Final Report

Practical review of the options regarding processes for monitoring, reporting and the verification (MRV) of CO2 emissions for CORSIA regarding the practicability, robustness of the monitoring methods and the development of a cost model to benchmark the MRV processes in climate protection using the example of CORSIA.

For:

BUNDESMINISTERIUM FÜR VERKEHR UND DIGITALE INFRASTRUKTUR

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1. PETITUM

A measure to limit CO_2 emissions from international aviation was agreed at the 39th Assembly of the International Civil Aviation Organization (ICAO) on 6th October 2016. Named CORSIA (the Carbon Offsetting and Reduction Scheme for International Aviation), the target is to offset CO_2 emissions through projected offsets to achieve the long-term goal of carbon-neutral growth in international aviation from 2020 onwards.

The focus of the project for BMVI (German Ministry for transport and digital infrastructure) was the analysis of the associated efforts and costs. In contrast to the existing MRV system of the EU Emissions Trading System (EU-ETS), CORSIA allows the aircraft operator to select one of five different monitoring methods.

The focus of the project therefore encompasses the extent to which the monitoring methods available in CORSIA provide comparable results and the corresponding different efforts that are associated with the individual procedures. The analysis therefore explicitly includes the existing methods of the EU ETS as a comparative point of reference. The main focus of this priority is to develop a detailed data base that will provide competent authorities with a balanced basis for decision-making in order to underpin the accuracy of emission measurement, cost-effectiveness of associated procedures and competitive implications, and the possible restrictions on the use of these methods.

Lufthansa provided extensive experience for this part of the project as the Lufthansa Group includes all types of air operations with different processes, data structures and IT equipment.

2. WORK PACKAGES

The BMVI outlined in the specifications of the project and the work packages (WP) that are to be made in the context of this project. These work packages are described briefly below.

2.1 Development of exemplary implementations

In this work package, the client was tasked to estimate the methods that are likely to be chosen or implemented by different sized aircraft operators.

Lufthansa Group comprises airlines of all sizes. The smallest operation is Air Dolomiti who operates 12 Embraer 190 aircraft and the largest operator is Lufthansa Passage with a fleet of more than 300 aircraft divided into 11 sub-fleets. Therein, the corporate airlines are increasingly using the same IT infrastructure and processes.

Lufthansa has attempted to include other airlines outside of the Lufthansa Group to fulfill this work package. The experience gained by Lufthansa from previous years was therefore used as part of this project. EU ETS was one of the key drivers for the harmonization and centralization of processes and IT in the Lufthansa Group. In 2010, the Group's airline operations were much less integrated compared to the present situation with the processes, IT equipment and the degree of automation of the individual Group airlines differing significantly.

2.2 Estimation of the effort for each method of monitoring

This work package can be seen directly in context with chapter 2.1 and covers forecasting implementation, operating and reporting costs for aeroplane operators. The assumption is that these three cost blocks depend both on the size of an aircraft operator, the processes applied and the level of automation.

Experience gained by Lufthansa from the very beginning of the EU ETS of Group airlines was useful for orientating the project towards the proposed approach in the specification of services including.

a) Identification of processes for each method

b) Estimation of Expenses (or Derivation from Experience)

c) A summary table

2.3 Comparative presentation of the monitoring concepts

This work package requires a graphical representation of the results of work packages 1 and 2. The presentation is undertaken in Chapter 5.

2.4 Presentation of results

Lufthansa will prepare a presentation based on WP 4 supported by a working group meeting with the BMVI. The presentation will take place on three different dates in Bonn, Berlin and Brussels and Lufthansa will be available for questions during the presentation.

3. Background

3.1 EU ETS versus CORSIA

Although emissions are based on calculated consumption of individual flights for both the EU ETS and in CORSIA, these two systems differ substantially. CORSIA is therefore not a copy of the EU ETS and therefore requires a separate implementation. The similarities are shown in the following table with the differences marked in the grey areas:

EU ETS	CORSIA
✈ Emissions Monitoring Plan	✈ Emissions Monitoring Plan
✈ Annual reporting and verification	✈ Annual reporting and verification
✈ Consumptions to derive from fuel data captured during physical refuling	✈ Consumptions to derive from fuel data captured during physical refuling
✈ Data gaps to close by data derived from a central database or by individual estimation	✈ Data gaps to close by data derived from a central database or by individual estimation
✈ Excluded from reporting obligation are for example following flights: VFR, HOSP, TEST, TRAINING, HUM, MILITARY, FIRE-FIGHTNG	✈ Excluded from reporting obligation are for example following flights: HOSP, MILITARY, FIRE-FIGHTNG not excluded are TEST, TRAINING
✈ Single reports (one report per ICAO designator)	✈ Pooling of several operators into one report, provided 100% affiliate companies reporting to one authority
✈ two monitoring methods	✈ five monitoring methods
✈ Same monitoring method for all flights (incl. Wet Lease)	✈ One particular monitoring method for wet leased flights, no matter which method is used for own flights
✈ Emissions factor = 3,15	✈ Emissions factor = 3,16
✈ Hierarchy for capturing density a) Onboard Measurements b) Supplier's Info c) standard value of 0,8 KG / Liter (subject to authority's approval)	✈ Use of the density which is used and captured for flight operations „… the density (which may be actual or a standard value of 0.8 kg per litre) that is used for operational and safety reasons …"

