing. The aviation contribution to climate change is based on the fact that CO_2 is a greenhouse gas. NOx act as ozone precursors with a heating effect but also as methane destroyers, with a cooling effect. Soot and water vapor have a small heating effect, while Sulphur oxides have a small cooling effect. Finally, water vapor may create condensation trails, known as contrails, and/or cirrus type clouds. This effect is not well known yet but might be potentially dangerous from the climate point of view.

A complete discussion on the state of the art regarding the very different levels of scientific understanding of the impact of each substance on climate change can be found in a previous deliverable of the GreAT project, D7.1: Spatial and temporal distribution characteristics of aviation emissions.

The different environmental impacts of air transport are not independent one from each other. Sometimes, the reduction of one of the effects to be controlled may have opposed results on other environmental factors. The most frequent opposite effects are:

- Noise and fuel consumption (CO_2 emissions)
- NO_x and HC
- NO_x and fuel consumption (CO_2 emissions)
- NO_x and nvPM

A classic example of these interdependencies was the Airbus A380 engines selection. Airbus 380 model was offered with two engine types: Rolls-Royce Trent 900 and Engine Alliance GP7200. The launching customer, Singapore Airlines, had selected the Trent engine and demanded the fulfilment of Heathrow night noise rules (category QC2). The solution for noise reduction was a larger diameter fan, a solution that also reduces the fuel specific consumption, but additionally adds more weight and more drag, worsen the fuel consumption in long range flights. Consequently, aircraft cruise drag increases and fuel consumption (and CO_2 emissions) went up around 0.3-0.5%

Design changes in engines combustion chambers are used by engine manufacturers to reduce the NOx emissions. These reduction in NOx emissions may result in an increase of other emissions. That was the case of the new combustion chamber that Pratt&Whitney developed for their PW4000 engine, under the TALON (Technology for Advanced Low NOx) program. The new combustion chamber reduced a substantial reduction in NOx emissions, as well as in CO and UHC levels, but increased largely the Soot level (although under the CAEP limits).

The replacement in the CFM56 of the single annular combustor by a double annular combustor is another classical example of interdependencies. The change produced the desired effect of reducing NOx emissions, and simultaneously soot levels, but increased UHC and CO emissions, again still within CAEP limits.

2.2. CHARACTERIZATION OF COMMERCIAL AIRCRAFT EMISSIONS

Since the very beginning of aviation, the selected fuel was from fossil origin. Piston engines were achieving some experience in using gasoline from cars application and Wright brothers decided to follow this trend in their prototypes. The aviation engine gasoline specification was moving to adapt to the more demanding performance of higher-pressure piston engines, until the present times.

The introduction of jet engines demanded a different fuel from a slightly different oil distillation fraction. A typical distribution of the distillation products can be seen in Table 4, ranked in order of increasing density.

Table 4. Typical oil distillation products distribution (*Source: Energy efficiency in air transportation, Benito & Alonso, 2018)*

Product	Percentage in weight
Kerosene and aviation gasoline	7
Automotive gasoline	43
Diesel and heavy fuel	23
Lubricant oil and asphalts	16
Waste	11

The percentages in Table 4 may vary within some small margins depending on the existing demand of each one of the products. In the present market conditions, aviation fuels of the lighter distillation fraction are:

- High-octane gasoline (Grade 100, alternative engine)
- Jet A (Kerosene, mostly used in United States, with -40°C freezing point)
- Jet A1 (Kerosene similar to Jet A, with -47°C freezing point, used by all other countries)
- Jet B (Wide cut kerosene with lower density than Jet A, much less used)
- JP (Kerosene with wider specification, generally used by military aircraft)

For commercial aviation, this time the experience was provided by military aircraft that started the use of kerosene in the 40´s. The military kerosene specification (JP) was refined to adapt the requirements of commercial flights and, under the umbrella of IATA, a common specification for commercial aviation kerosene was developed under the denomination of Jet A. In the last decades, Jet A is the fuel provided in United States, while Jet A1 is uploaded in the rest of the world. Both specifications are identical, except in the freezing points: -40°C for Jet A, and -47°C for Jet A1. As chemical properties are the same, their emissions may be considered identical.

Turbine jet engines produce energy by the combustion of kerosene mixed with oxygen at high pressure in the engine combustion chamber. Assuming a totally pure kerosene and perfect combustion, the chemical reaction would be:

$$C_{12}H_{23} + 17.75O_2 \rightarrow 12CO_2 + 11.5H_2O$$

where the resultant products are 3.15-3.16* carbon dioxide kg and 1.23-1.24 water vapour kg per each burned kerosene kg.

*The EU uses 3.15 value while ICAO generally applies 3.16

However, the Jet A composition is not a pure hydrocarbon, because contains certain levels of other substances, like sulphur or aromatics. Table 5 presents the ASTM D1655 Jet A1 specification values, indicating the maximum and minimum values of different physical and chemical characteristics.

On the other hand, the combustion conditions are not static and combustion chamber temperature and gas speed vary, producing zones where the balance between kerosene and oxygen is not perfect and the temperature changes. The lack of enough oxygen in relation to the amount of kerosene may produce carbon monoxide or even solid carbon particles, generally named as soot. In this situation, part of the kerosene may escape without chemical reactions, in the form of unburned hydrocarbons (UHC). The sulphur content of the fuel, a small quantity, smaller than 0.3% in weight, would combine with oxygen to create SO_2 and SO_3 commonly named as SOx. An additional benefit of the sulphur presence is helping to maintain the fuel viscosity within the specified range of values.

Another interesting element of the combustion chemistry is the combination of the two elements of air, oxygen and nitrogen, which at very high temperatures inside the combustor chamber combine themselves to form different nitrogen oxides, as NO, NO_2 and NO_3, globally included under the generic term NOx. In this case, the fuel composition and the chemistry do not intervene and the amount of NOx produced is proportional to the reached temperature and the residence time of the particles in the hottest areas.

Table 5. Jet A1 properties and specification values (Source: Exxon)

Feature	**Value**
Acidity, mg KOH/g	0.10 maximum
Aromatics, Vol. %	25 maximum
Sulphur, mercaptan, Wt. %	0.003 maximum
Sulphur, total, Wt. %	0.30 maximum
10% Distillation, ºC	205 maximum
Final Boiling Point, ºC	300 maximum
Distillation residue, %	1.5 maximum
Distillation loss, %	1.5 maximum
Flash Point, ºC	38 minimum
Density @ 15ºC, kg/m^3	775 to 840
Freeze Point	-47 ºC maximum
Viscosity @ 20ºC, mm/s	8.0 maximum
Net Heat of combustion, MJ/kg	42.8 minimum
Smoke point, mm	25.0 minimum
Naphthalene, Vol. %	3.0 maximum
Copper Strip corrosion, 2 h % 100ºC	No. 1 maximum
Thermal stability @ 260ºC Filter pressure drop, mm Hg Tube deposits	 25 maximum < 3 maximum
Existent Gum, mg/100mL	7 maximum
MSEP rating Without electrical conductivity additive With electrical conductivity additive	 85 70
Electrical conductivity, pS/m	50 minimum, 600 maximum

Figure 2 offers a schematic and quantitative view of the total process, based in a generic high by-pass turbofan engine. All the percentages refer to weight, taking as reference the amount of burned kerosene in a standard middle range operation. The actual emissions profile would depend on the engine operating regime and the surrounding atmospheric conditions, as air pressure, humidity, temperature wind and chemical composition.

Using a broad approach, in this framework of average conditions, the emissions corresponding to a kerosene ton consumption were shown in previous chapter2.1 of this paper.

2.3. DISTRIBUTION OF THE EMISSIONS BY THE PHASE OF THE FLIGHT

According to the European Environmental Agency, air pollutants may be categorised as primary or secondary. Primary pollutants are directly emitted to the atmosphere, whereas secondary pollutants are formed in the atmosphere from precursor gases through chemical reactions and microphysical processes. Air pollutants may have a natural, anthropogenic, or mixed origin, depending on their sources or the sources of their precursors.

Key primary air pollutants include particulate matter (PM), black carbon (BC), sulphur oxides (SOx), nitrogen oxides (NOx), ammonia (NH), carbon monoxide (CO), methane (CH), non-methane volatile organic compounds (NMVOCs), including benzene, and certain metals and polycyclic aromatic hydrocarbons, including benzo[a]pyrene (BaP).

Key secondary air pollutants are PM, ozone (O3), NO and several oxidised volatile organic compounds (VOCs). Key precursor gases for secondary PM are sulphur dioxide (SO_2), NO, NH and VOCs. These pollutants and their precursor gases can be of both natural and anthropogenic origin including: burning of fossil fuels in electricity generation, transport, industry and households; industrial processes and solvent use, for example in the chemical and mining industries; agriculture; waste treatment; natural sources, including volcanic eruptions, windblown dust, sea-salt spray and emissions of volatile organic compounds from plants.

The main difference of aviation and other emitters is the place where pollutants are injected in the atmosphere. Aviation is the only source emitting in a wide space, from the ground surface to the high atmospheric layers, close to the tropopause, the altitude of which depends on the geographic coordinates of the flight. The effects of the low altitude emissions are integrated with those of the other sources affecting local air quality, while high altitude emissions are more influential in the atmospheric dynamics and the climate change.

For the case of the local air quality, Table 6 provides an idea of the relative importance of the different transportation mode emissions in the European air quality, evaluating the comparative participation of their five more important elements in the total European emissions, including all type of sources.

As it is shown in the table, transportation is particularly important in nitrogen oxides, with 57.4% of the total emissions, where aviation represents 4.5% a much higher participation than any other of the other pollutants. Its effects are harmful because induces photochemical reactions, acid rain and toxicity. In addition, it increases the ozone creation that has oxidant and climate warming potential.

