EASA
European Union Aviation Safety Agency

EUROCONTROL

CRITICAL REVIEW OF ATM/ANS ENVIRONMENTAL PERFORMANCE MEASUREMENTS

ATM/ANS Environmental Transparency Working Group

Pillar 1 - Final Report

Acknowledgements

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EUROCONTROL and EASA would like to thank all experts and ANSPs who contributed to its development.

Executive Summary

The objective of the Air Traffic Management/Air Navigation Service (ATM/ANS) Environmental Transparency Working Group was to develop proposals on how ATM/ANS providers can increase environmental transparency and demonstrate their efforts to support the industry by reducing the environmental impacts of their operations and to support the ambitious goal of achieving net zero carbon for aviation by 2050. The work of this group of experts, 'Pillar 1' of a larger work programme has focused on how providers can identify environmental inefficiencies and how they measure improvements (or degradation) based on certain performance criteria (existing or to be developed). This document represents the final report of the ATM/ANS Environmental Transparency Working Group covering Pillar 1 activity during a two-year period, since 2020. This report is the result of more than 15 Air Navigation Services Providers (ANSPs) and other interested parties, Borealis, the Civil Air Navigation Services Organisation (CANSO), EUROCONTROL, and FABEC, working all together during a dozen of workshops and meetings.

A key finding of this work is that a "one size fits all" approach cannot be applied for measuring environmental ANSP performance. Rather, a set of fuel burn or CO_2 indicators, is recommended by the working group as the best option to measure the ATM contribution to aviation sustainability initiatives such as the EU Aviation Green Deal and the Long-Term Aspirational Goal (LTAG) adopted by ICAO Member States in October 2022. Such a set of indicators better reflects the complexity and interdependencies of measuring ANSP environmental performance. Measuring the efficiency of differing types of airspace requires indicators tailored to different sources of inefficiencies. Therefore, three different High-Level Principles (HLP) have been defined by the Working Group to cover three different areas of performance:

- Performance at Network Level (the Network Manager in cooperation with ANSPs) - How ANSPs manage traffic strategically across the airspace network (partly dependent on CNS infrastructure);
- Performance related to operations at tactical level (ANS/controller level) - How ANSPs manage traffic tactically (partly dependent on airspace design); and
- Performance related to airspace infrastructure at local part of the flight (due to airspace design limitations or CNS equipment) - How ANSPs decide to use CNS infrastructure -ground/space based (partly dependent on key traffic flows and geography).

This report applied a methodology and an approach based on a consistent review and assessment of the current and available environmental indicators, together with assessing the potential of new and/or still in development indicators. This allowed the group to produce an assessed list of indicators containing the ones already developed at European level[1], together with indicators already in use by Working Group members regardless of whether they are in development phase (such as KEO or Acropole) or operationally used (such as 3Di or MUAC indicators). The indicators

[1] EUROCONTROL Aviation Intelligence Unit (AIU) Portal, Excess Fuel Burn (XFB) from the Network Manager, TMA metrics from EUROCONTROL Innovation Hub (EIH).

were then provided with a score based on six criteria such as relevance, transparency, or maturity.

A single perfect indicator capturing the environmental performance fully under the control of an ANSP has not been found. Each of the assessed indicators has a specific ability to measure different contributions to the pool of ATM inefficiencies shared by all operational stakeholders (such as ANSPs, Airlines, Airports, Computerised Flight Plan Service Providers (CFSPs), and the Network Manager). However, it should be noted that each of the indicators considered may have some limitations that should be identified and communicated to avoid any misuse or misunderstanding.

The report highlights some promising new indicators, such as indicators based on Machine Learning (e.g., Acropole indicators) or indicators based upon the real fuel burn data from airlines (e.g., KEO). These evidenced indicators are not yet developed at European level. However, they deserve a high level of attention and further development in particular by adapting the algorithm and the trajectory to the ECAC dimension. Indeed, thanks to new technology like Artificial Intelligence or Machine Learning, it is believed that current proxy indicators could be improved, and new advanced proxy indicators could be developed by integrating interdependencies such as airspace users' choices or weather data. It shows that the research on ATM/ANS environmental performance indicators is not yet complete.