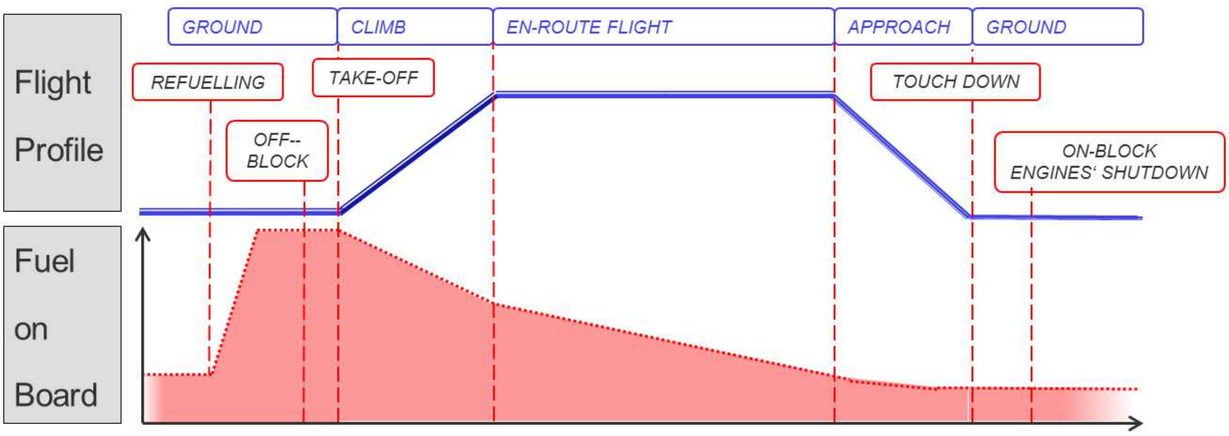
3.2 Monitoring-Methods

This chapter presents the individual monitoring methods available to aircraft operators under CORSIA. There is no hierarchy within these methods. Only for wet-lease flights a method is prescribed, the block-on / block-off method.

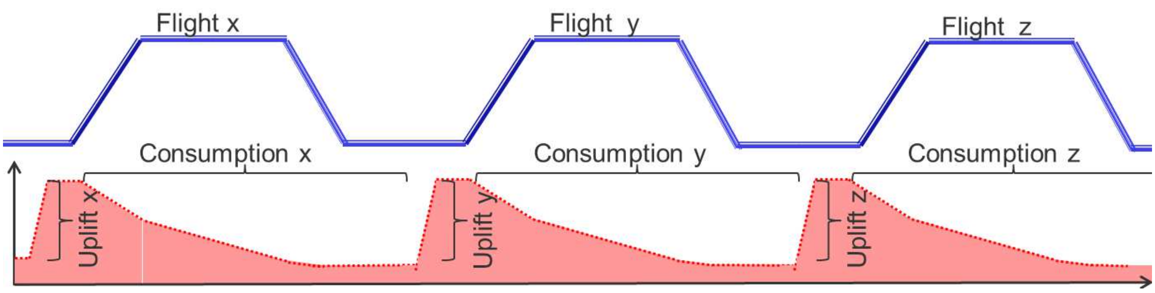
The methods differ by their underlying data, in the (temporal) measuring points of these data and thus inevitably in the calculated consumption, from which in turn the emissions are derived.

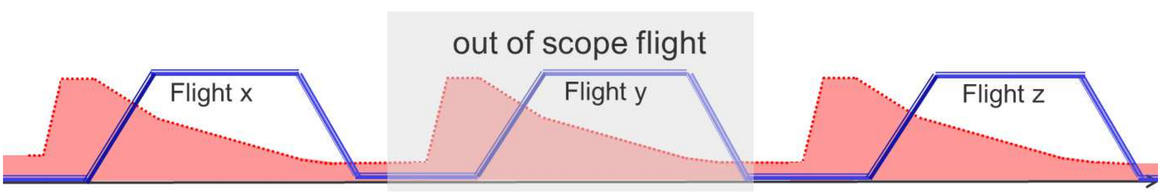
3.2.1 Fuel on board and measuring points in the Operations

The following figure symbolizes in the upper part of the sequence of ground and flight phases and, in the lower part, the amount of fuel on board. The red, dashed lines relate both timings. It can be seen that at the end of the refueling (i.e. after uplift) no measurement is provided, just as at the time of the off-block. Therefore, the Method A cannot be applied correctly. To apply this method correctly the airline industry had to implement this measurement and corresponding data flow and processing.



Fuel consumption is determined by the chaining of individual flights. The source for the different results of the methods is described briefly below because not every one of the flights of a rotation is reportable (bottom figure).

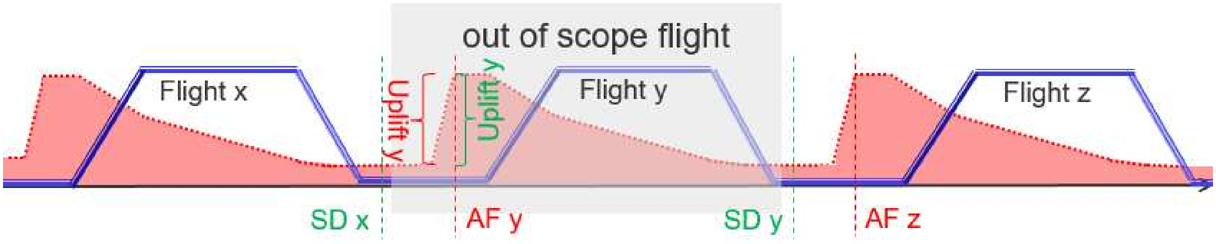




3.2.2 Methods A and B (EU ETS)

The EU ETS methods A and B are still part of CORSIA and have been anchored in Lufthansa's IT since 2010. These are only shown schematically.

The Lufthansa Group airlines use only method B such that this is used as a benchmark for the comparison of the methods.



Method A:

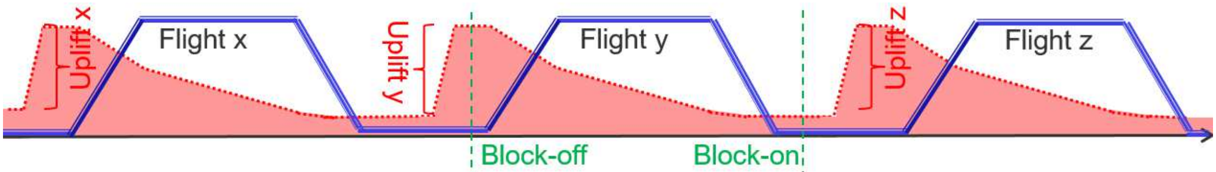
Consumption (Flight y) = AF (Flight y) – AF (Flight z) + UP (Flight y)

Method B:

Consumption (Flight y) = SD (Flight x) + UP (Flight y) – SD (Flight y)

3.2.3 Block-On / Block-Off-Method

This method only uses quantities of fuel that are measured on board. In each case, the measurements should take place from off-block to on-block. Density plays no role in this method due to a lack of reference to the uplift. This method is mandatory for wet-lease flights.



