Crusade against the carbon dioxide or how the civil aviation industry tries to rein its ever increasing carbon dioxide emission

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Introduction

From the chemical reaction of carbon hydrogens assuming perfect and clean combustion, carbon dioxide and water vapour is produced. Of course, that happens in gas turbine engine combustors, too. However, the combustion is not perfect in the combustors of gas turbine engines, so other combustion products (pollutants) are also generated like nitrogen oxides, sulphur oxides, carbon monoxide, soot, unburnt fuel particles, see Table 1 and Figure 1. The emission of these pollutants can be slightly reduced by optimising the combustion process improving the fuel nozzles and the combustor itself.

Figure 1.

High amount of soot emitted by the left hand side aircraft

Source: compiled by the author

These pollutants are responsible for the ground-surface pollution and basically significant in the vicinity of airports, and in this respect they are related to the phases of taxiing, takeoff and landing, as well as climbing and approach of the aircraft. As they directly affect the close environment of the airports and accordingly the population and nature there, this became the focus of attention and became the subject of early regulations. Accordingly, ICAO has been pushing ever stricter regulations from the 1960s to reduce these pollutants.

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Table 1.
Combustion products of one kg fuel in grams

Pollutant	CO_2	H_2O	NO_x	SO_x	CO	Unburnt fuel	Soot
Gram/kg fuel	3,100	1,394	9–15	0.3–0.8	0.2–0.6	0–0.1	0.01–0.05

Source: CUMPSTY 2003

On the other hand, improving the conditions of combustion, the amount of the emitted carbon dioxide and water vapour cannot be reduced, but only by decreasing the fuel consumption itself using more economical engines, aerodynamically better airframe and wing design, mass reduction (aircraft technology) and operational improvements. The high-atmospheric pollution, caused by carbon dioxide and water vapour, is not so obvious and immediate, but maybe its harm can be more severe in the future of mankind, taking into account the already present phenomena of climate change and ozone depletion. Water vapour can be said harmless, as a naturally occurring material that is an integral part of our lives. However, the effects of high-atmospheric emissions of water have not yet been clarified, but environmental and climate protection experts are increasingly concerned about the large volumes of water vapour entering the atmosphere. However, concerning the climate change the main 'enemy' is the carbon dioxide. As can be seen from Tables 1 and 2, each tonne of burnt fuel produces approximately 3.1 tonnes of carbon dioxide.

Table 2.
Products of perfect kerosene combustion

Stoichiometric combustion	kg_{air}/kg_{fuel}	kg_{CO2}/kg_{fuel}	kg_{H2O}/kg_{fuel}	kg_{fuel}/kg_{air}	Fuel heating value [MJ/kg]
$C_{10}H_{22}$ (kerosene)	14,985	3,099	1,394	0,0667	43,2171

Source: Compiled by the author.

Carbon dioxide emissions due to certain forms of human activity, based on the EDGAR database created by the European Commission and Netherlands Environmental Assessment Agency released in 2015 is 36,061.71 million tons. Other even more potent greenhouse gases, for example methane, are not included in this data. According to the most recent data from the Intergovernmental Panel on Climate Change (IPCC), air traffic (domestic and international) is responsible for 2% (814 million tons) of the global carbon dioxide emissions generated by human activity, of which international air traffic produces at about 1.3%. However, considering the expected growth rate of aviation, this amount of emitted carbon dioxide would be triplicated in the next 30 years without additional measures. Of course, it is not easy to even grasp these enormous numbers but easier to think an average airliner we generally travel with and a rough estimation for its one-year carbon dioxide emission. This aircraft consumes 1.4–1.5 kg kerosene in every second, accordingly produces roughly 4.5 kg carbon dioxide. That kind of aircraft spends minimum 12 hours from 24 hours in the air every day and 300 days in a year (lest its operation is not economical).