Finally, this report identifies strategic and technical recommendations including proposals for future work. Despite the amount of work that still needs to be done, this report aims to be an inventory of the existing and future environmental indicators that could be used to measure ATM/ANS environmental performance. The contents of this report will help ANSPs to increase environmental disclosure and in doing so, demonstrate their willingness to contribute to goals such as Net Zero Emission by 2050.

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1. Introduction

1.1. Background

While air connectivity brings significant socio-economic benefits, it also comes with environmental challenges such as aircraft Green House Gas emissions (GHG) and noise. Aircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), ozone (O_3), and methane (CH_4); trigger formation of condensation trails (contrails); and may increase cirrus cloudiness—all of which contribute to climate change [1].

Moreover, air traffic in Europe has doubled since 1990, and for the period 2005-2015, CO_2 emissions in the European Union (EU-27) increased by 7.6 % in 2005-2015 and are expected to see an even greater increase – by 21 % – in 2015-2050 [2]. A recent study [3], reports that the contribution of global aviation in 2011 was calculated to be 3.5 (4.0, 3.4) % of the net anthropogenic effective radiative forcing. In Europe (EU27+UK), aviation accounted for 3.66% and 1.72% of total GHG emissions in 2019 and 2020 respectively (2020 is the latest year for which the European Economic Area (EEA) data is available, although the significant reduction in travel as a consequence of the COVID-19 pandemic means that it is not a representative year) [4]. The aviation sector creates 13.9% of the emissions from transport and is the second biggest source of transport GHG emissions after road transport. If global aviation were a country, it would rank in the top 10 emitters [5].

The political will to reduce aviation emissions exists and is manifested through various initiatives, such as, the "European Green Deal" for the EU adopted in 2019 [6] [7] and the "Fitfor55 Package", by which the EU adopted new targets to reduce GHG emissions to at least 55% below 1990 levels by 2030 (previously 40%)[8]. According to the Green Deal communication, a 90 % reduction in transport emissions would be needed by 2050 to achieve a climate neutral economy [9].

The aviation industry is still working hard to recover from the effects of the COVID-19 pandemic and without any certainty of a full recovery, policy makers across Europe are calling for recovery efforts to be in line with the Green Deal environmental sustainability objectives. Achieving the ambitious goal of climate neutrality by 2050 calls for the EU to ensure a deep decarbonisation of the air transport sector. However, even though the aviation industry has committed to reducing its environmental impacts, ambitious targets can only be achieved if all aviation Stakeholders work together.

1.2. ATM/ANS Environmental Transparency Working Group

In this context, the European Union Aviation Safety Agency (EASA) and EUROCONTROL in the framework of the EASA-EUROCONTROL Joint Work Programme agreed to establish the "**ATM/ANS Environmental Transparency Working Group**" with the objective to develop proposals on how providers of Air Traffic Management (ATM) / Air Navigation Services (ANS) can increase environmental transparency and demonstrate their efforts to support the industry in the reduction of environmental impacts.

1.2.1. Group Members

The WG was technical in nature and the members have contributed with their relevant expertise, data, and analysis. The WG was composed of technical experts from Air Navigation Service Providers (ANSPs) and other interested parties and alliances, Borealis, the Civil Air Navigation Services Organisation (CANSO), EUROCONTROL, and FABEC.

Members of the WG consisted of the stakeholders representing all levels of Air Traffic Services (ATS) and airspace complexity and ensured geographical representation from across EU / the European Civil Aviation Conference (ECAC). The full member list can be found in Annex I - Work Group Members of this document.

1.3. Objectives

The overall objective of the WG was to make ATM/ANS environmental performance transparent, allowing ATM/ANS Providers (insofar 'Providers') to show improvements over time, and demonstrate their efforts to deliver environmentally friendly air navigation services to facilitate a holistic environmental approach in aviation.

1.4. Concept and Scope

The WG was tasked to develop proposals on how Providers can increase their collective disclosure and reporting of environmental performance using relevant and appropriate indicators, share best practices to measure environmental performance and hence demonstrate their efforts to support a net zero ambition for the aviation industry.

The proposals were planned to be divided into three main pillars:

1. **Pillar 1**: How Providers identify environmental inefficiencies where they are responsible, or where responsibility is shared, and how they measure environmental performance changes based on certain performance criteria (existing or to be developed);
2. **Pillar 2**: How individual Providers improve environmental performance through the implementation of technologies and procedures;
3. **Pillar 3**: How Providers are improving their organisation's environmental footprint.