Carbon monoxide is a powerful toxic, but when emitted in the open air, as it is the case of the engine exhaust, has a very short average life, because it combines with the air oxygen and derives into CO_2. Unburnt hydrocarbons (included in Volatile Organic compounds in Table 3) are toxic, as well, in addition of causing odour problems, as sulphur. Most of the emitted sulphur is in the shape of SO_2 and dilutes very fast in open air. Finally, small PM2.5 particles are causing breathing problems and lungs deterioration. They have a sizeable average life although emitted in the open air are dispersed very fast.

Other particles not mentioned in the table are soot or visible carbon particles, that appear in the form of smoke. This was the first aviation pollutant emission studied in the 60's, as it was visible from long distance and that creates a problem to the military aircraft. With combustion chamber technology progress, it has practically disappeared, although when emitted in altitude, its particles may help to generate condensation trails (contrails) a powerful atmospheric warming element.

Table 6. Main local air quality pollutants in Europe (Source: European Environmental Agency)

LOCAL AIR QUALITY EMISSIONS (EUROPE)

					NON-TRANSPORT	
NOx	32.9%	0.9%	19.1%	4.5%	NOx	42.6%
CO	26.6%	0.2%	2.3%	0.7%	CO	70.2%
SOx	0.1%	0.0%	20.9%	0.5%	SOx	78.5%
VOLATILE ORGANIC COMPOUNDS	15.4%	0.14%	2.52%	0.40%	VOLATILE ORGANIC COMPOUNDS	81.54%
FINE PARTICLES (PM2.5)	14.2%	0.4%	11.4%	0.6%	FINE PARTICLES (PM2.5)	73.4%

In % of total emissions | source: European Environment Agency, 2013

When discussing climate change, the only greenhouse gas (GHG) emitted by jet engines is carbon dioxide, a product of the perfect fuel combustion and not dangerous for breathing in the concentration of a typical airport. CO_2 emissions are now the first objective of the carbon footprint reduction of the industry, that has adopted the "Net Zero carbon emissions" target for the year 2050. As CO_2 is a product of the perfect fuel combustion, its elimination needs not only improving fuel efficiency but also change fossil-origin kerosene by new Sustainable Aviation Fuels (SAF) or new disruptive technologies like electricity or hydrogen fed powerplants.

The different nitrogen oxides, identified as NOx emissions, are not greenhouse gases, because N_2O, that is a GHG, is not emitted by jet engines. However, when NOx is injected in the high levels of the atmosphere, produce a dual effect creating ozone and destroying methane, both GHG. The resultant of both effects increases atmospheric warming.

Other emissions have a minor impact on climate change. Water vapour itself has a small warming effect. Direct sulphate depends on the sulphur content of the kerosene, that is regulated by fuel specifications, and direct soot is a consequence of the combustor efficiency, being reduced as the fuel and the air mix improves its quality.

The formation of condensation trails (usually mentioned as contrails) is more complex because depends on the physical conditions of the atmospheric region where the flight is being performed. A detailed analysis of the present situation of the scientific knowledge in this area was presented in the Deliverable D7.1. The incertitude levels continue being very high.

With respect to the emissions during the different flight phases, in standard atmospheric conditions, they depend on the engine regime. Schematically, they can be described as:

Low thrust period during aircraft taxi in and out: high amount of CO and UHC

Moderate thrust period during descent and approach: sizeable amount of CO and UHC, small amount of NOx

Mid thrust period during cruise: small amount of CO and UHC, sizeable amount of NOx

High thrust period during climb: High amount of NOx

Very high thrust period during take off and initial climb: High amount of NOx and soot

The established ICAO certification procedure covers all these phases and measure engine emissions in the test cell for new engines. The relationship between certificated values and actual values is contingent upon how much the actual operation is similar to the certification procedure.

2.4. ORGANIZATIONS WITH RELEVANT ACTIVITY IN AVIATION ENVIRONMENTAL REGULATION

There are a number of national and international organizations that play a fundamental role in the regulation and management of air transport environmental issues. They are listed in Table 7 and their activities briefly described in this Section.

Table 7. Organizations with relevant activity in the air transport environmental regulation. (Source: own elaboration)

WORLD	ADMINISTRATION	ICAO
		UNFCCC
	PRIVATE ENTITIES	IATA
		ACI
		ICCAIA
		CANSO
		ICSA
EUROPE	ADMINISTRATION	EU
		CEAC
		EUROCONTROL
	PRIVATE ENTITIES	A4E
OTHER REGIONS		FAA
		ATAG

International Civil Aviation Organisation (ICAO)

ICAO is the United Nations Agency in charge of international civil aviation. It was created in 1944, according to the Chicago Convention Part II. With 193 Member States in 2022, its mission is to ensure a safe, reliable and cost-effective world civil aviation development. It has a mandate to establish and keep updated the Standards and Recommended Procedures

(SARPs) in the 19 Technical Annexes to the Chicago Convention and the adoption of procedures and guidance material.

The following is a list of the Standards and Recommended Procedures (SARPs) related to environment protection:

- Annex 16, Environmental Protection
    - Part 1 Aircraft Noise
    - Part 2 Aviation Engine Emissions
    - Part 3 CO_2 Emissions
    - Part 4 CORSIA
- Environmental Technical Manual (Doc 9501)
- Airport Planning Manual (Doc 9184) Part 2 – Land use and environmental control
- Circulars
    - (218) Economic implications of future noise restrictions on subsonic jet aircraft
    - (303) Operational opportunities to minimize fuel use and reduce emissions (to be replaced by a Technical Manual)
- Guidance Material:
    - ICAO's policies on charges for airports and air navigation services (Doc 9082)
    - Guidance on the Balanced Approach to aircraft noise management (Doc 9829)
    - Guidance on aircraft emission charges related to local air quality (Doc 9884)
    - Draft guidance on the use of emissions trading for aviation (Doc 9885)
    - Airport air quality manual (Doc 9889)
    - Recommended method for computing noise contours around airports (Doc 9911)
    - Environmental Management system (EMS). Practices in the aviation sector (Doc 9968)

In addition to the SARPs, ICAO issues Policies and Procedures, which are consolidated statements of continuing ICAO policies and practices related to environmental protection. For instance, the following last Assembly resolutions are of particular importance:

- Assembly Resolution A40-17 (2019) – Consolidated statement of continuing ICAO policies and practices related to environmental protection - General provisions, Noise and local air quality
- Assembly Resolution A40-18 (2019) – Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change
- Assembly Resolution A40-19 (2019) – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

The purpose of those resolutions is:

- To limit or reduce the number of people severely affected by noise
- To limit or reduce aviation emissions impact on local air quality
- To limit or reduce aviation greenhouse gas emissions contribution to climate change

Committee on aircraft Environmental Protection (CAEP)

The mission of CAEP is to perform specific studies, approved by ICAO Council, on the control of aircraft noise and gaseous emissions from aviation engines, taking into account what is technically feasible, economically reasonable and environmentally beneficial. It is composed by experts representing 23 States, and 12 Observers with voice but no vote. The CAEP Plenary meets once every three years, before the ICAO Assembly.

CAEP meetings and their most important decisions are summarized hereafter:

CAEP/10 (February 2016):

- Review and analysis of the civil supersonic aircraft noise requirements
- Propose to the Assembly the certification requirements for nvPM (a standard to be approved by 2019)
- Propose to the assembly a CO_2 emissions standard for the certification of civil aircraft
- Propose to the Council the basic scheme of a worldwide Market-Based Measure system to control global aviation CO_2 emissions to be developed and approved in the September 2016 Assembly
- All these proposals were approved during the 39th ICAO Assembly in September-October 2016.

CAEP/11 (February 2019)

- Recommendation on a new Standard for non-volatile Particulate Matter (nvPM) mass and number engine emissions to be incorporated in Annex 16, Volume II.
- Propose the development of an Eco-Airport Toolkit e-collection.
- Propose the creation of the first integrated independent expert technology goals assessment, including new aircraft noise, nitrogen oxides (NOx) emissions and fuel efficiency technology goals for the aviation sector.
- Agreed to develop an exploratory study for SST aeroplanes during the CAEP/12 cycle, with the aim of providing a better understanding of airport noise impacts. Regarding sonic boom, CAEP recommended continuing the development of a sonic boom standard, while monitoring trends in supersonic engine technology and assessing consequences for emissions certification standards.
- The meeting also discussed the progress and next steps on the task to explore the feasibility of a potential long-term global aspirational goal (LTAG) for international aviation.
- Regarding the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the CAEP/11 meeting made recommendations on various CORSIA Implementation Elements.

The present CAEP goals for the different environmental impacts are:

- Noise:
    - Technology and Standards review
    - SST standards
- Emissions:
    - Technology and Standards review
    - Operating measures (Energetic efficiency)
- Interdependencies among different measures and possible joint noise-emissions standard
- Elaboration of a Long Term Aspirational Goal on environment up to 2035-2050 period

United Nations Framework Convention on Climate Change (UNFCCC)

UNFCCC is a convention that was signed during the Rio Summit in 1992, entering into force in 1994. Its goal is to stabilize greenhouse gas (GHG) atmospheric concentration at a level that avoids dangerous interference of human activities in the climate system. Its executive body is the Conference of the Parties (CoP), meeting once a year.

Kyoto Protocol (1997)

It was approved in December 1997during COP/3 and entered into force in February 200, after Russia’s ratification. The Developed States (listed in Annex 1), committed to reduce their global GHG emissions in the 2008-2012 period at 95 of the 1990 levels. Each State had a different target, according to its per capita emissions. The European Union as a whole had an 8% reduction target to be distributed among its Member States (for instance Spain's target was an increase of no more than 15%).

The control of international aviation and maritime traffic was left to the UN organizations ICAO and IMO respectively.