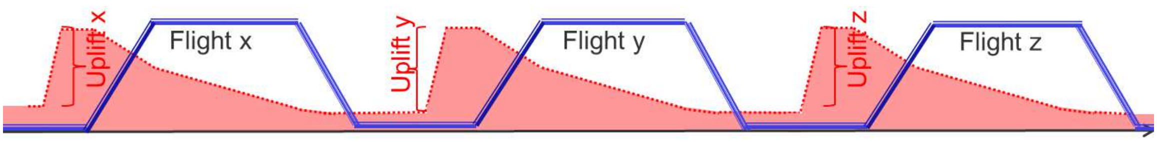
Block-off Block-on Method:

Consumption (Flight y) = Block-off (Flight y) – Block-on (Flight y)

no Density required obligatory for wet leases

3.2.4 Uplift-Method

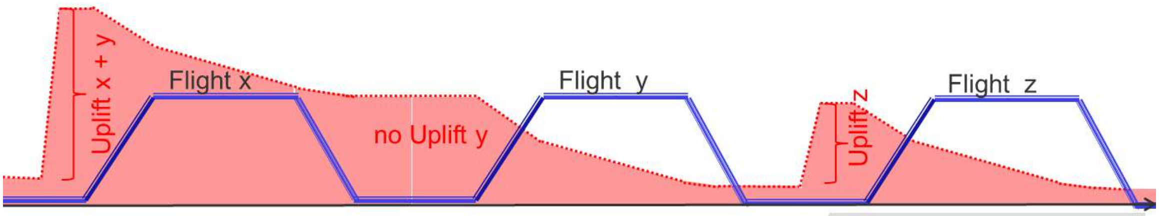
The uplift method is based on the assumption that uplifted fuel quantities are also consumed. The previously uplifted amount of fuel is assigned to each flight.



Uplift Method:

Consumption (Flight y) = Uplift (Flight y)

In the case that there is no uplift for a flight (the so-called tankering), then the uplift quantity of the last refueled flight is distributed according to the block times of the refueled and the subsequent flight / flights without uplift.



Uplift Method:

Consumption (Flight y) = Uplift (Flight y)

special treatment of Tankering Flights

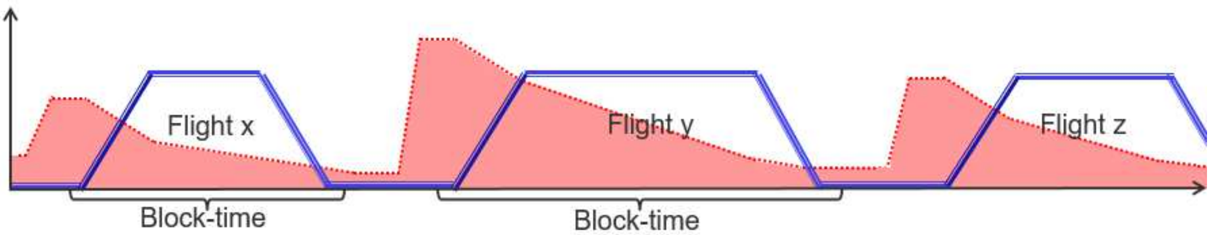
Consumption (Flight x) = Uplift (Flight x+y) * $\frac{BH_x}{BH_x+BH_y}$

Consumption (Flight y) = Uplift (Flight x+y) * $\frac{BH_y}{BH_x+BH_y}$

Uplift assigned to flights according to block-hours

3.2.5 Fuel-Allocation with Block-Hour

This method assigns to each reported flight, a virtual consumption which is calculated by multiplying the average consumption of international flights for this aircraft type by the respective block time of each flight. The averages are to be determined annually. Therefore the total amount of uplifted fuel for a specific aircraft type for international flights is divided by the corresponding block time.



$$\text{Average Fuel-Burn} = \frac{\sum \text{Uplift}}{\sum \text{Block-hrs}}$$

Consumption (Flight x) = Average Fuel-Burn * Block-hrs (Flight x)

3.3 Analysis

3.3.1 Objective

A relatively large amount of data was used for the analysis. The operational data used was for the entire year 2017 as operated by the German airline operators of the Lufthansa Group comprising about 600,000 flights in total.

The analysis was undertaken according to the following objectives:

a) Demonstrate the accuracy and robustness of each method.
   The largest possible population of flights was selected. Benchmark Method B was applied from EU ETS as this is considered to be the method with the highest accuracy.

b) Forecast of the implementation effort.
   Existing data flows should be taken into account in order to estimate the implementation costs for the individual methods.

3.3.2 Exemplary flight operations

As part of the analysis, fictitious flight operations were created that differ in size and degree of automation. This was based on the experiences of the Lufthansa Group over the past years.

a) Small scale flight operators
   Aircraft operators of up to 20 aircraft were classified as small airlines. It is assumed that there is, at most, a small degree of automation. Both the rotation data and the fuel data are kept in simple databases without networking. The recording of fuel data is based on Journey Logs and the testing of fuel bills is conducted manually and based on paper invoices. Emission monitoring takes place in Excel.

   A practical example is Air Dolomiti, an operator within the Lufthansa Group with 12 medium-haul aircraft. Prior to the integration of Air Dolomiti into Lufthansa Group IT, the processes and equipment described above existed.

b) Medium scale flight operators
   Aircraft operators with fleets of more than 20 but less than 100 aircraft were classified as medium-sized operators. It is assumed that the data processing takes place by means of basic IT equipment with some media breaks. This means that the rotation management takes place with a standard rotation planning system. The testing of fuel calculations is undertaken manually on the basis of paper invoices and that fuel data is recorded on paper Journey Logs. The emission monitoring takes place by means of a simple database solution (often an in-house development).

   A practical example was provided by Austrian Airlines, which operates within the Lufthansa Group with around 80 short, medium and long-haul aircraft. Prior to the integration of Austrian Airlines into Lufthansa Group IT, the processes and equipment described above existed.

c) Large scale flight operators
   Aircraft operators with (clearly) more than 100 aircraft are considered (very) large airlines whereby it is assumed that modern, integrated and powerful IT equipment is used. The rotation management, fuel data collection and invoice

verification are based on automated data flows. Emissions monitoring is based on this integrated IT whereby the central challenge is no longer the collection of data but the reliable operation of interfaces and IT systems.

A practical example was provided by Lufthansa Classic (Passage), a flight service within the Lufthansa Group with approximately 280 medium and long-haul aircraft. The Lufthansa Group IT is largely developed, operated and promoted by the Passage and made available to the other airlines of the Group.