In summary, the Pillar 1 report aims to identify factors affecting environmental efficiency that are under Provider's control. Additionally, it provides assessment of the current environmental performance indicators (PIs), identifies potential areas of improvement, and areas in the gate-to-gate environment where measurements of environmental performance are missing.

Based on WG Terms of Reference (ToR), Pillar 1 focused on review and assessment of indicators linked to CO_2 emissions, whilst Pillar 2 considered other indicators, including non-CO_2 emissions.

Note that Pillars 2 and 3 are presented as separate reports.

1.5. High Level Principles

ANSPs fulfil at least three fundamental roles – they strategically (directly or in consultation) manage the airspace network, they tactically manage traffic using the airspace network as efficiently as they can (considering all constraints), and they plan the deployment and use of Communication, Navigation and Surveillance (CNS) infrastructure to enable the most optimal network.

The scope of this report is therefore aligned with the three different strategic dimensions, i.e. **High Level Principles** (HLP). Three agreed drivers of performance based on the HLPs are:

- "Network performance": Performance at Network Level (NM in cooperation with ANSPs) - How ANSPs manage traffic strategically across the airspace network (partly dependent on CNS infrastructure);
- "Operational tactical": Performance related to operations at tactical level (ANS/ATCo level) - How ANSPs manage traffic tactically (partly dependent on airspace design); and
- "Airspace infrastructure": Performance related to airspace infrastructure at local part of the flight (due to airspace design limitations or CNS equipment) - How ANSPs decide to use CNS infrastructure -ground/space based (partly dependent on key traffic flows and geography).

These HLP were developed and agreed during consultation process as described in section 2.1.

1.6. Additional criteria for potential new indicators

Based on the ToR, bilateral consultations, questionnaire and subsequent discussions, several principles have emerged and been agreed by the WG in case of development of the new indicators. These are as follows:

1. Indicators should support ANSPs to identify inefficiency, both where ANSPs are responsible and where that responsibility is shared with others;
2. Indicators should support ANSPs to improve their environmental performance;
3. Indicators should support measurement of aviation CO_2 emissions towards the aviation sector's net zero goal;
4. Indicators should drive behaviours consistent with net-zero target CO_2 emissions;
5. Indicators should include all of the ECAC region and be transferrable to the sub-regional / local level, e.g. Functional Airspace Block (FAB), Flight Information Region (FIR), or Terminal Manoeuvring Area (TMA);
6. Managing airspace is a complex task and therefore the new indicators should not be oversimplified;
7. Future indicators should reflect three main drivers of ANSP environmental performance as indicated in section 1.5.

Based on this list of principles, it was recommended to develop a set of combined CO_2 indicators to better represent the different sources of ATM/ANS contributions/roles to CO_2emissions reduction.

2. Methodology and Approach

This chapter explains the work methodology and approach taken to review, assess the current and available environmental indicators, and identify areas of improvement and potential for the development of the new environmental indicators that could answer what can Providers do to reduce the environmental impacts of their operations.

The overall work approach for Pillar 1 consisted of two distinct work streams (Figure 1).

- Work Package 1 (WP1) – which consisted of identification of the main/important **environmental inefficiencies** (environmental pressures), specifically under the ATM/ANS control, and contribution of Providers activities in different environmental aspects (relevance); This work package aim was:
  - Task 1.1 – to determine what are the main/important inefficiencies (environmental pressures) under the ATM/ANS control (Stakeholder survey, interviews, desktop review), and,
  - Task 1.2 – to determine how much (relevance) the Providers contribute in different environmental aspects (related to different phases of flight). Evaluate and determine the most important environmental aspects particularly those related to overall system performance (Stakeholder survey, interviews, desktop review);
- Work Package 2 (WP2) – which covered identification of available **indicators, metrics, and methodologies**, development of the assessment criteria to be used for the evaluation of existing indicators and metrics, and proposal for potential development of the new ones. This WP consisted of:
  - Task 2.1 - Review and evaluation of existing criteria, methodologies and indicators applied and used, identification of gaps (review of existing methodologies, studies, reports and relevant research; and evaluation of applicability of the current indicators), and
  - Task 2.2 – Proposal for potential development of the new indicators (based on identification of existing indicators and gaps in knowledge).