The production of this average (rather underestimated) use is 4.5 x 3,600 x 12 x 300 = 58,320,000 kg, or 58,320 tons of carbon dioxide.

This is the reality, despite the fact that there has been significant technological progress in the aviation sector, as the fuel consumption per passenger-kilometres of today manufactured aircraft decreased by about 50% compared to the 1960s, see Figure 2 right. The diagram presents the fuel efficiency of commercial aircraft weighted by their proportion in the total number of planes delivered in the particular year. If there were a large number of aircraft with good fuel efficiency that year, there is an intense drop in diagram. Good example is the 1969–1971 period, when more than 30% of newly delivered airplanes were the new Boeing 747-100 and 200 series. When the market was full and most of the purchases again shifted towards buying small and medium-sized less fuel-efficient aircraft, the curve moved upward again.

The gas turbine engines have had an especially huge role in this fuel efficiency improvement. For example, the specific fuel consumption (sfc) of Rolls Royce gas turbine engines halved between 1958 and 2000, see Figure 2 left, but we can mention the winglets which also improved the fuel efficiency by 3–5%. Unfortunately, in the near future we cannot expect huge breakthrough in this field and that is the reason the aviation industry has to think about a complex measurement package to rein its ever increasing carbon dioxide emission.

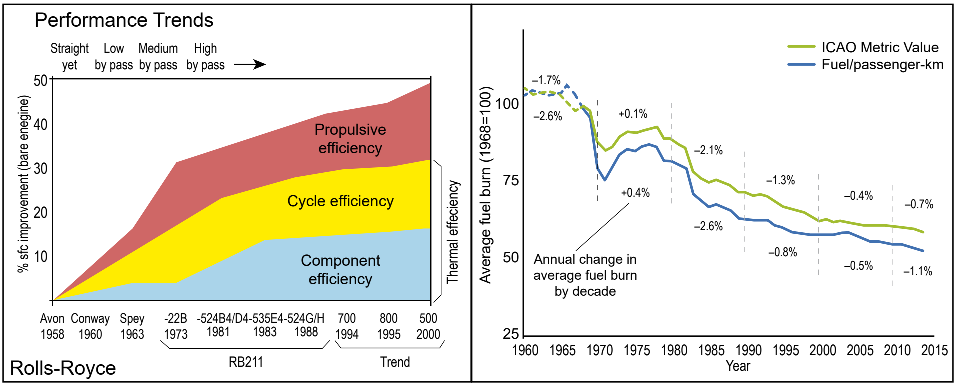

Figure 2.

To the left, improvement of the specific fuel consumption of Rolls Royce engines between 1958 and 2000, to the right fuel efficiency improvement of civil aviation industry between 1960 and 2014

Source: Turbine cooling s. a.; KHARINA–RUTHERFORD 2015.

1. Carbon neutral growth of international aviation

In the next decades, the fuel efficiency of aircraft may improve by about 1–2%, while the aviation industry's expected 5% of annual growth greatly exceeds this. Based on the environmental trend assessment by the ICAO Council's Committee on Aviation Environmental Protection (CAEP), international aviation fuel consumption is estimated to grow somewhere between 2.8 to 3.9 times by 2040 compared to the 2010 levels, see Figure 3.

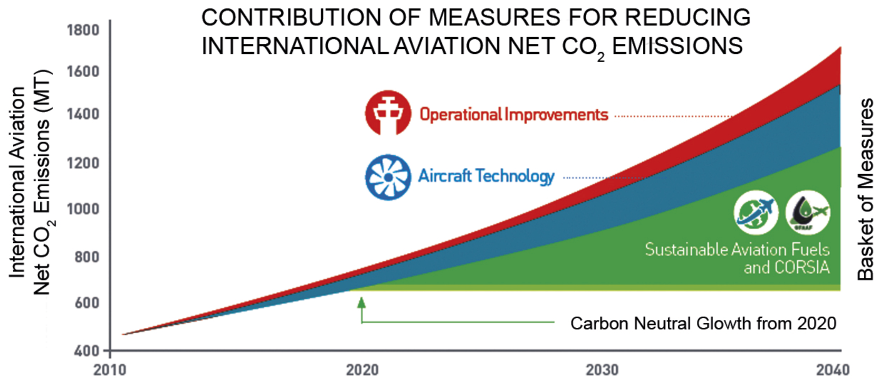

Figure 3.