3.3.3 Data foundation and registration

Emission monitoring is based on aircraft rotation data and on two groups of data: supplier fuel invoices and aircraft fuel data.

a) Fuel invoices are provided by fuel suppliers and include the single-flight uplift quantities for a given period. For example; this means that for every refueled flight (the vast majority of flights) there is an uplift invoice.
Each flight operator therefore has an uplift invoice for each individual flight. Uplift invoices are submitted electronically and transmitted providing an aircraft operator is sufficiently equipped. Otherwise, the fuel supplier / company provides paper invoices which, in turn, are collected and paid by the airlines.

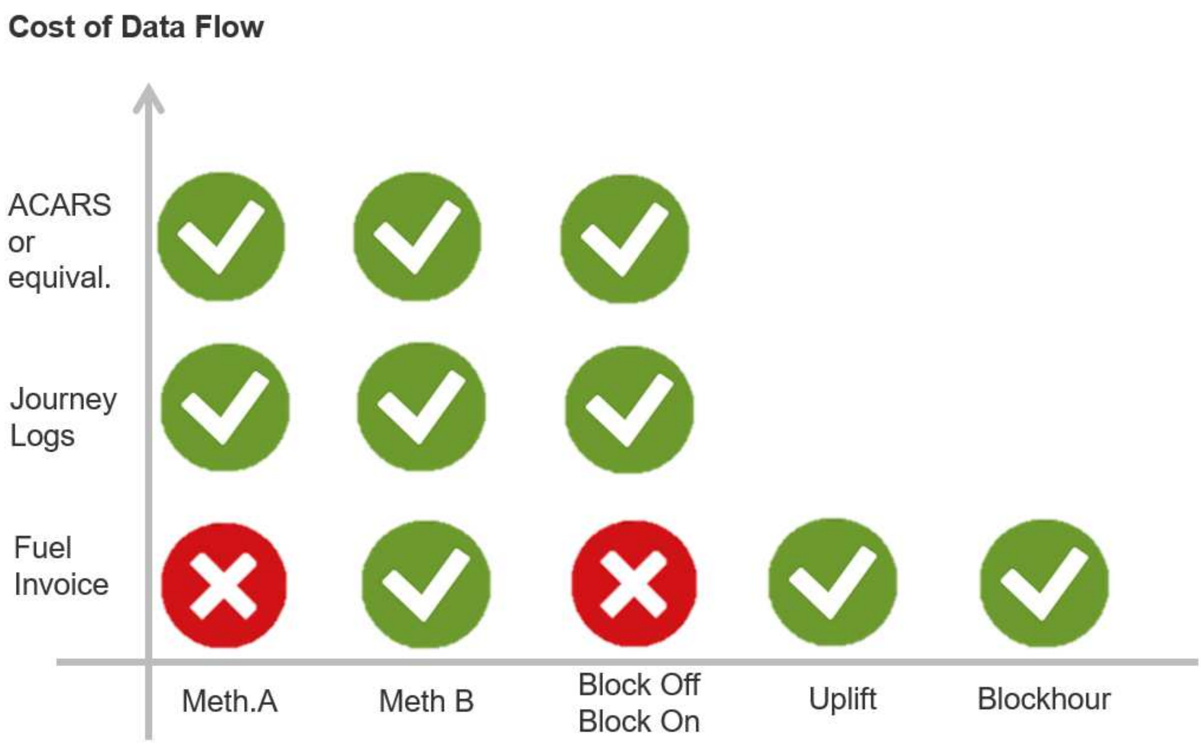
b) For all fuel data except for the uplift quantities, airplanes are the only source of data. Neither block fuel quantities nor remaining-before-refueling or remaining-after-engine'-shutdown can be obtained from any other source. This data is collected by airlines in different ways. Either:
   - the collection takes place on paper, the so-called Journey Logs - which are then, in turn, sent to the traffic center where the data is entered into the existing IT, or
   - the data collection and transmission are automated together with the integration process into the flight operations IT.

As with any paper based process, the variant with the Journey Logs initially costs less. The quality of such processes is highly dependent on the reliability of the transmission and the later quality assurance. Nevertheless, such a process can make sense for small and perhaps medium-sized airlines because the alternative „automated aircraft capture and transmission" only makes economic sense for mid-sized and large airlines.

3.4 Method Selection

Airlines are free to choose a specific method of calculation. Restrictions arise due to their IT equipment, already implemented data flows and data collection processes. Once CORSIA comes into force on the premise that every flight operation can (largely) rely on its existing data flows, then the aforementioned restrictions become hard restrictions.

In the diagram below, only on the ordinate is a real value to be displayed, namely the cost of choosing a method. On the abscissa, the individual methods are listed side by side free of each evaluation.



3.4.1 Consideration of the costs (Ordinate)

The cost side places the data creation and integration into the foreground.

Airlines should select a monitoring method based on uplift invoices because, as shown in chapter 3.3.3, each airline receives uplift invoices from its suppliers, the fuel companies. This data basis is the only external data source made available to every flight operation. Should it function as the basis of the CORSIA monitoring process then the aircraft operators are only responsible for data integration.

If a flight operator chooses a monitoring method based on operational data, then the data taken from individual aircraft must always be recorded and integrated. There are several ways of capture that can be roughly divided into two groups. Namely; manual capture and transmission using paper journey logs or automated capture and transmission.

The variant using paper Journey Logs appears to be the cheaper option initially because the implementation effort for the recording and transmission of data to and from the aircraft is eliminated. This variant is therefore often used by small operators or new airline market entrants. This variant must nevertheless account for the fact that downstream processes are necessary for the data acquisition and that a certain amount of data losses in the context of the transfer are to be expected.

An automated variant (e.g. via ACARS) is therefore normally used by large airlines. This variant has the highest cost since each individual aircraft requires the necessary technical conditions that must be created.

3.4.2 Consideration of the method axis (Abscissa)

The method page focuses on data usage or the need for specific data.

The methods A and Block-Off-Block-On are based solely on data collected during the flight operations. Uplift calculations cannot be used for such methods. The use of (low-cost) uplift calculations is therefore out of the question for these methods such that they have been given a red cross in the graph. Both of these methods are therefore considered to be relatively expensive implementation options.