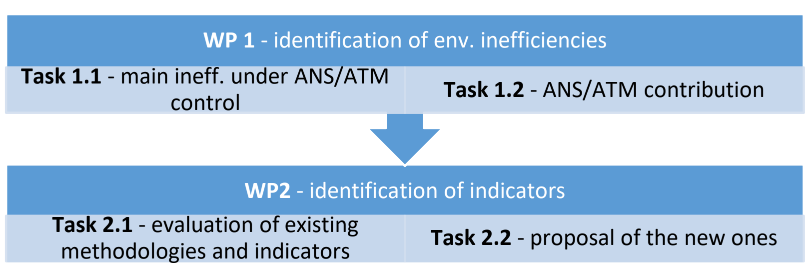

Figure 1. Overall work approach

2.1. Overview of the process

Diagram on right shows Pillar-1 work and consultation timeline in the period 2020 to 2022 (Figure 2). Figure 3 shows Pillar-1 methodology and approach, identifying the key milestones and deliverables.

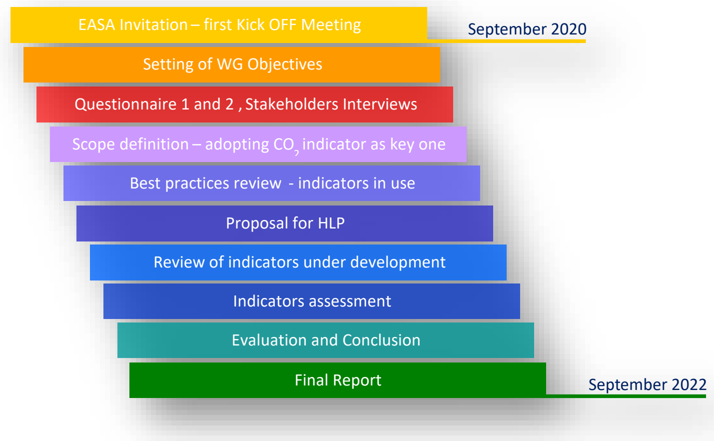

Figure 2. Work process

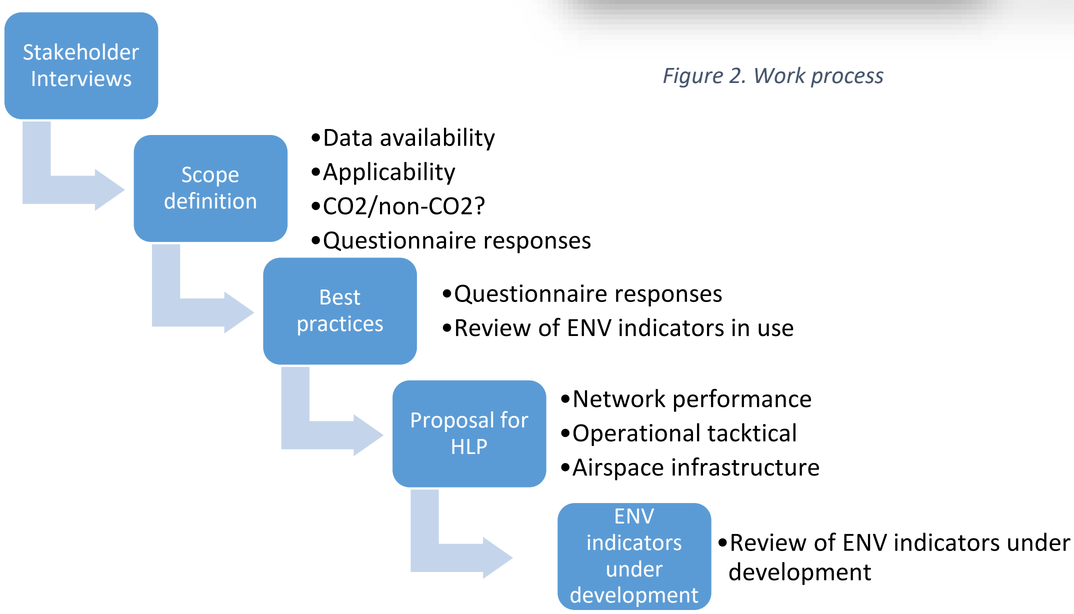

Figure 3. Methodology and Approach

2.2. Stakeholder Consultations and Interviews

The questionnaire was sent to the members of the WG on the 27th of November 2020. A more focused questionnaire update was shared with the WG members in January 2021, which also included an additional three questions.