Paris Agreement (2015)

Approved in December 2015 during COP/21, it entered into force after being ratified by 55 States with at least 55% of the World greenhouse emissions.

The Paris agreement requires the adoption of measures to keep global warming at 1.5 ºC average temperature and, in any case, less than 2 ºC. Although it does not refer directly to aviation, the possibility of using air transport as a levy-type means of payment for this policy cost is not excluded.

International Air Transport Association (IATA)

IATA was created in Havana in 1945 as a voluntary association for international airlines, with initially 260 members. It represents the largest association of international airlines with its members serving around 95% of the total international and 84% of the global world air traffic. IATA has six permanent committees: Financial, Operations, Industry Affairs, Cargo, Legal and Environment.

The IATA Environmental Committee (ENCON) comprises 19 Member Airlines and meets twice a year. It also includes observers from regional airline associations, manufacturers and fuel suppliers. Its main purposes are:

- Submit to the Board of Governors airlines common positions and proposals on environmental issues
- Support ICAO as the appropriate forum for developing global environmental standards and policies for air transport
- Assist members in managing their impact on the environment

Airports Council International (ACI)

ACI was created in Washington in 1948, with headquarters currently in Montreal since 1991. It has about 600 members operating over 1650 airports in 176 countries (96% of world traffic).

The ACI permanent Environmental Committee has 25 members. They cover not only noise and emissions but also ground, water, water, wildlife and resource management. Its main goal is to ensure that traffic growth can be maintained within the environmental capacity limitations imposed.

Civil Aviation Navigation Services Organisation (CANSO)

CANSO was created in 1996 and has its headquarters in Hoofddorp (Holland). It comprises 158 ATM providers members (87 members covering over 85% of world air traffic movements plus 71 associated). The main goals are:

- Provide safe, efficient and economic ATM services
- Optimize ATM routes and procedures in order to reduce noise and emissions

The International Coordinating Council of Aerospace Industries Associations (ICCAIA)

ICCAIA represents major aircraft, engines and aeronautical equipment and aerospace industries associations (AIA, AIAC, ASD). They provide the technological base for long term solutions and help to perform cost-benefit analysis of different environmental proposals. Their key role is the development of quieter, cleaner and more fuel-efficient aircraft.

International Coalition for Sustainable Aviation (ICSA)

ICSA was created in 1999 with the purpose of participating in the CAEP work, representing the NGOs with a single voice. Its most active members are US and European organisations specialized in energy and transport, like the International Council for Clean Transport (ICCT) and Transport & environment (T&E).

ICSA main goals are:

- Noise and emissions reduction in aviation
- Develop strategies for improving aviation environmental impact
- Evaluate the potential impact of environmental regulation proposals

European Union (EU)

The European Union was legally established by the Rome Treaty in March 1957. It has 27 Member States (19 of them sharing the Euro currency). Some others are candidates to join. The EU main government bodies are the Commission, the Parliament and the Council.

The environmental protection is one of the official goals of the EU. Some EU environmental regulations applicable to civil aviation are:

- Directive 1996/62/EC: On ambient air quality assessment and management
- Directive 1996/82/EC: On the control of major accidents hazards involving dangerous substances
- Directive 2002/30/EC: On the establishment of rules and procedures with regard to the introduction of noise-related restrictions at EU airports
- Directive 2002/49/EC: Assessment and management of environmental noise
- Directive 2003/87/EC: Emissions Trading (modified in 2008)
- Directive 2003/96/EC: Energy taxation
- Directive 2008/101/EC: Modifying 2003/87 to include aviation activities in the European Emissions Trade System, starting in 2012

The European Civil Aviation Conference (CEAC)

CEAC was created in 1955 and in headquartered in Paris. 44 European Member States are represented. CEAC harmonizes policies and procedures in the European aviation sector, developing technical standards through the Joint airworthiness Authorities (JAA) and taking care of environmental aspects in the ANCAT group (Abatement of Nuisances caused by Air Transport. The working groups of ANCAT are:

- AIRMOD: Aircraft Noise Modelling
- PLANO: Operational Noise Mitigation procedures around airports
- EMTRA: Emissions Trading
- ERLIG: Emissions Related Landing charges Investigation Group
- TANC: Transport aircraft Noise Classification
- Environmental indicators

EUROCONTROL (The European Organisation for the safety of Air Navigation)

EUROCONTROL was created in 1960, with headquarters in Brussels. It has 42 members (41 European States and the European Union). EUROCONTROL harmonizes European Air Navigation Services, receives users' payments and distributes them among Member States.

EUROCONTROL cooperates in the development of operating procedures for reducing noise and emissions. It also keeps statistics of all flights within the European air space.

Airlines for Europe (A4E)

Group of European airlines that has replaced in 2016 to the former AEA. AEA was established in 1952 in Brussels. It had 22 member European airlines and it is considered the preferred contact to represent airlines in front of European Commission and Parliament. AEA had an Environmental Committee. While AEA was integrated only by scheduled airlines, its replacement, A4E, has every type of airlines, among them, the three largest groups of schedule airlines (AF-KLM, IAG, Lufthansa) and the three largest low cost operators (EasyJet, Norwegian and Ryanair).

FAA (Federal Aviation Agency)

FAA is the organism of the US Department of Transport in charge of civil aviation technical issues. It has an Environmental Department coordinating the certification rules in FAR 33 (engine emissions) and FAR 36 (aircraft noise). FAA leads the US environmental aeronautic research, in collaboration with the Environmental Protection Agency (EPA).

Air Transport Action Group (ATAG)

ATAG was created in 1991 and has its headquarters in Geneva. ATAG is a global coalition representing all sectors of the air transport industry: airlines, airports, manufacturers and air navigation service providers. There are other members from different sectors: tourism institutions, chambers of commerce, travel agencies, trade unions, etc. ATG purpose is to promote the aviation sustainable development. It publishes a number of environmental documents.

2.5. ENVIRONMENTAL IMPACT REDUCTION

The environmental impact reduction goal is, in the long term, making air transport growth compatible with its sustainability, having as partial goals the reduction of the number of people seriously affected by aeronautic noise, keeping the air quality in the airport zone within the regulatory limits and achieving air transport growth without increasing its effects on climate change.

While all the civil aviation stakeholders share the environmental impact reduction targets, they do not agree on the price to be paid and who has to do it, leading to a conflict of interest:

- Airlines ask for no growth limits and the adoption of measures not endangering their economic results
- Airports propose giving priority to operating restrictions
- Manufacturers wish more research and an accelerated fleet renewal
- NGOs support airline offer reduction and ticket price increases

This conflict of interest led to the adoption of the Balanced Approach to tackle airport noise problems in the most effective way, and similarly to the Four Pillars to deal with aviation emissions reduction. Historically aviation emissions reduction had been concentrated on improving local air quality. The recognition of climate change importance changed this perspective and made it clear that the certification approach, like Annex 16 Part 2 rules was not sufficient to manage the problem. In 2004 AEA (precedent of today’s A4E) presented a formulation to cover both aspects with a set of measures, following the Balanced Approach line which, with minor modifications, reached general consensus.

Another important aspect to be considered is that each one of the environmental impacts (noise, NOx, unburnt HC, smoke, nvPM and CO_2 emissions) cannot be independently reduced without affecting some of the others, because there are interdependencies. Measures must be evaluated taking into account their global effects, not only in terms of one of the impacts reduction. Some of the relationships among the different impacts are still in the research phase.

AEA launched the so-called Four Pillars policy in 2003, as an alternative to the proposal of imposing taxes on emission levels. The Four Pillars policy suggests the need of actions in four different areas:

- Research and development of better technology
- Infrastructure improvements (airports and air navigation services)
- Optimisation of operating procedures
- Introduction of Market-Based Measures (MBM)

Research and development of better technology

Aircraft design balances numerous and diverse criteria: payload (passengers and cargo), range, cruise altitude, cruise Mach, take-off field length, landing speed, cost, reliability, maintainability, etc. Fuel economy, together with emissions and noise solutions must be compatible with all other requirements.

Modern commercial aircraft, at 75% load factor, burn typically between 2.5 and 3.0 litres per RPK. This consumption is comparable or even better than that of a medium size car with 1.5 passengers. The commercial jet efficiency has improved more than 70% during the last 50 years, but they are just somewhat better than piston engine aircraft of that time.

A first and obvious line of action in order to reduce fuel consumption in the air transport industry is the development of more efficient aircraft from an energetic point of view. The improvement levels may come from different elements: aerodynamics, materials and processes and propulsive systems. These are the three large technological areas where progress have been achieved uninterruptedly from the 80's in the last century, and where research is still intensively pursued. A fourth area should be added to the previous three: the aircraft systems. They also contribute largely to the aircraft energetic efficiency because they allow a more precise navigation. However, the overall fuel burning saving potential is not the sum of the individual technologies. It depends upon the configuration of the aircraft and the integration of those in it.

New technological developments need time in order to be introduced in new aircraft models. This is why sometimes it is said that every new aircraft model enters into service with a technology level corresponding to approximately five years before. This consideration gives an idea of the importance of the development of new technologies and their industrialization so they are available in the aircraft conceptual design phase.

These developments are terribly costly, and they are heavily supported by European (Clean Sky, Clean Aviation) and American (CLEEN, PARTNER, ASCENT) research programmes.

Infrastructure improvements (airports and air navigation services)

Air Transport Infrastructure integrates all the ground facilities needed to support airline services with the adequate levels of safety, reliability and economy. The two main elements of those facilities are airports and air navigation services.