In contrast, the uplift method and the block-hour method are based solely on the uplift data. They can but do not have to be collected from supplier data. Even if the data is obtained via uplift invoices, it can also be collected from operational flight operations. The use of or examination against supplier data is not compulsory. These two methods can therefore be considered as the easiest methods to implement.

Method B is based on data collected during operational flight operations as well as the billing process. Method B therefore represents the most expensive option of the five methods for (new) flight operations.

Even for airlines that have already reported under Method B under EU ETS, the question arises as to whether a different method for CORSIA reporting should be selected. This is because not only the implementation but also the preservation and continued operation of this method require the highest level of resources.

3.4.3 Consideration of methods' inherent risks

The methods differ not only as measured by their implementation costs. The decision for a particular method that is accompanied by a level of risk specific to data security, data quality and the transparency of reporting.

In turn, the quality of report content is controlled by regulators whereby material errors can be sanctioned. A flight operation should therefore, when selecting a method, not only assess the implementation and operating costs but also the sanction risks.

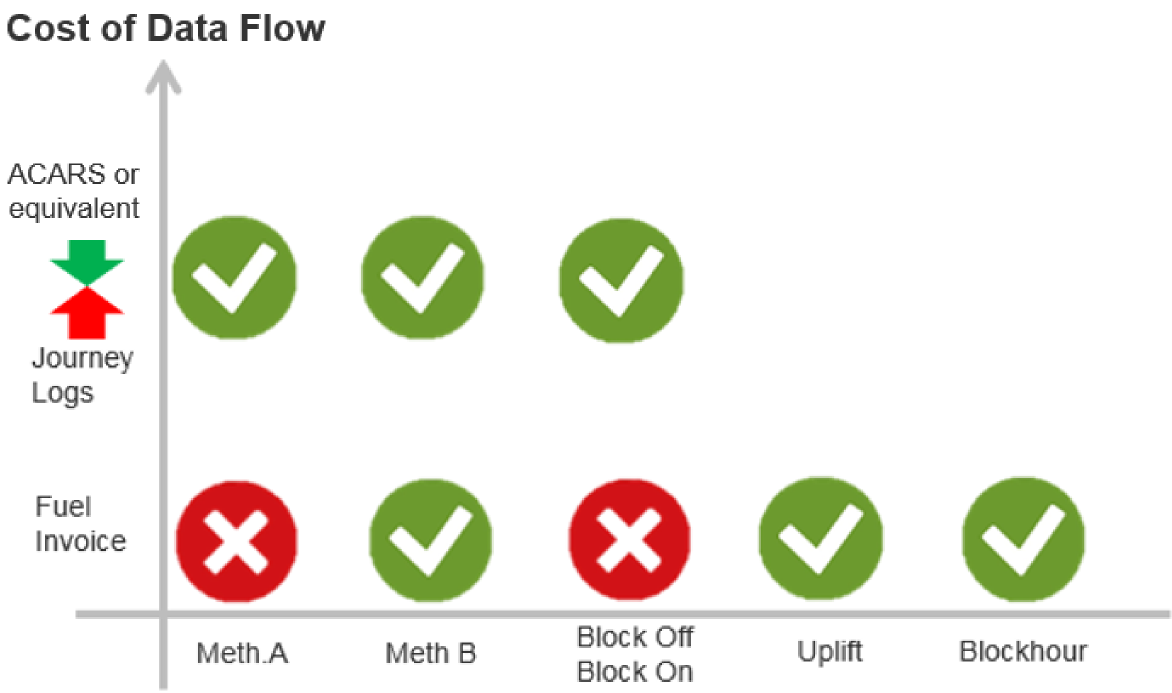
Paper Journey Logs are easy to capture on board aircraft. The transfer of the flight operations data (mostly via Company-Mail) to the office is uncertain and takes much time however. Their subsequent inclusion in an IT tool is another source of uncertainty because handwritten data can be illegible and misinterpreted while traceability is a problem because this primary data must be securely stored.

Electronic recording on board the aircraft (e. g. via ACARS) is often the safer option because ACARS can communicate with the FMS (Flight Management System) of an aircraft such that many values can already be recorded automatically in ACARS and only need to be controlled immediately prior to transmission. Nevertheless, the adoption of ACARS carries risks because not all airfields have ACARS radio coverage especially at mountain airfields (e. g. in the Alps) or in light air traffic regions where an ACARS radio coverage is rare or even missing.

Aircraft equipped with ACARS can be used legally for a certain period of time without a functioning ACARS. According to CAMO (Continuing Airworthiness Management) it is allowed to fly for several weeks without working ACARS equipment. In such cases, there are data gaps.

Uplift values are always present because each flight operator receives invoices from petroleum companies that include the uplift amounts for each flight and ground event. A monitoring method based on uplift values is thus the one with the lowest data risks.

If the data completeness and sanction risks are included in the cost matrix, the picture is slightly different: costs based on Journey Logs increase, those with ACARS (or equivalent) decrease.



4. EMPIRICAL STUDY

4.1 Data collection and cleansing

For the study, the data for the entire year 2017 of the German Lufthansa Group airlines, which were collected empirically for EU ETS, were used. This comprises data sets for 479,030 flights and with 16 aircraft types.

In addition to the fuel data of the suppliers and aircraft, blockfuel data from the mass-and-balance calculations were used even though the respective block fuel quantities do not meet the requirements of CORSIA with regard to measurement. However, they are to be regarded as equivalent in terms of quality and content because, during the loading of an aircraft and its flight planning, the respective value is given as an absolute value in the observation. If there are deviations then a flight cannot (legally) start. Against this background, the mass-and-balance blockfuel quantities were used as substitute for After-Fueling value for the Method A in this study.

Proceeding data collection, flights were excluded from consideration, namely:

a) Flights operated on a wet-lease basis - these flights are calculated under CORSIA using only the block-off-block-on method and possibly provided misleading results in this study.
b) Flights for which there was no blockfuel quantity - this data has no relevance under EU ETS so that in 2017 there was no security for the data acquisition
c) Flights not calculable under all 5 CORSIA methods - To ensure the comparison of the results, first the remaining flights were calculated using all five methods. Flights that were unpredictable under one of the methods were excluded.

333,559 flights with 16 aircraft types therefore remained in the analysis. Most flights were excluded in the context of the block fuel quantity (method A and block off block on method).