The expected increase in carbon dioxide emissions by 2040 and the envisaged package of measures to maintain carbon dioxide neutral growth

Source: ICAO s. a.a

In October 2013, the 38th Session of the ICAO Assembly adopted Resolution A38-18, which resolved that ICAO and its Member States, with relevant organisations, would work together to strive to achieve a collective medium term global aspirational goal of keeping the global net CO_2 emissions from international aviation from 2020 at the same level (so-called "carbon neutral growth from 2020"). It means that the net carbon dioxide emissions from the international aviation industry cannot exceed the 2020 level of emission. This basket includes numerous measures from aircraft technologies to operational improvements, sustainable alternative fuels, and market-based measures (MBMs) (ICAO s. a.a).

The General Assembly set a package of measures to achieve ICAO's global aspirations. In accordance with Figure 3, it includes:

- the technological requirements of both the engine and the airframe structure (Aircraft Technology)
- traffic developments, both for ground operations and for air traffic controlling (Operational Improvements)
- the use of Sustainable Alternative Fuels and Market Based Measures (MBMs)

Market-based Measures have been named by the ICAO as CORSIA, which is the abbreviation of Carbon Offsetting and Reduction Scheme of International Aviation. It should be noted, however, that the CORSIA only applies to international aviation industry and includes fixed wing aircraft.

2. CORSIA in a nutshell

As it became clear from the previous chapter, the overall environmental benefit of non-MBM measures will not be enough to keep the international aviation sector's carbon dioxide-neutral growth after 2020 due to the intense growth of aviation.

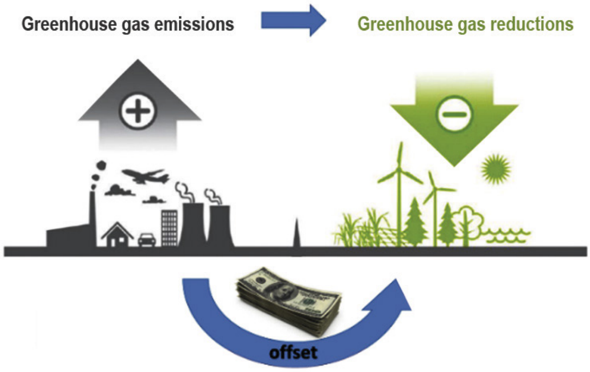

Figure 4.
The essence of Market-based Measures (MBM)

Source: ICAO s. a.a

The global MBM system allows to maintain the net emission level by means of offsetting the remaining gap, through carbon dioxide emission reducing, or even carbon dioxide absorbing projects, the essence of which is shown in Figure 4. What does offset mean? The emitter organisations, companies compensate their carbon dioxide emission in the Carbon Market buying Carbon Credits. Carbon Credits create the financial basis for carbon dioxide emission reducing projects at various places (preferred in least-developed countries) in the world, which can maintain the level of net carbon dioxide emissions.