From the management point of view, they are very different. Airports are ground infrastructures, placed generally close to the cities they serve, acting as interchange center of different transport modes and including many commercial services that take advantage of the great number of passengers going in and out through the terminals. In terms of energetic efficiency, the weight of pure aeronautical services may be small, compared with the energy consumption of the other activities, in particular in the case of large airports. They need to be certified by their own State CAA. While most of the airports management are subject of State regulation and control, many of them have a private, business-minded management, are quoted in the stock market and are able to compete in an open entrepreneurial environment.

Air navigation services are, with a small number of exceptions, either part of the State administration departments or corporatized state-owned companies, with modest private enterprise participation. ICAO divides world airspace in areas under the control of ATM facilities of individual States, with neither overlapping nor empty zones and efforts are done to improve coordination and collaboration rather than competition.

In addition of their own energy efficiency magnitudes, air transport infrastructure collaborates to optimize the performance of the flights, trying to adapt flight itineraries to the operating aircraft and routes requirements, and minimizing delays both in flight and on ground. Intergovernmental Panel for Climate Change (IPCC) experts consider that the fuel saving potential of these activities may reach the 12% figure.

The structure and operation of the airspace is an exclusive competence of each individual State, complying basic technical rules established by ICAO, and is usually limited by national borders, including the 12 nautical miles area of coastal seawaters.

Each National Authority can decide which parts of its airspace are available for civil aviation use and in which conditions. Part of the airspace may be reserved for military use, or simply prohibited to fly as it is over military bases, strategic facilities, governmental dependencies or other places that the State is interested into protect and leaving free of undesired interferences.

Optimization of flight tracks with the target of getting as close as possible to the orthodromic trajectory (direct point to point or "as the crow flies") can greatly increase fuel efficiency by reducing the flown distance. However, this is not the only factor to be taken into account. Global airspace capacity is a key issue because it can facilitate the reduction of congestion, eliminating holdings, diversions and other disruptions of the flight plan and, at the same time, ample capacity offer provides operators with more possibilities of optimizing flight trajectory in the four dimensions (three geometric plus time). If airspace is not restricted, each flight can decide the optimum trajectory at each moment of time, considering aircraft features (weight, thrust, speed) and external variables, like actual position, temperature, wind or altitude.

A great part of the effort by the aeronautical community in the last years has been devoted to open new routes, optimize existing ones and develop a better coordination among CAAs, ANSPs, airports, airlines and military authorities who, in many cases, are the owners of airspace zones of dual civil and military use or making frontier with the civil use areas.

The respect to the States sovereignty in their airspace does not preclude the adoption of international measures that need the participation of multiple States, in order to ensemble their frontiers and coordinate the ATM procedures. A number of different procedures have been applied or are in the implementation process to optimize time-related flight sequences and trajectories in the horizontal and vertical planes.

ICAO Global Air Navigation Plan

The improvement in the ATM efficiency has two main elements: development of new and advanced technologies and the introductory timeline of those elements in the world different flight regions. New technologies can be tested on ground and in some airports equipped for that purpose, like EUROCONTROL's Bretigny facilities, but once it is decided their introduction, the deadlines become very long, because all users (ATC, airports and airlines) have to progressively modify their equipment and operational procedures in order to adapt to the new situation.

During the 2011-2013 period, ICAO has agreed a GANP to organize the zonal introduction of those elements into a time-flexible series of performance improvements and timelines. The pace of the process is determine by individual States, according to their available technology and resource levels. This resolution was supported unanimously by aviation stakeholders and was structured in four Aviation System Block Upgrades (ASBUs), with the following temporal sequence:

- Block 0 Year 2013
- Block 1 Year 2019
- Block 2 Year 2025
- Block 3 Year 2031 and onwards

Regarding to the energetic efficiency, the main action lines applied in these coordination programs can be divided in six groups:

- <u>Flight information integration</u>, with participation of ATM, airports and airlines, compiling together all the flight data since the initial planning phase. The purpose is to put the conditions for a free of incidences flight without any avoidable delay and, at the same time, be able to monitor the flight development and take the adequate actions when a disruption appears. The first concept is known as Gate-to-Gate plan and needs to be implemented by each one of the stakeholders. Airport, airline and ATC adjust their schedules in such a way that the aircraft starts engines and do the taxi out, take off and climb without any waiting time or delay. To do so, everybody must be prepared for a real time interchange of data, with digitized and data-driven Collaborative Decision-Making (CDMA). This is complemented by the continuous monitoring of the controlled flights in the airspace, capable of suggesting the most likely solutions to the unexpected incidents. EUROCONTROL system for this purpose is the Central Flow Management Unit (CFMU), placed in Haren, close to Brussels. CFMU is fed with all IFR flight plans in the European airspace and can act as a monitoring system but it is capable to perform simulations and provide results in term of fuel burnt, flight time and economic repercussions. Suggested solutions for real time problems are typically optimized in terms of accumulated delays of all the affected flights, a solution that may induce a higher number of affected flights, but with very small delays in each one.
- <u>Terminal airspace development</u>, structuring the operations with optimum climb/descent profiles and preparing the use of advanced approach/landing navigation aids. The the most frequent low fuel procedures are the Continuous Descent Approach (CDA) and the Continuous Climb Operations (CCO). In any case, the final decision of using them or not is always in the hands of the local ATC responsible.
- <u>RNAV routes definition</u>, applying automated traffic management tools. Area Navigation (RNAV was originally coming from *Random Navigation*) can be defined as a method of navigation that permits aircraft operation on any desired course within the coverage of station-referenced navigation signals, or within the limits of a self-contained system capability, or a combination of these. It requires a determined performance level, defined by the Required Navigation Performance (RNP) category. In accordance with this, Performance Based Navigation (PBN) specifies that aircraft RNP and RNAV systems performance requirements are defined in terms of the accuracy, integrity, availability, continuity, and functionality required for the proposed operations in the context of a

particular airspace, when supported by the appropriate navigation infrastructure. In 2010, ICAO and IATA jointly established a Task Force with the objective to disseminate the best practices of the global and regional structures already put in place for PBN implementation. At this moment, more than two thirds of the 193 ICAO Member States are committed to implement PBN and are in different stages of the process.

- Flexible airspace use (FAU), building up the capability of flying within forbidden areas (military or reserved zones) in some periods of time or under certain pre-stablished conditions. This is in principle a coordination and information problem, the benefits of which may be important in flight regions with many of those areas and a heavy traffic demand, like Central Europe.
- Reduce Vertical Separation Minima (RVSM), creating additional flight levels to be used by the operators as a mean of flight optimizing. This has been a long ICAO program, started in 1997. Annex 2 to the Chicago Convention established the separation between westwards and eastwards IFR flight levels in order to reduce collision probability. Up to FL 290 (altitude of 29,000 ft.) the separation was 1,000 ft. (i. e. eastwards FL 210, 230, 250, 270, 290; westwards 200, 220, 240, 260, 280), but at higher altitudes, it changes to 2,000 ft (eastwards 290, 330, 370, 410, 450, etc.; westwards FL 310, 350, 390, 430, 470, etc.), taking into consideration the lower precision of the old aircraft instrumentation.

  With the progress of the positioning systems, ICAO started the RVSM program to change the upper space separation to the standard 1,000 ft. (westwards FL 300, 320, 340, 360, 380, 400; eastwards 290, 310, 330, 350, 370, 390, 410), creating 6 new flight levels to increase 15% air space capacity. As it is evident, a number of westwards levels in the former configuration (310, 350, 390) pass to become eastwards in the new architecture, making complicate the transition period. RVSM introduction started in the North Atlantic Region in March 1997 and was developed in 13 phases until its end in November 2011, with the addition of Russian and Iraq FIR (Flight Information Region) airspaces.

  The transformation process was made by ICAO airspace regions, starting by the highest traffic and best equipped North Atlantic y finishing by Russia in 2011, leaving practically only the Antarctic airspace in the former status. Having more levels to choose, the airspace capacity increases and airlines can do a better optimization of the flight plans, according to meteorological conditions and other traffic circumstances. The benefits were quantified in savings of 310,000 yearly tonnes of fuel.
- Free Flight, when the flight is free and direct, without using airways or navigation from VOR to VOR (Very High Frequency Omnidirectional Range) and not needing any indication from ground. This is the future scenario of the civil aviation world for the next couple of decades. The aircraft will be able to determine their position in flight with a high level of accuracy, using only satellite indications. Several constellations of satellites (the American GPS, the European Galileo, the Russian GLONASS and the Chinese program BeiDou) will provide the information to onboard systems. At this moment, GPS and GLONASS are fully operative, with global coverture; BeiDou is only available in China and the Asia-Pacific region, but will reach worldwide range by 2020; Galileo is in initial test phase that will be finished around the same year than its Chinese counterpart. Collision avoidance will be exclusive responsibility of the aircraft Advanced Collision Avoidance System (ACAS) and the role of ground stations will be reduced to monitor the correct performance of the global system. In this scenario, airways and waypoints will not be needed anymore and all flight will move along the shortest route. Potential fuel savings go up to 15% of present consumption, contingent on the amount of traffic in the different areas.

International routes can be improved with the collaboration of the overflown States. The most common procedures are to align the waypoints with the shortest trajectory or eliminate the some of the intermediate reference points.

The application of the best technologies to intercontinental flights requires the collaboration of multiple stakeholders of different States. The international pressure to reduce CO_2 emissions (and consequently fuel consumption) has fostered the launching of different initiatives in different world areas, like Atlantic Interoperability Initiative to Reduce Emissions (AIRE) in the North Atlantic in 2007. The equivalent Asia-South Pacific Interoperability Initiative to Reduce Emissions (ASPIRE), was formed in 2008 with participation of Australia, New Zealand and USA at the beginning, joined later by Japan, Singapore and Thailand. Three year later, Australia, India and South Africa set up the Indian-South Pacific Initiative to Reduce Emissions (INSPIRE).