Step 1: Basic Population	**Step 2: Data Cleansing**	**Step 3: Comparisation**
✈ 2017 empiric data of an European airline group with all kinds of operations ✈ under EU ETS experiences with Method B, Block-Off / Block-On, and Blockhour ✈ no previous experience with Method A and Uplift-method ✈ sample flights could be pooled into one report under the CORSIA ✈ 479.030 flights 16 aircraft types	✈ deletion of flights with a lack of underlying data for at least one of the five methods) ✈ reasons: - Method A 80.818 flights - Method B 14.943 flights - Block-Off / Block-On 48.399 flights - Uplift-Method 1.311 flights ✈ 333.559 flights 16 aircraft types	✈ Benchmark: Method B

4.2 Benchmark and significant deviation

The analysis itself was a comparison against Method B because this method is also considered by the European Commission to be the method with the highest accuracy. In addition, the analysis also made comparisons to the other methods.

4.3 Results for three exemplary airlines

For the analysis, flight operations were selected in accordance to section 3.3.2. Inclusive small, medium and large flight operators. The fleets selected correspond to common and proven aircraft models of all sizes which are used in the long- as well as in the short- and medium-haul networks.

The consumption was calculated according to each individual method as shown in the first line. In the line below is the deviation to Method B is listed.

4.3.1 Small operator

For the illustration of a small flight operations, 10 (ten) Airbus A319 and therefore only one type of aircraft were selected from the adjusted population. With these 10 aircraft, a total of 11,234 short and medium-haul flights were undertaken during 2017.

	No. Flights	Consum	Method A	Method B	Block-Off / Block-On	Uplift (Method D)	Blockhour (Method E)
A319	11.234	m/tons	36.644	36.614	36.539	36.517	36.517
10 aircraft		vs. Meth B	0,1%		-0,2%	-0,3%	-0,3%

In absolute terms, the consumption of the individual methods is very close to each other with, even the largest deviation of -0.3%.

4.3.2 Medium sized operator

Two aircraft types and a total of 49 aircraft were selected for the mapping of medium-sized operations. Both aircraft types are among the most advanced designs currently available including the Airbus A320 CEO and Airbus A350-900. These aircraft fly long, medium and short haul routes.

	No. Flights	Consum	Method A	Method B	Block-Off / Block-On	Uplift (Method D)	Blockhour (Method E)
A320 CEO 43 aircraft	43.662	m/tons	187.073	186.945	186.626	187.358	187.358
		vs. Meth B	0,1%		-0,2%	0,2%	0,2%
A359 6 aircraft	1.392	m/tons	65.103	65.110	64.871	64.927	64.927
		vs. Meth B	0,0%		-0,4%	-0,3%	-0,3%
A320 CEO + A359	45.054	m/tons	252.176	252.055	251.497	252.285	252.285
		vs. Meth B	0,0%		-0,2%	0,1%	0,1%

In absolute terms, the consumption for the individual methods is very close to each other for both aircraft types with even the largest deviation of -0.4%.

It should be noted that the two aircraft patterns partially deviate in different directions from method B, such the overall deviation is equaled out by part of the deviation. The deviation in the overall view (red marking) is lower than that of individual aircraft types.

4.3.2 Large operator

As a model of a large flight operator, five aircraft types and a total of 174 aircraft were selected. The aircraft types belong to established and common patterns which can be found at many airports in the world. Two large short and medium twin-engine fleets were selected for the analysis inclusive Airbus A320 and Airbus A321. In addition, there are three four-engine long-haul fleets comprising Airbus A340-300, Airbus A380-800 and Boeing B747-400 aircraft.

	No. Flights	Consum	Method A	Method B	Block-Off / Block-On	Uplift (Method D)	Blockhour (Method E)
A320 66 aircraft	64.302	m/tons	269.500	269.436	270.246	269.177	269.177
		vs. Meth B	0,0%		0,3%	-0,1%	-0,1%
A321 63 aircraft	51.926	m/tons	321.212	321.144	321.360	321.292	321.292
		vs. Meth B	0,0%		0,1%	0,0%	0,0%
A343 18 aircraft	5.527	m/tons	360.349	360.370	358.777	357.717	357.717
		vs. Meth B	0,0%		-0,4%	-0,7%	-0,7%
A388 14 aircraft	5.099	m/tons	660.128	660.215	659.668	655.766	655.766
		vs. Meth B	0,0%		-0,1%	-0,7%	-0,7%
B744 13 aircraft	5.284	m/tons	469.137	469.069	468.276	467.391	467.391
		vs. Meth B	0,0%		-0,2%	-0,4%	-0,4%
total	132.138	m/tons	2.080.326	2.080.234	2.078.326	2.071.343	2.071.343
		vs. Meth B	0,0%		-0,1%	-0,4%	-0,4%

In absolute terms, the consumption of the individual methods is very close to each other for all five aircraft types with the largest deviation at -0.7%.

It should also be noted that the deviations in the individual aircraft patterns deviate in different directions from method B such that, in total, the deviation partially equals itself out. The deviation in the overall view (red marking) is lower than that of individual aircraft types.

4.4 Interpretation of the result

In chapter 4.3, it was shown that the results of the individual methods are very close matches to each other. It is therefore assumed that a flight operation will be oriented towards the implementation effort for the selection of the most appropriate method to be used.

While flight operations can consider other decision-making criteria in addition to the expenses shown in chapter 3.4 such as an efficiency program of its fleets, such aspects are disregarded by this analysis.

To ensure comparability of efforts across borders, this analysis uses full-time equivalents (FTE) as a benchmark.

4.4.1 Operational costs depending on the size of the flight operations

The upper part of the table below shows expenses for the implementation and operation of a dedicated IT solution for monitoring. These expenses increase with the size of the flight operations, which also corresponds to our assumptions shown in chapter 3.3.2. A large flight operation has a higher cost than a medium-sized flight due to the larger number of aircraft and aircraft models. This is also the case when the degree of automation does not differ between the two airlines.