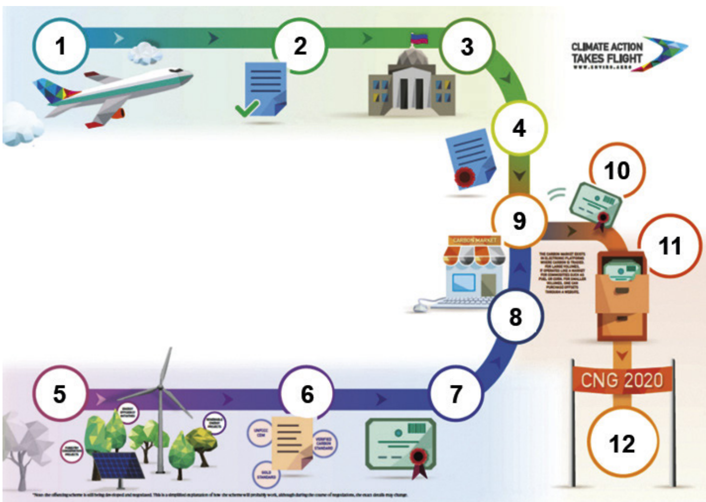

Figure 5.
Carbon dioxide offsetting process

Source: ATAG 2016

How is the offset calculated? Figure 5 helps us to understand the process.

1. Airlines and aircraft operators must monitor and record their carbon emissions (each tonne of fuel equals 3.06 tonnes of carbon dioxide emission).
2. Carbon emissions reports from airlines are approved by independent verification agencies.
3. Airlines will submit their audited and approved emission reports to the respective governmental bodies in their country.
4. Governmental bodies, with ICAO, shall inform the airline of the amount of carbon dioxide emissions they are supposed to offset.
5. Compensation is based on climate projects (energy efficiency solutions, renewable energy projects, afforestation, see Figure 6) in different parts of the world, often in developing countries.
6. Considering the above mentioned projects, the actual carbon dioxide emission reduction effect must be demonstrated on the basis of internationally recognised standards.
7. A tonne of carbon dioxide emissions "savings" is a carbon offset or with another word Carbon Credit.
8. These carbon offset-units (Carbon Credits) are available for sale and can be purchased through independent traders, brokers or banks.
9. The two processes meet when the airline purchases the appropriate amount of Carbon Credit on this "market".
10. When Carbon Credit is used in order to offset carbon emissions of an airline, it will be cancelled to avoid its reuse.
11. For a control, a global registration system monitors the compensation process through member country registration systems providing a global overview.
12. Carbon-neutral growth will be achieved if Carbon Credit purchased by airlines covers the increase in carbon dioxide emissions from international aviation on the basis of 2020 levels.

Figure 6.

Examples of climate projects supported by CORSIA

Source: firstclimate.com, 12.23.2017.

3. CORSIA schedule and participants

CORSIA consists of three phases. Pilot Phase 2021–2023. First Phase 2024–2026. Both phases are voluntary. So far 72 states have volunteered to implement the program, which is expected to account for about 80% of CO_2 growth in the period of 2021–2035, and these countries currently cover 87.7% of the international aviation industry, see Figure 7. Volunteering is open, so joining of more countries can still be expected.

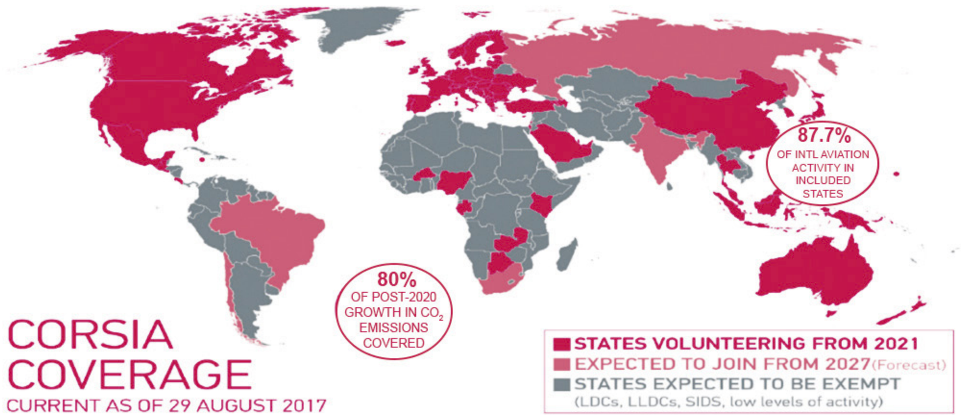

Figure 7.