As a good example, AIRE was established through an EU-USA agreement, and developed initially by a consortium of 15 ANSPs, system manufacturers, engineering companies and airlines during the first phase 2008-2009, trying to optimize oceanic operations. In the second phase 2010-2011, with the participation of 43 entities, the scope was widen to include all and each one of the different sectors of a commercial flight between the two continents.

A precedent for all these multinational actions was the Russian-American Coordination Group for Air Traffic (RACGAT), created in 1998 to open new routes over Siberia or China and North Pole, shortening the distance for flights between North America and the Far East. Satellite-based navigation guidance and some specific measures to prevent fuel freezing at high cruise temperatures made them viable and very successful, cutting flight time and fuel consumption.

Other interesting approach to increase fuel efficiency improving navigation procedures is the integration of several national ANSPs in a single organization with common equipment and procedures, eliminating the differences among airspace management in neighbour countries. This is the EU approach with the Single European Sky (SES) program that intends to move from an airspace with 40 ANSPs to a single unified ATM region.

The Public Private Partnership (PPP) consortium SESAR (Single European Sky Advance Research) develops the technical part of the program with the following targets:

- Increase three times the European air space management capability
- Increase safety by a factor of 10
- Reduce 50% the ATM cost to the users
- Optimize flight trajectories to save between 8 and 14 minutes per flight, reducing fuel consumption by an average of 300 to 500 kg

The program started in 2006 and it is assumed to last until 2025. It includes the launching and put into service a global navigation satellite system, named Galileo, to provide a highly accurate, guaranteed global positioning service, interoperable with the similar US system (GPS) and Russian system (GLONASS). The satellite constellation will have 24 operative units and 6 spares and its enter into service is expected in 2020. Galileo was initially developed by the European Space Agency (ESA), a multinational State scientific body. In July 2017, ESA transferred the formal responsibility for oversight of the Galileo operations and provision of services to a newly created entity, Global Navigation Satellite System Agency (GSA).

The transition from a highly fragmented airspace to a single airspace will be done in several steps that will join neighbour States airspace in commonly operated ATC areas. In 2014, a total of 9 Functional Airspace Blocks (FABs) were consolidated, including 31 European States:

- North Atlantic FAB: Ireland, UK
- Scandinavian FAB: Denmark, Sweden
- Baltic FAB: Lithuania, Poland
- Blue Med FAB: Cyprus, Greece, Italy, Malta
- Danube FAB: Bulgaria, Rumania
- Central Europe FAB: Austria, Bosnia & Herzegovina, Croatia, Czech Republic, Hungary, Slovak Republic, Slovenia
- FABEC FAB: Belgium, France, Germany, Luxembourg, the Netherlands, Switzerland
- North European FAB: Estonia, Finland, Latvia, Norway
- South West FAB: Portugal, Spain

FAB definition has been made as a function of the existing airspace national limits and are not equivalent in terms of traffic volume. FABEC is the most important one, with a 55% of the whole European traffic crossing it.

An already proven precedent, at small scale, is the Free Route Airspace Maastricht (FRAM), a program run by the Maastricht EUROCONTROL Centre which gives air navigation services in the upper airspace (over 25,000 ft. altitude) of Belgium, Luxembourg, the Netherlands and the Hamburg FIR. FRAM has opened 142 new direct routes since 2011 with 12,000 tonnes of CO_2 savings per year.

United States has already a similar satellite constellation, GPS that is operating successfully, but is also involved in an ambitious program of ATM improvement, titled NextGen, in order to speed up the transition from former Communication, Navigation, Surveillance (CNS) to the modern satellite-based technology. The NextGen program started in 2003 and its implementation is increasing airspace capacity, improving safety and reducing flying time, with accumulated results until the year 2018, of a 35% delay reduction and 14 million tons CO_2 savings.

ATM efficiency evaluation

All of the above-mentioned initiatives have the target of improving the efficiency of the ATM system in different issues like safety, fuel consumption, reliability, capacity, environmental impact and interoperability. Projected improvements have to take into account the traffic evolution in global and local terms and the technology progress, in flight and ground based equipment. The evaluation of the ATM system efficiency has to consider the positive effects of technological and organizational efforts and the negative weight of traffic growth that asks for additional growth of capacity.

The question of how efficient is the actual ATM, compared with an ideal condition of everything working exactly as intended, is not easy to answer. At the beginning of the GANS study, ICAO considered that 2010 ATM efficiency was between 87% and 90%, meaning that, on average, every operating flight was consuming between 10% and 13% more fuel than it needs to. The traffic forecast associated to this analysis showed that the number of flights would double in the 2010-2030 period. Imposing this growth in traffic on the 2010 ATM system, without any improvement, would result in an efficiency degradation of 0.2% per year or a total of 4% in the 20 years covered by the study.

ICAO figures do not coincide with the analysis made by the Civil Air Navigation Services Organization (CANSO), an association of the main world ANSPs. In 2012, CANSO published a document with an evaluation of tentative ATM Global Environment Efficiency Goals in

2050. The baseline year was 2005 and the global ATM efficiency was considered to be between 92% and 94%.

The main difference of both evaluations was the approach adopted. While ICAO accounts for all the different factors in a package, CANSO makes a distinction between effects that have direct repercussions on fuel consumption, like the flown distance, and other indirect elements, as insufficient airport capacity, grouped under the name of interdependencies.

The interdependencies identified in the CANSO report can be divided in seven categories:

- Airline practices, because not all the operators have flight planning systems with the capability and flexibility needed for taking advantage of all the most optimum routings that may be available. These deficiencies may be organizational or coming from the technological level of the operating aircraft and support equipment.
- Capacity, when capacity limitations appear, an aircraft may be required to hold in-flight, waiting for an available slot or wait during the taxi out before take-off. ATM system has the possibility of increase the airspace capacity but has no authority on airport capacity or on the slot allocation procedures.
- Institutional, if fragmented airspace constrains flight planning. Different regions or countries may have different non-compatible operating procedures, requiring deviations from the optimum conditions. A mention should be made on charging systems: if air navigation charges are very different, the operator might be tempted to make longer flights for using the cheapest airspace. For example, under EUROCONTROL charging system, the 2017 unit prices in different airspaces vary from the most expensive area (Switzerland) to the cheapest (Portuguese Azores Islands FIR) in a ratio of 10 to 1.
- Military, as it was previously discussed, military restricted air zones, permanently or temporarily, require close cooperation between civil and military ATM, in order to optimize the trajectories.
- Noise, if noise abatement procedures, specific for the operation in some airports, are different of the minimum consumption ones. It depends on the location of noise sensible areas around the airport and uses to be more problematic for take-offs, if the tracks try to avoid some populated areas. Most modern aircraft have FMS equipment with automated climb procedures for either minimum fuel or minimum noise trajectories. In the case of approach and landing, the CDA procedure is able, in most of the occasions, to reduce both noise on ground and fuel consumption at the same time.
- Safety, as a flight can be deviated from the optimum track in order to ensure adequate separation from other close aircraft. This separation can be dictated by aircraft types (wake vortex) or by the accuracy level of the local ATM facilities.
- Weather, if avoidance of adverse weather systems may recommend non-optimum routing to ensure a safe and smooth flight.

There are a number of good examples in which interdependency effects can be drastically reduced by effective collaboration among different stakeholders. The RVSM operation, described in the previous chapter, is a success story to take into account.

A different and more aggregated evaluation is in the 1999 IPCC report, giving a range of 6-12% fuel reduction per trip thanks to potential ATM improvements, implemented in the 2000-2020 period. The achievement of those figures is considered contingent on the implementation of a number of essential institutional arrangements at an international level. The analysis does not consider any airport or other infrastructure capacity constraints.

In 2014, ICAO performed a study of the potential efficiency results of the ASBU Block 0, the finalization of which was scheduled for the end of 2018. The most likely results point to something between 2.3 and 4.1 million tonnes of fuel savings per year, considering the level of predicted implementation of the different proposed measures. With an oil price around 60 USD per Brent barrel that will provide 1,200-2,200 MUSD yearly savings to the operators.

The results indicated that a fuel burn reduction of 2% to 3% was possible if the totality of the measures was implemented worldwide in that time period.

The evaluation of efficiency improvements in local air spaces is a complicated task, prone to offer many different results when non-homogeneous methodologies are used. However, individual states have to offer some indicative results of the different initiatives implemented in their sovereign airspace.

In order to make those analysis more comparable each other, ICAO has developed a Fuel savings Estimation Tool (IFSET) to assist States to estimate fuel savings in a manner consistent with CAEP approved models and aligned with GANP.

IFSET methodology is to evaluate the differences in flight trajectory performance in terms of fuel consumption before and after implementation of operational improvements in the analysed area. The calculation covers four different categories of improvements:

- Reduced cruise distance or time
- Availability of optimal altitude, requested for the flight plan
- Reduced taxi time
- More efficient departure and approach/arrival procedures

This methodology has a highly simplified aircraft characterisation, in terms of weight, thrust, CG position and airframe/engine combination. Then, it is not appropriate to calculate actual fuel consumption and its best use is to give a comparison between any two scenarios. A number of analysis have been made for individual countries (like India) and for associations of State ATMs, like ASECNA and COCESNA.

Optimisation of operating procedures

The basic rules for operating fuel savings according to the IATA Flight Path to Environmental Excellent document are:

- Program the most efficient aircraft for each route
- Choose the best taxi out way
- Fly the most efficient trajectory
- Fly at the most efficient speed
- Keep the most economic altitudes
- Maximize load factor
- Minimize aircraft operating empty weight
- Upload the minimum amount of fuel required by safety reasons
- Minimize the number of non-commercial flights
- Specific maintenance procedures for engines, airframe and systems

Some of those rules are dependent on the airline flight planning and aircraft scheduling and others are related to the flight planning optimization. However, even having the best possible flight planning on hand, there are a number of important fuel efficiency decisions to be taken by the crew during the flight, with the help of the ground flight monitoring team.