Subsequently, WG members were invited to join bilateral consultations with the co-chairs in January 2021 to capture expectations on the outcome of the working group and gather their views on both existing and future indicators, as well as to clarify the objectives and priorities of the WG.

Providers were asked to identify the main environmental inefficiencies under their direct control and responsibility, or where responsibility is shared, and provide their view on quantification of those impacts. Lastly, questions were asked about how they measure environmental performance and improvements based on certain performance criteria (existing or under development). The questionnaire had the detailed objectives:

- To identify the key environmental impacts of interest to ANSPs;
- To identify which ANSPs measure environmental performance;
- To identify which methodologies and tools are used by ANSPs to measure environmental performance;
- To identify what environmental indicators are used by ANSPs to measure environmental performance; and,
- To assess the ATM contribution of each ATM impact by determining which parts are under ATM/ANS control.

The results were used to support the identification of the Pillar-1 scope and develop a set of HLP upon which Pillar 1 indicators should be focused. The questionnaire also served as a basis for structuring the framework of the Pillars of the ATM/ANS Environmental Transparency Working Group and document construction. In addition, the results were used for further planning and the development of strategies aimed at identifying the most important environmental concerns related to ATM/ANS.

Using this valuable feedback, the group was able to understand the environmental pressures that should be addressed by ANSPs together with understanding which environmental performance aspects are under ATM/ANS control and which ones can be measured, controlled, and reduced.

The full list of questions can be found in Annex II – **List of Questions** of this report.

2.3. Scope definition

There was a widespread agreement concerning the relevance of the environmental indicators, although some strong concerns on the appropriateness and scope of existing indicators were expressed by the WG. The strong support to initially focus on a new CO_2 emissions indicator was commonly agreed.

Adopting a CO_2 indicator was considered a key to achieving the WG objectives. Although non-CO_2 emissions have recently received increasing attention and scientific knowledge about their impact is slowly improving (current science suggests that non-CO_2 emissions contribute twice as much to global warming and that their impacts may remain in the atmosphere for a much shorter amount of time, compared to CO_2, by several orders of magnitude), they are not considered in this report and more attention will be paid to them under Pillar-2.

Focusing (at the moment) on development of CO_2 environmental indicators would allow better communication with the public, airline operators and regulators on environmental performance. Nevertheless, appetite and interest for considering other environmental impacts in future work remains, including noise, and emissions affecting either local air quality or climate change (including contrails and contrail cirrus).

Focusing on CO_2 environmental indicators would allow better communication with the public, airline operators, and regulators.

2.4. Data availability and processing

The WG members have acknowledged that the use of Flight Data Recorder (FDR) data would be the best solution for environmental performance measurement. However, although it would allow a direct measurement of fuel consumption, speeds, and more, breakdown of the flight fuel data in a way that would allow correlation to individual operational procedures is more problematic (e.g., not legally possible in some countries).

Moreover, the WG acknowledged that, ideally, CO_2 measurement should come from actual fuel burn data, however, these are not available to ANSPs at local level nor to EUROCONTROL at ECAC level. Although, fuel data are sometimes shared by airlines for specific projects (e.g., SESAR projects), this temporary and very limited data availability is not suitable for development of the new CO_2 indicators. Nevertheless, if the fuel data would become more widely available at European level (e.g., through EASA's D4S programme), it could become a primary source to feed the new environmental indicators or could be used to further validate or enhance existing ones.

The new environmental indicators will be based on radar data available at ECAC and local level; and CO_2 emissions will be estimated based on fuel burn modelling.

It was agreed that any potential new indicators developed will therefore be based on radar data available at both ECAC and local level. CO_2 emissions will be estimated based on fuel burn calculation derived from BADA[2] performance modelling.

2.5. Applicability

WG members agreed that environmental indicators measuring performance of both the en-route and TMA airspace should be available. Moreover, it was agreed that environmental PIs should be used to identify opportunities for improvement for ANSPs, both from operational improvements under the control of one stakeholder and from those for which multiple stakeholders may share responsibility for.

[2] EUROCONTROL's Aircraft Database (BADA)

Lastly, the group decided that environmental PIs should be used to identify opportunities for improvement for ANSPs, while acknowledging the factors beyond their control through the involvement / contribution of other stakeholders.