Small Operator Low / No Automation	**Mid-size Operator Partly Automated**	**Large Operator Highly Automated**
IT = Excel or equivalent ✈ no dedicated IT-staff	IT = simple data-base ✈ data collection 0,3 FTE ✈ data integration 0,7 FTE	IT = sophisticated tool(s) ✈ data collection 1,0 FTE ✈ data integration 1,5 FTE
Monitoring & Reporting: ✈ data collection 0,4 FTE ✈ data integration 0,2 FTE ✈ data cleansing 0,35 FTE ✈ Authority Contact, Monitoring Plan, Reporting 0,05 FTE	Monitoring & Reporting: ✈ data collection 1,0 FTE ✈ data integration 0,3 FTE ✈ data cleansing 1,6 FTE ✈ Authority Contact, Monitoring Plan, Reporting 0,1 FTE	Monitoring & Reporting: ✈ data collection 0,2 FTE ✈ data integration 0,2 FTE ✈ data cleansing 1,0 FTE ✈ Authority Contact, Monitoring Plan, Reporting 0,1 FTE

The lower part of the table shows the expenses for monitoring and reporting. It is assumed that data collection and cleansing costs are the highest level for mid-sized flight operations because not all data collection and / or transmission processes are automated albeit there is more data in absolute terms compared to small operators.

The expenses listed herein were determined in 2010 as part of the EU ETS for Lufthansa Group airlines. These correspond to the operators and their size described in chapter 3.3.2.

Overall, it should be noted that in the case of a large flight operator, that the expenses of the operational part (monitoring) compared to the administrative part (IT) shift. The highest administrative effort in monitoring was seen in absolute terms in a medium-sized flight operator.

4.4.2 Implementation effort for electronic data flows

ACARS has been adopted by aviation since the 1970s and is based on short communication messages exchanged via radio or satellite. The flight operation-specific design of this communication platform varies greatly from a simple free-text message to special standard messages stored in a database. The defined standard messages comprise special surface dialogs (screens). Both the messages and the corresponding screens must be configured and stored in a database in each aircraft.
The physical data transmission between the aircraft and the ground modules of the operations is conducted via satellites and antenna systems owned by certain operators whereby a cost is applicable to every message. Data can only be exchanged if an aircraft actually has a connection.

The figure shows an example of a screen for the transmission of fuel data after refueling. This screen is suitable for:

a) electronic delivery note data from tank service records (left side of the screen, blue entries)
b) checking the data for plausibility (red mark)
c) the transmission of data to the ground services / flight operations.

Such screens and the corresponding standard telegrams for the transmission of data are flight operation-specific solutions and require both programming effort and a rollout to each individual aircraft. In addition, such functions are subject to approval and are monitored by the supervisory authorities under the CAMO (Continuing Airworthiness Management).

The transmission of messages via ACARS is very costly. Aircraft operators therefore aim to exchange messages during the ground time of an aircraft via more cost-effective means. The functionality for sending these messages is implemented in so-called EFBs (Electronic Flight Bags) or EFFs (Electronic Flight Folder) that are based on notebooks or tablets that can be located in the aircraft or assigned to individual pilots. The recording of the relevant data takes place in such devices whereby the transmission to the ground departments is undertaken by either by a regular synchronization process (e.g. at pilot briefings) or by communication via mobile telephone networks. In the case of the latter, the operators must ensure that the exchange or transfer if all relevant data can be organized in all of their destinations.

Similar to ACARS; EFB or EFF solutions must be programmed, tested, rolled out, and approved by the authorities. As with ACARS-based solutions, the appropriate technical personnel, hardware, development processes and infrastructure must be procured and operated. While this results in high costs, it is seen nevertheless as beneficial (robustness).

Uplift invoices may be generated and sent electronically. IATA provided a corresponding standard which is well accepted and widely used within the airline industry. Processing such electronic invoices and also subsequent automated invoice checking is part of long established accounting processes. Since uplift invoices are always available and always provided by external sources, airlines just need to establish the processing steps. This holds not only for emissions monitoring but also for another essential business process, i. e. accounting.

4.4.3 Risks depending on the monitoring method and dataflow

As explained in chapter 3.4.3, the individual data sources and transmission methodologies pose different risks with regard to their safety and quality.

The monitoring methods, which are based exclusively on uplift values, carry the lowest risks. This is because there is only one data source that provides reliable data; uplift invoices from the fuel suppliers. In addition, the data is used by each aircraft operator for the payment of fuel and are the basis of another well-structured and supervised business process, i. e. accounting. The other process also benefits from the optimization and further development of a process. The uplift and the block-hour methods therefore pose the least risks in terms of data quality and completeness.

The monitoring methods, which are based on several data measurement points or data sources, carry relatively high risks whereby errors are possible with every entry. These risks increase further if, in addition, the data transmission incurs more risks via, for example, a lack of infrastructure or the misinterpretation of data that can reduce data quality.

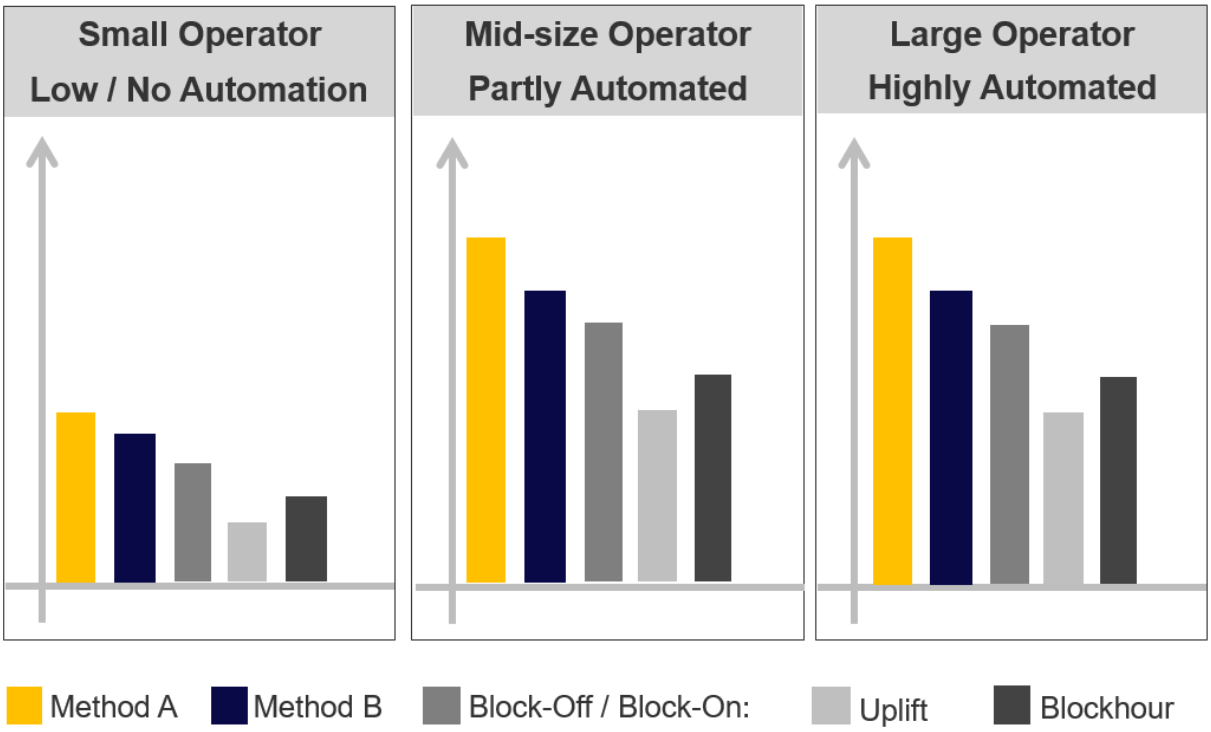
The block-off-block-on method uses only two measurement points whereby the risks are almost exclusively in the transmission of data. Both the Journey-Log transmission and the electronic data transmission entail risks that every flight operator should evaluate. The block-off-block-on method is, in our opinion, a middle ranked option.