Summarising these operational measures, the example of Iberia can be brought, with the company recently announcing a plan aiming at reducing fuel consumption based on the following operational measures:

- Aircraft weight reduction (reassignment of nearest alternate airports, aircraft interior renewal with lighter seats and trolleys, potable water load control)
- Cruise speed adjustments, flights at optimum altitude levels, engine-out taxi
- Optimization of landing manoeuvers (engine idle reverse, lower flap setting, Continuous Descent Approach)
- Maintenance: increasing the frequency of engine and fuselage wash, new and lighter aircraft painting
- Improved energy efficiency through flights planning incorporating Cost Index, fleet assignment for different routes and load factor optimization

In particular, and based on the application of those actions, an airline can achieve a 2-3% fuel savings applying operational measures all along the flight:

- Flight planning: match planned and real operation; fuel optimised payload, route, Flight Level and speed
- Execution excellence: best fuel efficiencies practices applied in flight execution; continuous feedback between Flight Ops Management and Crews, focusing on efficiency issues
- Balance weight on board vs. profit: optimisation of in flight retail and pantry as a function of profitability; overall cabin weight reduction: lighter trolleys, water and magazines

Market Based Measures (MBM)

Environmental impact management, in addition to the solutions based in the technology, may use different economic actions, most of them in the shape of Market-based Measures (MBM). The most promising options, explored by ICAO, are:

- Voluntary agreements between the Administration, some operators, the consumers, or any combination of those three groups
- Taxes imposed by Central, Regional or Local Administrations
- Charges related with different aeronautical payments, as airport, air navigation or passenger fees
- Emissions Trading System (ETS) as defined in Kyoto Protocol

The goals of this type of economic measures are:

- To complement traditional regulatory measures with others with participation of stakeholders other than the Administrations
- To offer flexibility to the operators looking for the most economic option to comply with the rules
- To create incentives for operators and/or consumers with the purpose of modifying their behaviour
- To "internalize" the "externalities", building up prices which include the total cost of the activity

Domestic air transport is included in the national GHG inventories, regulated in the Kyoto Protocol (1997). The Protocol gives ICAO a mandate to regulate GHG emissions produced by international air transport (at that time quantified as 3.5-4.0% of total anthropogenic effects, 2.0-2.5% of CO_2 emissions). ICAO analysis shows that a mix of short term voluntary agreements and long term emissions trading is the most efficient MBM procedure for emissions limitation. ICAO recommends the ETS application through its inclusion in bilateral or multilateral traffic agreements. MBM were evaluated by CAEP in the 2001-2004 period, and the results showed the following conclusions:

- Voluntary Agreements are beneficial in the short term, but are not a solution in the long term
- Taxes show very low cost / benefit efficiency
- Charges may be acceptable for local problems, but act like taxes in a global application
- Emissions Trading is the most efficient system, when applied in open regime, i.e. allowing trading with other industrial sector.

The first type of Market Based Measures are voluntary agreements. There may be different types of voluntary agreements, for instance:

- Between the Administration and the industry, with the commitment to adopt energetic efficiency measures and good practices. Examples can be found in Canada and Japan. ICAO approved recommendations for this type of projects in 2004.
- Between some industry sectors and the public opinion. IATA has settled energetic efficiency targets and publishes yearly the achieved position versus those targets. One of these agreements established a total efficiency improvement for the period 1990-2012 of 26%, resulting in an annual efficiency improvement for that period of 1.1% (Figure 4).
- Between airlines and their customers, who are offered the possibility to pay an extra amount of money to offset the CO_2 emitted by their part of the flight.

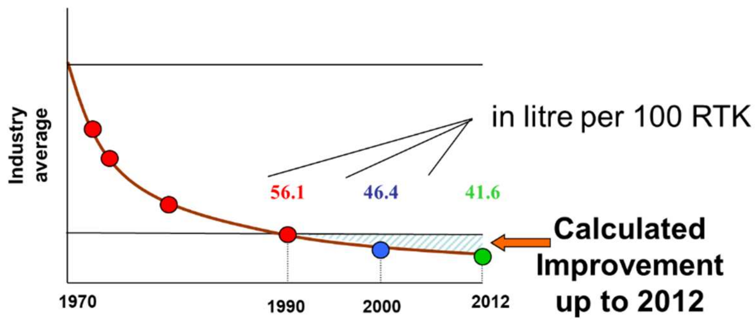

Figure 4. IATA voluntary agreement (Source: IATA).

The following IATA goals were adopted by the IATA Council in 2009. The purpose was to achieve a traffic growth without increasing CO_2 emissions (Carbon Neutral Growth or CNG) from 2020 levels (using Market-Based Measures as well). Between 2020 and 2050 commercial aviation would reduce CO_2 emissions 50% with respect to 2020 (Figure 5). IATA has developed an energetic auditing program and makes active best practice diffusion among its members.

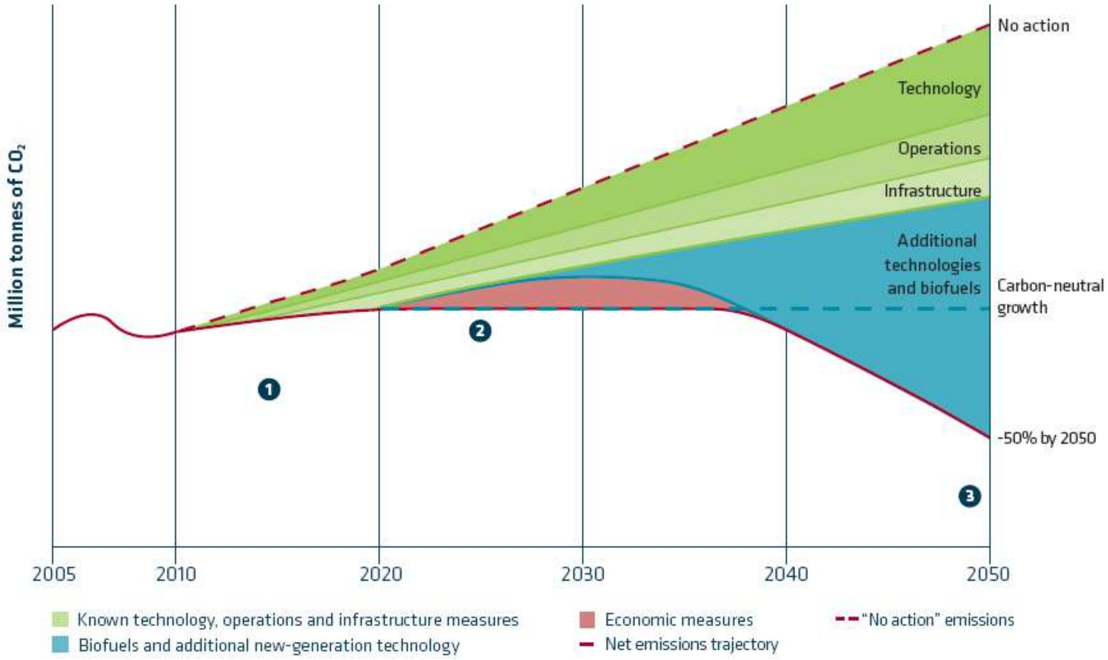

Figure 5. Aspirational goals of CO_2 emissions future development in 2009 (Source: IATA)

With the approval of Paris Declaration in 2015, the pressure to reduce carbon emission increases and in October 2021, IATA General Assembly approved a new target of zero net carbon emissions for 2050 (see Figure 6).

The plan was presented in the COP26 in Glasgow IATA presented a plan for achieving a Net-Zero carbon emissions for commercial aviation in the year 2050.The document outlined a detailed schedule in five-year steps, starting in 2025, with the needed amount of SAF and other new carburants and the size of the emissions that would need to be compensated to achieve the Net-Zero target.

There is a preliminary agreement among the main industry stakeholders to support that plan that requires action not only by industry partners but also by States and energy providers. The proposal went to the ICAO CAEP 2022 meeting (February) and has a good chance of being approved in the General Assembly. If this happens, ICAO support will give States a tool to take many actions in this direction, difficult to adopt with the only base of a declaration.

Most of commercial aviation stakeholders (manufacturers, air navigation service providers, airports, NGOs) joined to this initiative, supported also by a number of Governments. It is expected that it will be discussed and eventually approved in the next ICAO Assembly (September-October 2022), becoming the objective to be reached in the future.

The elements needed to reach that target are shown in Figure 7. About two thirds of the carbon saving should be obtained by the use of SAF. New technologies, mainly new propulsion systems like hybrid, electrical and hydrogen would provide almost 2%. A small part, about 3%, would come from infrastructure improvements, mainly in the air navigation area, and the rest would depend on carbon offsetting (CORSIA and similar mechanisms) and carbon capture to manufacture e-fuels.

Taxes are the second type of Market Based Measures. Taxes may adopt two different lines: fuel (or CO_2 tax), or a general environmental tax applied to the passenger.