The voluntary CORSIA countries, the countries which are to join in the mandatory period and which are expected to be exempted

Source: ICAO s. a.b

Second Phase 2027–2035. Participation is mandatory for all countries with a share in international aviation industry greater than 0.5% of total international aviation volume (light blue coloured column), or all countries in international aviation, ranking them by their individual share, until the cumulative share of RTKs reaches 90% (purple coloured column), see Table 3. The individual share of a given country and the calculation of cumulative share are based on Revenue Tonne Kilometres (RTK) performed in 2018. RTK is a standard measuring system for the characterisation of the cargo, in which the weight delivered (in the case of passengers normally calculated on 90 kg per passenger) is multiplied by the distance in kilometre.

The countries with green colour in Table 3 are already volunteering in the program and became so-called "CORSIA countries", although after 2027, most of them would be obliged to take part by their individual share of RTK. Due to the gaps in Table 3, Hungary is not listed among the countries. By my estimation, due to our individual share, it would not be obligatory to participate from 2027, but Hungary is also among the voluntary countries. In addition to the countries exempted by their individual or cumulative share, further countries will be exempted in the mandatory phase and these countries are the Least Developed

Countries (LDCs), Small Island Developing States (SIDs) and Landlocked Developing Countries (LLDCs), unless they volunteer to participate.

Table 3.

Example for the determination of participating and exempted countries in the mandatory phase

State	Individual share of total RTK	Cumulative share of total RTK
China	11.76%	11.76%
United States	11.70%	23.46%
UAE	8.8%	32.27%
…	…	…
Ethiopia	0.55%	88.73%
South Africa	0.54%	89.26%
Indonesia	0.52%	89.78%
Finland	0.52%	90.30%
Mexico	0.52%	90.82%
Israel	0.50%	91.32%
Austria	0.49%	91.81%
Panama	0.47%	92.28%
Viet Nam	0.44%	92.71%
Colombia	0.43%	93.14%
…	…	…
Iran	0.12%	97.84%
…	…	…

LDC/SIDS/LLDC
Volinteer
Individual RTK > 0.5%
Cumulative RTK < 90%

Source: ICAO s. a.b

ICAO also encourages the exempted countries to volunteer. The main reason is that CORSIA is "route based" which means the offset is obligatory for the routes between CORSIA countries and even if there are no aircraft operators registered in that country (and therefore there is no obligation to participate), participation increases the routes covered by CORSIA, further reducing uncovered carbon dioxide emission, see yellow coloured "country" and plus green ticks in Figure 8.

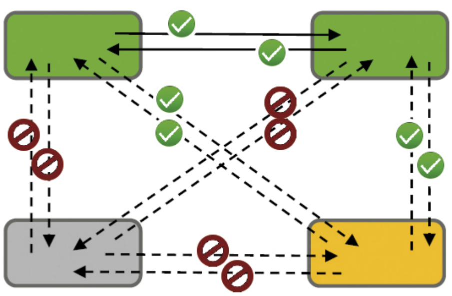

Figure 8.

Any new participant ("yellow country") increases the covered CO_2 emissions

Source: http://epa.uz.ua/02600/02694/00075/pdf/EPA02694_rtk_2017_03_243-252.pdf 01.04. 2018.

Probably the willingness to join the CORSIA can be quite strong given that the compensation in these countries can be significant. Resolution ICAO A39-3 calls on the attention of the participating countries to note that most of the offset in carbon dioxide reduction projects should be implemented in developing countries. At this stage (from 2027), CORSIA countries are expected to cover at least 90% of the international aviation industry.

Some countries may be exempted for more than one reason, but this is not particularly relevant. It should be noted that countries that have been exempted due to their socio-economic situation (LDC, SIDS, LLDC) are likely to be exempted by their low share of civil aviation industry, too.