Method B is well established in Europe where many aircraft operators have optimized their data management. However, this requires a relatively large amounts of work because data must be controlled and purged before reporting.

The highest risk comes from Method A, because aircraft operators will need to implement one measuring point, the corresponding data transmission and the downstream data processing. The risks described for Method B are additionally applicable to this monitoring method.

4.4.4 Expenses depending on the monitoring method and dataflow

The relative expenses for the implementation of a monitoring system are shown in the following diagram. As described in chapter 3.4, the individual methods differ in terms of the requirement for data itself and the corresponding possibilities for acquiring data.



The effort for the implementation of method A is the highest because the required measuring point for the determination of the block fuel is not established by the airline industry (refer to chapter 3.2.1, 4.1 and 4.4.3). On-board fuel measurement at the time of off-block is not currently available and needs to be initially implemented throughout the industry to be a valid option.

The effort required to implement method B is very high because data from several sources must be used (see chapter 3.4.2) with both operational data and commercial data necessary for reporting.

The Uplift method is to be classified as the most favorable method to implement, since the data required for this can be collected during flight operations and, moreover, can also be provided externally (refer to chapter 3.3.3, 3.4.1, 3.4 .2).

The Block-hour method is based on the same data basis as the Uplift method. The respective operational data still needs to be summed up and compared to the averaging of the sum of all block times that are considered.

The block-off-block-on method is in the midfield. The collection and integration of data is more difficult than with the uplink or block-hour method, but easier than that of methods B and A.

Comparing medium and large airlines to each other, the monitoring costs are about the same. Large airlines can achieve cost digressions with their IT and the scaling of the processes.

5. Conclusion

As shown in chapter 3.2, the five methods presented require different levels of implementation effort while their results differ. The following table summarizes the strengths and weaknesses of each method.

Method B	high accuracy established points of measurement established data flows	large data requirement (of 2 flights each) high implementation effort very sensitve towards data gaps (low robustness)
Uplift & Blockhour Method	Data source open to all operators Easy to implement Highly robust Highly reliable	High rotation-sensitivity (in-scope vs. out-of-scope), but not significant
Block-Off-Block-On-Method	Limited data requirement (only data of the flights under consideration) Medium robustness (sensitiv towards transmission failures)	Journey Logs: several process steps ACARS / EFB: higher implemen-tation effort Lower completeness (APU-consumption) than Method B, but not significant
Method A	High accuracy	Measurement of After-Fueling not established in the industry yet High implementation effort large data requirement (of 2 flights each) very sensitive towards data gaps (low robustness)

In view of the relatively close calculation results of the individual methods, it can be assumed that the airlines should be guided by the implementation effort and the already existing processes and data flows when choosing the method to be used. Regulators (Competent Authorities), however, should consider that the impact of data quality plus the robustness and accuracy of a method may be greater than the non-significant differences in the calculation results of each method.

It is therefore recommended that, in order to increase the acceptance of the system itself, that all five methods should be permitted.

6. ABREVIATIONS & SYNONYMS

ACARS - Aircraft Communications Addressing and Reporting System
AF - After Fueling (Fuel on board quantity right after refueling)
AOC - Air Operational Certificate
Approach - Descend- and landing-flight phase
BH - time from leaving a parking positing until the arrival of the next parking position
Block-Fuel - Fuel on board quantity right after refueling at time of off-block
Block-Hour - ref to BH
Block-Off - ref to off-block
Block-On - ref to on-block
CAMO - Continuing Airworthiness Management Organization
CAEP - Committee on Aviation Environmental Protection
Climb - climbing flight
CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation
Dry-Lease - lease of an aircraft without flight crew
EFB - Electronic Flight Bag
EFF - Electronic Flight Folder
En-Route - horizontal- or cruise-flight
Engines-Shutdown - switch off of the last engine
EU-ETS - European Emission Trade Scheme
FMS - Flight Management System
FOB - Fuel on Board quantity
FTE - Full Time Equivalent
GMTF - Global Market Based Measure Technical Task Force
Ground - ground time of an aircraft
HOSP - flight which is considered as an ambulance flight
HUM - flight for humanitarian reasons
ICAO - International Civil Aviation Organization
IT - information technology
Journey Log - log of a single flight
Mass & Balance - weight and trim calculation, performed for each flight
MRV - Monitoring, Reporting & Verification
Off-Block - aircraft leaves a parking position
On-Block - aircraft arrives at a parking position
Take-Off - aircraft' airborn
Touch-Down - first gear touches the landing runway
TEST - flight which is performed for technical tests
TRAINING - flight which is performed for professional training reasons
SD - Shutdown (fuel on board quantity after last engines' switch off
UP - Uplift (refueling quantity)
Uplift - refueling quantity
VFR - Visual Flight Rules
Weight & Balance - ref to Mass & Balance
Wet-Lease - lease of an aircraft incl. flight crew