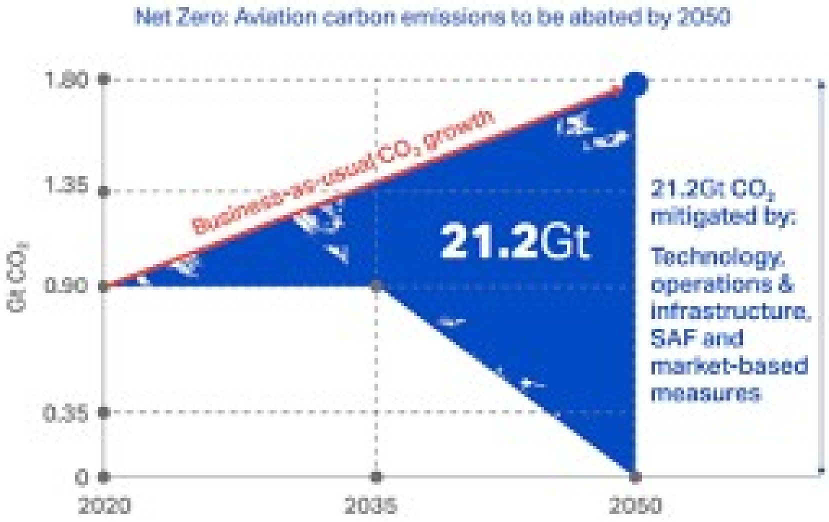

Figure 6. Aspirational target of net zero carbon emissions in 2050 (Source IATA)

Concerning fuel taxes, the Chicago Convention in its Article 24 (and an ICAO Council Resolution on 14/12/1993) recommends Member States not to apply taxes on the products uploaded in an international flight aimed at being consumed during the flight. Obviously, fuel is one of these products. This is confirmed in the ICAO Doc 8632 on charges and taxes and it is included in the traffic rights bilateral agreements between States. Many bilateral agreements on traffic rights use to have a reference to that Article. EU considers this provision inadequate and defends its suppression. The EU regulation allows the introduction of this fuel tax inflight between two countries if both States agree on this point. There have been no application so far. Outside the EU, some States apply fuel taxes to domestic flights (USA, Japan, Norway) but with much lower levels than to the road transport fuels.

Regarding environmental taxes, some States like Austria and Germany have taxes with the revenues assigned to environmental programs. The United Kingdom collects the Air Passenger Duty (APD) from the passengers boarding in UK airports. APD gets about 4,500 MUS$ yearly. Up to now, the experience from this approach is negative in terms of economic benefit per unit of cost, with a cos close to 1,000 € per CO_2 ton reduction.

Taxes and charges have very different definitions in ICAO texts. Taxes are paid to collect funds for local or national Governments and may be used for any purpose. Charges are paid to compensate the cost of different services provided to the operators. They are finalist. ICAO defends the use of charges rather than taxes. Both elements are put together under the term levies. The questions are: is the concept applicable to environmental charges? What services are they supporting?

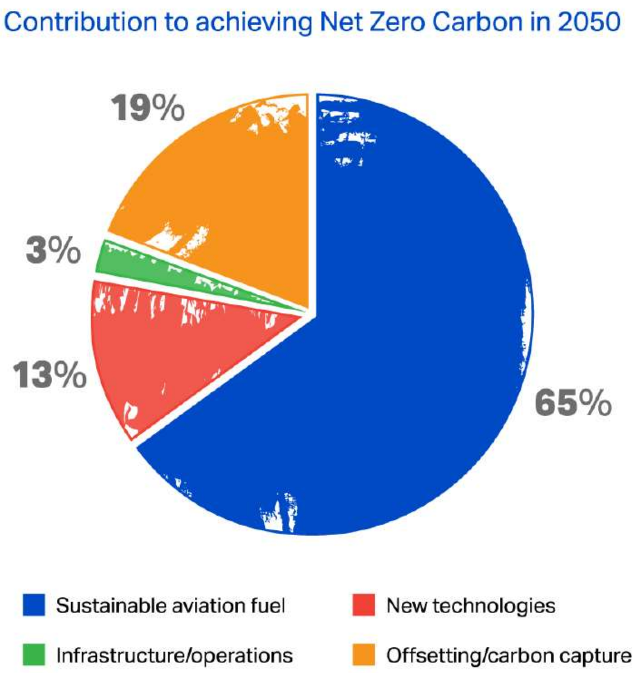

Figure 7. Technologies to achieve net zero carbo in 2050 (Source: IATA)

Noise charges are being used for the last forty years. There are 28 States using them in different ways. Normally they have different values in each airport, generally related to the landing charge as a surcharge. Collected money is paying for noise control and monitoring, house insulation, zoning and any other noise related airport activity. May be based on the certified noise values of each aircraft type or in the actual noise registered by the airport monitoring system. ICAO recommends those schemes to be in compliance with a number of recommendations given in Doc 9082, chapter 30:

- To be applied only in airports with a noise problem
- The collected amount of money not to be higher than the cost of the airport noise reduction programs
- Preferably associated to the landing charges
- Taking into account the Annex 16, Part 1, certificated values
- Do not discriminate among operators or aircraft types
- Not being so expensive as making uneconomic the operation of certain aircraft types

ICAO has established its position on Emissions charges in three documents. Existing schemes are complying with that guidance material. The documents are:

- Doc. 9082/7 referring to airport and air navigation charges policies
- Council Resolution (09/12/1996) on aeronautical charges and taxes
- Resolution A35-5 of ICAO 2004 General Assembly

Doc. 9082/7 confirms the application to emissions charges of the same general guidance than for noise charges. They are the following:

- They will be based in the cost of mitigating aircraft engine emissions impact, as far as those costs can be clearly identified and directly attributed to the air transport.
- In addition to those costs, the system must be neutral in total revenues.
- There will be no discrimination among the users.
- Charges will be transparent and settled in consultation with the operators.

The 1996 Council Resolution accepts the principle of each economic sector must pay for the complete cost of its environmental impact and recommends that the money collected through emissions related charges is spent in mitigation actions to reduce the environmental impact of those emissions, defending the non-discrimination of air transport with respect to other transportation modes. The 2004 General Assembly affirms that direct CO_2 charges are not adequate to mitigate climate change and declares its preference for the use of an emissions trading mechanism.

Emissions charges are being used since 1997, only for NOx. Today there are landing charges modulated with NOx emissions in the largest twelve airports in Sweden, Basel, Berna, Geneva, Lugano and Zurich airports in Switzerland, Gatwick, Heathrow and Luton airports in the UK, Dusseldorf, Frankfurt, Hamburg and Munich airports in Germany and Copenhagen airport in Denmark.

All of them use the ERLIG system, based on certified values and proposed by ECAC, with little local variations. The ECAC recommendation 27-4, prepared by the ERLIG Group, proposes a continuous scale, based on the LTO cycle certified emissions. ERLIG divides aircraft considering the margin of its engine certified NOx values with respect to the Annex 16, Part 2, levels. Some old engines have good NOx margins but very poor figures in HC and CO. The scale is applicable if HC values do not reach a certain maximum value. In that case the NOx surcharge would be the highest, i.e. over a top level of HC emissions, the aircraft is classified in the most expensive group, independently of its NOx values.

When technical measures and improved operating procedures are not enough, the dilemma is to implement regulatory or economic measures to complement them. In the absence of a Chicago Convention modification, it is not possible to apply generalized taxes on the international flight kerosene and the States are not willing to include it in bilateral agreements.

According to ICAO, the most environmentally efficient measure is Emissions Trading, one of the three flexibility mechanisms included in the Kyoto Protocol, in addition to Joint Implementation (JI) and the Clean Development Mechanism (CDM).

Emissions Trading is a cap and trade system. It sets up a cap for a participant emissions and provide them allowances to emit, i.e. rights to emit a fixed amount of emissions per year. The system allows participant to buy and sell emissions allowances, i.e. rights to emit a fixed amount of emissions per year. This way, emission goals to be met can be established in the most cost-effective way by letting the market determine the lowest-cost pollution abatement opportunities. At the end of each trading year, participants have to hand over or surrender allowances corresponding to their actual emissions in that year. Participants can either sell unused allowances to other participants in the scheme or must buy the allowances needed to cover their extra emissions from other participants on the open market. The goal is to minimize the cost of reducing emissions globally.

The European Emissions Trading System (EU ETS) is applied in 6 economic sectors (46% of EU CO_2 emissions) since 2005. In 2007 EU Commission published a draft Directive to include civil aviation in the EU ETS, starting 1st of January, 2012. The proposal became the Directive 2008/101/EC, issued in January 2009. Different than Kyoto, it is based on a non-national scheme, with the Airlines as the stakeholders and owners of emission allowances. It does not distinguish between domestic and international flights.

The efficiency unit is the amount of emitted CO_2 per RTK, adding up passengers, freight and mail, including APU emissions. The weight of the emitted CO_2 is computed multiplying the consumed fuel weight by 3.15 (emission factor), when is standard kerosene. Biofuels have zero emission factor. Payload weight is the one stated in each flight mass & cg documentation or, by default, 100 kg per passenger and his baggage. Flight distance is the orthodromic plus 95 km.

The extraterritorial application (inclusion of non-EU airline flights) does not comply with ICAO recommendations. The growing opposition of some important States, like Brazil, China, Russia and USA, has brought back the ETS discussion to ICAO. In November 2012, EU decided *"stop the clock"* on the inclusion of flights coming from or going to non-EU countries in the European ETS, waiting for a new global system to be approved by ICAO. ETS rules remain the same for internal EU flights. In September 2013, ICAO Assembly ordered a study on a worldwide MBM to be approved in the 2016 Assembly and applied in 2020.

World airlines increase their fuel efficiency 1.5-2.0% yearly. If the served demand increases 4.0-5.0% annually, air transport sector will be an emission allowances net buyer forever. A closed ETS (only commerce among airlines) will be very expensive due to the small number of sellers. An open ETS would be cheaper for aviation, although general price levels might increase. Present economy weakness has reduced the allowance price down to 4€ per CO_2 ton. It remains the legal problem of mixing Kyoto domestic flights allowances with the new "aviation" ones, not included in the Protocol.

After its 2007 failure to get an international agreement on international ETS, in 2010 ICAO look again at CO_2 MBMs and approved a dual way of approach the problem. On the regulatory side, a new part of Annex 16 (the Volume III) will be requiring new aircraft models to comply with maximum levels of CO_2 emissions before achieving their type certificates. The regulation was approved in 2016 [ICAO, 2017] and was applicable starting in 2020.