4. The determination of carbon dioxide emission baseline and offset calculation

Countries and their aircraft operators will start monitoring and reporting their carbon dioxide emissions from 2019. The average of the 2019 and 2020 values gives the so-called Baseline, which must be kept as net carbon dioxide emission (carbon neutral growth), and the excess above it must be offset by the CORSIA participants.

Table 4.

Calculation of baseline and CO_2 compensation

			Baseline	**Year Y 100% sectoral 0% individual**	**Year X 80% sectoral 20% individual**	**Year Z 30% sectoral 70% individual**
Total industry	Total CO_2		10 000	10 350	10 712	11 087
	Growth above baseline	*in tCO_2*		350	712	1087
	Sector's "growth factor"			3.38%	6.65%	9.80%
Airline A	Total CO_2		100	107	114	122
	Individual "growth factor"			6.54%	12.28%	08.03%
	Sectoral component	*in tCO_2*		3.62	7.58	11.96
	Individual component	*in tCO_2*		n/a	14	22
	Offsetting requirement	*in tCO_2*		3.62	8.86	18.99
Airline B	Total CO_2		100	103	106	109
	Individual "growth factor"			2.91%	5.66%	8.26%
	Sectoral component	*in tCO_2*		3.48	7.05	10.69
	Individual component	*in tCO_2*		n/a	6	9
	Offsetting requirement	*in tCO_2*		3.48	6.84	9.51

Source: ICAO 2017

Table 4 helps to understand this process. Of course, these data serve only for the purposes of illustration. It is important to point out that each country is obliged to report (not just the CORSIA countries) their carbon dioxide emission, but the offset obligation is related only to the CO_2 surplus generated on the CORSIA routes (Route Based Approach, both the initial and final airport is in a CORSIA country). We presume, the baseline by Table 4 is 100,000 tonnes, the average of the 2019 and 2020 carbon dioxide emission of CORSIA countries and valid for 2021. Since the first two voluntary stages (2021–2026) countries and even after 2027 the exempted countries may decide to join or leave the CORSIA each year (they must take their declaration by 30 June of the particular year), so this Baseline must be re-defined annually. The method is easy. The carbon dioxide emission of each country is available from 2019–2020. Emission of new countries is added to the old ones to get the new Baseline and of course the actual yearly emission data will also be higher with the emission of newly joined countries.

The next step is the determination of sectoral and individual Growth Factor, but before we start it we have to take some simplifications in accordance with Table 4. We presume that the Baseline is unchanged in every year (there are no leaving and joining countries).

Year Y can be in the period between 2021–2029, and in this period the sector Growth Factor should be applied to the definition of Carbon Credits. The sectoral Growth Factor is: (103,500–100,000)/103,500 = 3.38%, individual Growth Factor of Airline A is: (107–100)/107 = 6.54%. In this period the individual Growth Factor does not matter so the carbon dioxide emission Airline A has to compensate is: 107*0.0338 = 3.616 t, after rounding 3.62 tonnes.

Year X can be between 2030–2032 with a 80–20% ratio of sectoral and individual Growth Factor. The carbon dioxide emission Airline B has to compensate is: 0.8*106*0.0665 + 0.2*106*0.0566 = 6,389 t, after rounding 6.84 tonnes.

The offset requirement for Year Z and any company can be calculated in a similar way but with a 30–70% ratio of sectoral and individual Growth Factor. The question is why the system punishes, particularly in the period of 2021–2029, the slower growing airlines, and fast-growing airlines are practically "free raiders", see Year Y in Table 4. Practically, there is no difference in the Offsetting Requirement between Airline A and B; however, their individual Growth Factor, consequently their extra CO_2 emission is significantly different.

5. Immediate tasks of the Aircraft Operators and National Aviation Authorities

Measuring, Report and Verification of carbon dioxide emission is a complex process, hereinafter referred to as MRV. In this context, the tasks of both national authorities and airline companies began in 2018.