2.6. Proposal for High Level Principles

The WG identified three main drivers of environmental performance, these were named HLPs (Figure 4). Following sections, provide more information about each HLP, their scope and the main areas of performance that set of environmental indicators should capture.

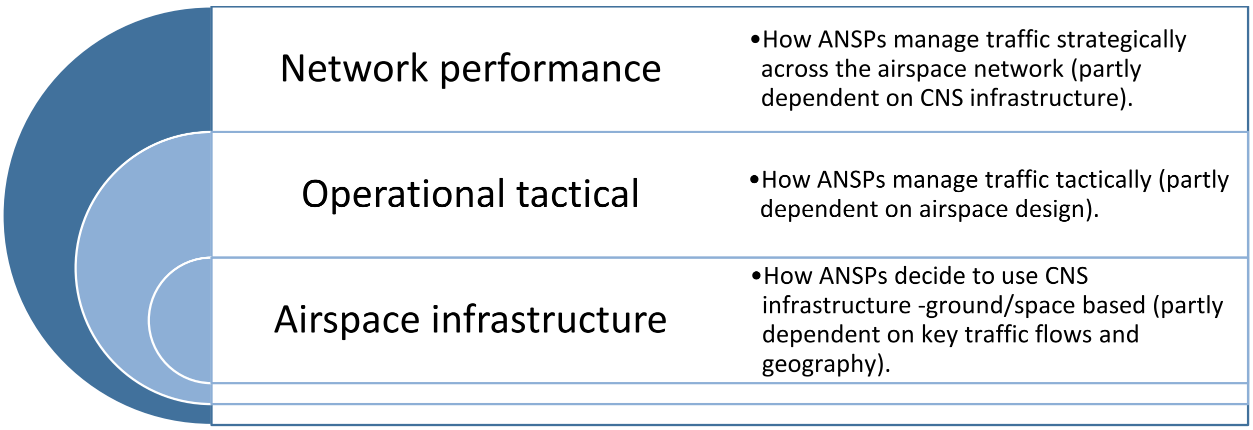

Figure 4. High Level Principles

2.6.1. Network performance

Network refers to all stakeholders (such as, ANSPs, airlines, airports, the NM) and the network design. The network has a number of dependencies, as well as enablers. For example, the network responds to civil traffic demand and patterns, military user requirements, airport interface (e.g., terminal airspace design), as well as the location and type of CNS infrastructure.

Recognising the dynamic nature of the network, a new indicator should consider the full horizontal and vertical flight profile combined. This may allow ANSPs to identify and analyse the priority opportunities to reduce CO_2 emissions across the full flight trajectory, if the horizontal / vertical contributions to the inefficiencies, together with the impact of wind, cannot be isolated. The metric should ideally measure performance from gate to gate, however, may initially focus on the trajectory from the first to the last radar point. This indicator is also an option to assess interdependencies between capacity, safety, and environment and to show the respective contributions of other involved stakeholders (e.g., military, airlines) in terms of flight/fuel inefficiency.

2.6.2. Operational tactical performance

An operational tactical performance considers local specificities, especially in TMAs where trade-offs are required to respect local noise regulations.

The conventional approach to measuring the performance of ANSPs has focused on pre-tactical/tactical operations and the tools available to manage traffic flows. This is dependent on airspace design, which in turn is also dependent on the infrastructure to operate the airspace network.

Additional operational factors include military users and the airspace they require, time of day, day of the week, and weather, among others. Operational/tactical indicators could also be influenced by pilot skills/airline policies and Flight Management System (FMS) support tools. ANSPs can enable efficient profiles, however pilots must make use of them. Within the ANSP there is potential for additional factors to influence operations, including minor variations between how individual controllers or Air Traffic Control (ATC) watches manage traffic.

Given the availability of data, there are numerous possibilities to identify tactical metrics, based on phase of flight, geography, aircraft type and others.

2.6.3. Performance related to airspace infrastructure

European airspace is designed based on a set of general principles, detailed technical specifications, and methods of application for a common airspace design which results in a series of routes, free route areas and sectors, military areas, all controlled by ATC. Whilst the airspace network is harmonised at the European level, it is supported by CNS infrastructure and equipment which can impact separation standards, coordination processes and sector capacities. ANSPs, airports, the military and regulators can each influence the location and type of CNS equipment in use across the ECAC region. This is also historically based on national borders, airport locations and traffic flows. However, ANSPs have a lead role in determining what kind of CNS equipment should be used based on their requirements, as well as its operation.