The second action was the creation of a worldwide system with the purpose of keeping net carbon international flight emissions at the average level of the 2019-2020 years, in such a way that airlines would be paying to offset the emissions excess over that level. The system was called CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) and is applicable since 2021 [ICAO, 2021].

CORSIA has some advantages with respect to ETS. It is more simple, in spite of having to certified included emissions as well and achieved a wide consensus among ICAO Member States. However, there are also some important drawbacks. First, as all ICAO regulations, covers only international flights. Second, some countries of lower development levels, isolated in islands or without an easy way to get to the ocean, asked for being exempted. And the third and more important, States with a very recent air transport industry growth argued that developed States had been emitting high quantities of CO_2, many years before and they considered unfair offsetting new emissions when former ones were exempted. This last point obliged to not individualize the payments in the first application years, when there will be a global payment by airlines altogether for the global CO_2 excess. In the subsequent years, those payments will progressively be apported by each one of the operators.

In principle, CORSIA will be covering around two thirds of total aviation emissions when enough number of States join the system. The States participation is voluntary and, at the moment, a total of 107 States has declared their will to enter in the system in 2022.

Standard offsetting systems do not seem appropriate for global emissions reductions but may play a role in keeping emissions under control until more progressive MBMs are implemented.

However, there were a number of Carbon Offsetting and Reduction Scheme for International Aviation international organisms making declarations on some environmental targets to achieve in the future, under a voluntary based procedure. ICAO itself pointed out a goal of improving fuel efficiency by 2% per year since 2010 to 2020 and continue that way after that date. The behaviour of the large organisations dealing with climatic change was also on this voluntary commitment line. Paris COP21 approved in 2015 an increase in global warming of 1.5ºC (2.0ºC the acceptable maximum) as the red line not to be exceeded, assuming that a majority of large States will work in that direction, without any specific regulatory body.

Sustainable aviation fuels

Sustainable aviation fuels (SAF) represent a substitutive product to fossil kerosene, reducing the dependency and decreasing also the CO_2 emissions. The ideal option would be a drop-in fuel that can be blended with kerosene, and consequently not requiring modifications in engines, fuel system or logistic fuel distribution system.

One of the measures to reduce the emissions from aviation under CORSIA is the deployment of drop-in, sustainable aviation fuels (SAF) from biomass feedstocks [ICAO, 2019]. SAF is a blend of fossil-based kerosene with renewable jet fuel, and this mixture can be used without any modifications to the aircraft or to the infrastructure (hence the term "drop-in"). Fuel production pathways, along with blending ratios for these drop-in fuels, are certified by ASTM International that defines international standards for aviation fuels. As of June 2020, 8 drop-in fuel pathways had been authorized [ASTM].

In an effort to specify the fuels with potential environmental benefits certain criteria was set under CORSIA. A CORSIA eligible fuel (CEF) was defined as, SAF that provides at least 10% greenhouse gas (GHG) emissions reduction compared to conventional aviation fuel. Another prerequisite is that the biomass used for a CEF should not be obtained from a land with high carbon stock, causing high emissions from land use change (LUC). For the selection of biomass feedstocks, and jet fuel production pathways with lower GHG emissions, CAEP has developed specific methodologies for the calculation of life cycle emission values (LSf) for SAF[ICAO, 2020]. Currently there are 16 different feedstocks included for various pathways, and research is on-going for the addition of others.

The high cost of SAF is the main problem to extend its use. High quantities of production are needed in order to reach economies of scale, which need high initial investment levels in crops and distillation, including special technology for cultivation and harvesting.

SAF show on the other hand some additional advantages:

- Environmental: CO_2 emissions reduction without competing with the production of food for people or animals. The specification may be cleaner than fossil kerosene, taking out sulphur and aromatics
- Strategic: diversifying fuel production sources from chemical and geographic points of view, reducing the oil producers dependency
- Economic: stabilising fuel price, reducing the typical oscillations of the oil market

The aim to stabilize, reduce and eventually neutralize CO_2 emissions between 2020 and 2050 relies largely on the development at large scale of SAFs, as it can be seen in Figure 5.

There is little doubt that present technology can create a fuel that replicates standard aviation kerosene from sustainable alternative raw materials, but doing so in a cost effective way and at the scale of the industry needs remains a formidable challenge. It is widely accepted that the introduction of biofuels cannot be done using current market mechanisms because their high production and distribution cost, at least during the initial stage limit their competitiveness with fossil fuels. Then, all States interested in promoting the use of biofuels are going to use special incentives to gain public acceptance of these new products.

There are several feasible options for incentive policies, varying on the type of economic mechanism applied, subsidies or quotas, and in the phase of the production-consumption cycle where is applied to, farming, recollection, manufacturing, distribution or consumption.

All these potential schemes can be broadly included in two groups: mandate for blending and tax measures.

2.6. PRODUCT LIFE CYCLE

The modern concept of the environmental impact of air transport affects not only the aircraft operation, but the so-called Product Life Cycle, i.e. all the activities from aircraft manufacturing to their final disposal. Large aircraft manufacturers such as Airbus and Boeing, but also airlines and other agents in the industry, especially airports, are taking steps along this process of considering the environmental implications of the full product life cycle.

For instance, the Airbus environmental lifecycle approach is shown in Figure 8 and consists basically of the following main lines of action:

- Investing in research to design cleaner and quieter aircraft
- Managing the supply chain for a shared vision of environmental responsibility
- Managing the impact of manufacturing on the environment thanks to cleaner technologies and processes
- Optimising aircraft operations and maintenance for enhanced environmental performance
- Implementing new best practices to disassemble and recycle end-of-life aircraft

Another example related to Product life cycle is TARMAC (Tarbes Advanced Recycling & Maintenance Aircraft Company) a European platform with the participation of Airbus complying with applicable regulations related to environment, health & safety and airworthiness using dedicated zones and infrastructures based upon business related risk analyses. The Platform activities and services are: parking & storage, light maintenance, part-out and storage of components and smart and selective dismantling.

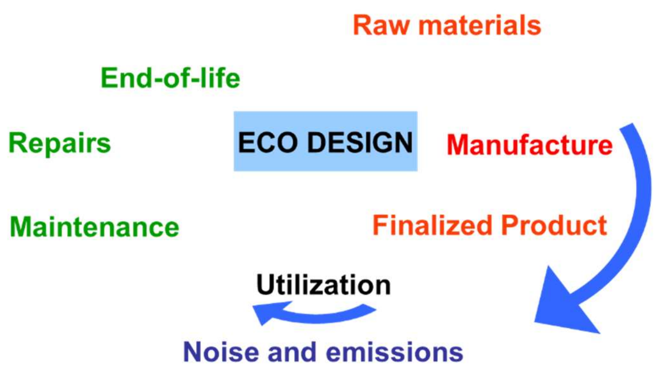

Figure 8. Need to consider the total life cycle (Source: Airbus)

Boeing is also investing to improve the fuel-efficiency and environmental performance of their products, services and operations. The company takes into account environmental performance at every step of a product's lifecycle, from materials, design and manufacturing, through in-service use and end-of-service recycling and disposal, calling this strategy Design for Environment.

In 2006 Boeing and 10 other companies established the Aircraft Fleet Recycling Association (AFRA). There are now more than 40 member companies from 11 countries. AFRA is committed to continuously improving aircraft recycling methods' efficiency and environmental benefits. By working to efficiently process as many aircraft as possible, AFRA member recyclers make recycling more cost-effective for aircraft owners (an aircraft manufacturer is not an aircraft recycler itself.) This will ultimately help ensure that aircraft recycling has an economically viable future in the marketplace. Collectively, AFRA member organizations have already rrecycled approximately 6,000 commercial aircraft and approximately 1,000 military aircraft (800 tactical) and also remarketed (returned to service) approximately 2,000 airplanes.

AFRA's goal for its certified members is to recycle 90 % of each aircraft by end of 2016. This includes safe and economical return of aircraft, engines and parts to revenue service as well as return of reclaimed metallic and composite materials back into commercial and aircraft manufacturing.

An example of recycling is the Boeing agreement with InterfaceFLOR to develop carpet tiles made from 100 % recycled aerospace carpeting. Stating in March 2012, Southwest 737s began receiving their new planes off the Renton Assembly lies with the carpet tiles installed. Recycled carpet tiles will be soon an option available to customers on all Boeing airplanes. By using carpet tile instead of wall-to-wall carpeting, airlines replace only those sections that get stained and that maintenance can be completed overnight. The carpet tiles that are replaced can be recycled over and over again. On most airplanes, the carpeting is replaced 20 to 30 times over its lifetime. On a 777, that can add up to 18 tons of carpeting sent to landfills if the airplane is in service for 20 years. Given that aerospace carpeting is made from a synthetic material that is designed to be durable and meet aerospace fire-retardant properties, it doesn't break down readily in landfills.

2.7. DEVIATIONS AND CORRECTIVE ACTIONS

2.7.1. DESCRIPTION OF THE DEVIATION

No deviations to be reported with respect to the original project plan.

2.7.2. CORRECTIVE MEASURES IMPLEMENTED

N. A.

3. CONCLUSIONS AND NEXT STEPS

The information contained in this report provides the second and last input to characterize the scientific description of the impact of aviation emissions to climate change, which is the objective of the first WP of MWP7. The results of the tasks corresponding to the state-of-the-art review on aviation environment impact and the spatial and temporal distribution characteristics of aviation emissions were included in D7.1. Now, a description of the aviation emissions impact on the environment has been reported.

These results provide the necessary inputs to continue the work in this MWP7 and begin the next WP7.2 Development of an evaluation methodology for environmental impact, which is the work planned for the next 12 months.

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