January–September 2018: National authorities must ensure the necessary information for aircraft operators to develop MRV procedures

September 30, 2018: Aircraft Operators submit their MRV procedures for approval

30 November 2018: National Authorities approve these procedures

January 1, 2019: Measuring of the carbon dioxide emission begins

December 31, 2019: Measurement of the first year is completed

May 31, 2020: Aircraft Operators submit their 2019 CO_2 emissions report to the national authorities after verification

August 31, 2020: Countries will submit the total carbon dioxide report to ICAO

As outlined above, in summary, CORSIA is subject to civilian, fixed wing, international flights, where the take-off and landing is in CORSIA countries. In CORSIA countries some aircraft operators or aircraft are exempted:

- Airplanes with a maximum take-off mass not exceeding 5,700 kg
- Aircraft operators whose total CO_2 emissions in a given year are less than 10,000 tonnes
- All humanitarian, health and firefighting aviation.

6. CORSIA and the Paris Agreement and the EU ETS[3]

In the industry's view, the agreement reached in ICAO harmonises with the spirit of the Paris Agreement and the principle of equity and common but differentiated responsibilities and respective capabilities, however, such a voluntary, bottom-up approach would not be suitable for international air transport. For the air transport sector, one of the main benefits of a global MBM is to avoid a "patchwork" of national measures. This is why a single global market-based measure for international aviation is important.

Considering the EU ETS, the implementation of CORSIA from 1 January 2021 should obviate the need for existing and new economic measures to be applied to international aviation emissions on a regional or national basis. Therefore, as from 1 January 2021, all international flights to/from airports in Europe should be subject exclusively to CORSIA and removed from the scope of the EU ETS.

Domestic flights are beyond the scope of CORSIA, any market-based measure applicable to domestic flights should be aligned and made compatible with CORSIA to avoid regulatory fragmentation and to reduce the administrative burden for operators and Governments and minimise potential market distortions.

7. Conclusion

ICAO has sought to develop a single global carbon-dioxide compensation system to keep the net carbon dioxide emissions at 2020 level avoiding "Patchwork" solutions, which include carbon dioxide taxes or other remedies through national or regional systems. The main reason that these solutions would not be a uniform standard is that they would be more complicated and less cost effective. In case of taxes, these funds would not necessarily be used in the actual carbon dioxide reduction projects. A single measure not only simplifies the system but also reduces the risk of market distortion as it imposes uniform requirements on all airlines. CORSIA does not in itself lead to a sustainable future of aviation. With this global, market-based measure, the industry continues to pursue a four-pillar strategy on climate change, including technology, operational and infrastructure developments. ICAO officials

[3] ETS: Emissions Trading System.

are very optimistic that these measures not only keep the net CO_2 emission at 2020 level, but they hope in secondary effects, namely its driver effect on technological improvements and hopefully compels the Aircraft Operator for investing in new aircraft fleet. To be honest, I do not agree with this optimism especially till 2029, when the offset requirement is based on the Sectoral Growth factor. The offset requirement spreading among countries universally does not stimulate for new investments.

Taking part at a conference organised by the ICAO in London about Market Based Measures (MBM) with the participation of ICAO officials, airlines' representatives, NGOs, alternative fuel producers and Carbon Market representatives, our impressions were that the aviation industry is confident that technology, operations and infrastructure measures will provide the long-term solution for aviation's sustainable growth. Due to the time required for new technologies and infrastructure to deploy their full effect, an MBM will be needed as a "gap-filler" in the interim period. The invited NGOs also referred to the CORSIA as a positive initiation.

There were only few words about other financial effects of these measures, namely the ticket prices. Surely we, the travellers also pay the carbon dioxide offset. It will depend on the will and ability of the airlines to pass on this cost fully or partially to passengers. We can only hope that the airline business is incredibly competitive and they are not always in need to pass on costs to passengers, but this hope is weak.

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