Historically indicators have not been used to assess whether ANSPs have the right equipment in the right place to provide the most efficient service to traffic flows. The type and location of surveillance equipment (e.g., space or ground based), or navigational beacons can influence the airspace network – both en-route and in the TMA.

2.7. Review of indicators

The review of environmental indicators and methodologies currently used by Providers, as well as those in development, was performed within the WG. Moreover, a possibility of development of a set of new CO_2 indicators, aligned with the HLP, was considered. Lastly, possibility to slightly adapt existing indicators to be in line with HLP principles was also considered. The aim was to analyse different options to measure CO_2 and to assess if they are suitable to identify where environmental inefficiencies are and how Providers are contributing to their reduction.

2.8. Indicators and metrics

Before going into any review, assessment and especially proposal for development of the new indicators it was necessary to set up a framework under which metrics, indicators and performance areas are defined.

Current, past performance, and expected future performance (estimated as part of forecasting and performance modelling), as well as actual progress in achieving performance objectives is quantitatively expressed by means of indicators (sometimes called Key Performance Indicators, or KPIs) [10].

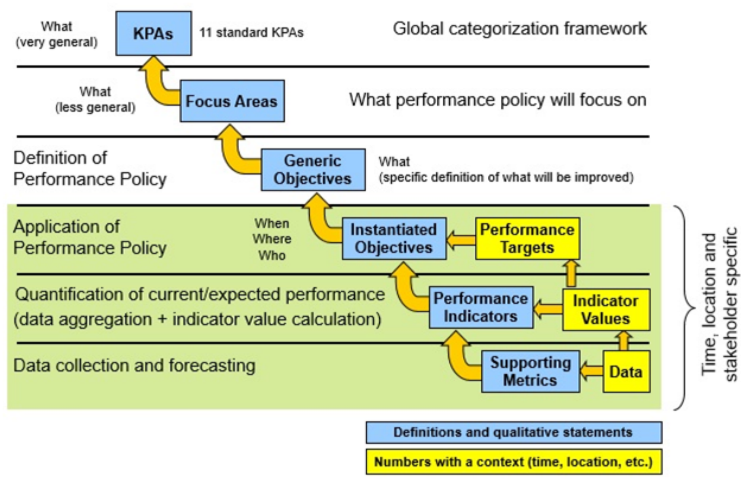

Figure 5. ICAO indicators and metrics development framework (Source: ICAO Doc 9883)

To be relevant, indicators need to correctly express the intention of the associated performance objective. Since indicators support objectives, they should not be defined without having a specific performance objective in mind. Indicators are not often directly measured. They are calculated from supporting metrics according to clearly defined formulas, e.g., cost-per-flight-indicator = Sum(cost)/Sum(flights). Performance measurement is therefore done through the collection of data for the supporting metrics [10].

2.8.1. Indicators assessment criteria

To apply consistent evaluation for all indicators, assessment criteria consisting of six different principles was proposed, and it is presented in the next table.

Table 1. Indicator assessment criteria

Criteria	Description
Relevance	Does the indicator measure the inefficiency identified in an achievable and adequate way? Does it drive the right behaviour (e.g. does not lead to unintended consequences by incentivising actions that increase fuel use)? Does the indicator clearly identify accountable entities? Is indicator CO_2 ready (can indicator measure be converted to CO_2)?
Transparency	Is indicator transparent, replicable, and auditable?
Proportionality	Are the implementation costs in proportion to potential benefits/added value (e.g., is the data flow in place or not too costly to establish or what is extent of post-processing effort to get accountability right)? Does the proposal take the computation burden on all stakeholders into account?
Granularity	Is the indicator able to measure different geographical scopes (e.g., European airspace, FAB, national, or local level)?
Maturity	Is the indicator based on sufficient evidence and robust analysis? Has the indicator been tested, and does it rely on sufficient and validated historical data?
Acceptability	Does the indicator benefit from a reasonable buy-in from stakeholders?

Score	Definition
-	No evidence of criteria successfully applied
+	Minimal evidence of criteria satisfied
++	some / several evidence of criteria satisfied
+++	criteria satisfied in full

3. Results

This chapter presents results of various WG tasks, including a survey of Stakeholder input on the use of environmental indicators, methodologies, and their requirements, as well as an assessment of current and potentially new indicators and metrics for measurement of environmental performance.

It is widely recognised that interdependencies and trade-offs exist both between environmental impacts and with capacity, cost, and safety performance. Moreover, whilst safety is paramount, factors related to capacity, efficiency, cost, and weather may all have an impact upon environmental performance. However, analysis of the extent to which such interdependencies impact performance was outside the scope of this report. Consideration of the interdependencies and trade-offs between the different impacts of an operational change can only be truly determined at the local level as the priorities of the stakeholders will differ according to local requirements, conditions, and expectations.

In addition, when trying to isolate the share of responsibility of individual ATM stakeholders, it should be noted that whilst ATM is a shared task that falls primarily on ATC and aircraft operators, it also involves other stakeholders all of whom need to play their part to maximise the potential for ATM and operational measures to support emission reduction.

3.1. Questionnaire Responses

Stakeholder questionnaires collected 19 responses from 16 ANSPs, one FAB, and two Alliances (more details available in section 2.1).

WG agreed that Key Performance Indicators (KPIs) and PIs are the vital navigation instruments used by both managers and operational staff to understand whether business (and operations) is on a successful path or off-track.

ANSP representatives have expressed the desire to improve their reporting of environmental performance, share best practice on measuring environmental benefits, and demonstrate how they can support Destination 2050 and the European industry's net zero emissions goal. They also welcomed the opportunity to consider new approaches to improving network-wide environmental transparency and performance. Lastly, strong support for initially focusing on a new CO_2 emissions metric within Pillar 1 was given by all members of the group.

In general, the responses revealed a somehow scattered set of tools, ideas, solutions in use as well as future plans. Results revealed that, in general, the indicators and/or guidelines provided by EUROCONTROL Performance Review Unit (PRU) have some value and are used in various ways, however, at the same time they are outnumbered by bespoke solutions and applications.

Among the solutions to improve environmental performance the most frequently mentioned one by Stakeholders was improving the vertical and horizontal flight efficiency. This does not come as a surprise as these topics have been discussed throughout the aviation industry for some time. Reduction of miles flown at inefficient altitudes or miles flown in excess is a goal that is easy to identify and can pay off.

Amongst operational solutions that improve environmental performance, as expected, concepts such as Free Route Airspace (FRA) and Continuous Climb Operations and Continuous Descent Operations (CCO/CDO) were mentioned.

Detailed questionnaire results can be found in Annex III – Questionnaire Results.

3.2. Assessment of environmental indicators in use

The following sections provide an overview of indicators and methodologies widely used for measuring ANSP environmental performance, which were discussed within the WG. Each indicator was reviewed and assessed, to provide a) indicator description; b) its benefits and shortcomings; and c) on-going and proposed improvement actions, if any.

3.2.1. Horizontal Flight Efficiency

Horizontal Flight Efficiency (HFE) is very simply defined at its highest level: the comparison between the length of a trajectory and the shortest distance between its endpoints (it refers to the whole flight, not the local measurement). It calculates the additional distance flown between take-off and landing with respect to the most direct route between the two airports (at the moment measured as the Great Circle Distance (GCD) as acceptable proxy for the geodesic). It measures the distance outside the 40NM circle around the airport or the ENTRY/EXIT point in the ECAC Area [11].

HFE was developed by the EUROCONTROL Performance Review Commission (PRC) as a ratio of distance flown within a given airspace vs 'achieved distance' in this airspace. 'Achieved distance' is a function of four points: the position of the entry and exit points of the flight into and out of each portion of airspace for all parts of the trajectory, and origin and destination (https://ansperformance.eu/methodology/horizontal-flight-efficiency-pi/). The distances are measured as GCD (lengths come from NM).

The term horizontal could even be dropped, as the indicator takes as a reference the distance value and does not use any reference trajectory. HFE is a measure of efficiency and not of optimality, as it does not consider costs or time trade-offs.

The general framework for the analysis of flight efficiency is presented at Figure 6 which shows the three indicators currently used for measurement of HFE and corresponding used for analysis of trajectories:

- KEA uses the actual flown trajectories generated using radar data (PRISME data that consider a managed trajectory mixed with missed points/CPRs). The KPI is used in the Single European Sky (SES) Performance Scheme. The actual flown trajectory is based on the flight plan trajectory. It is influenced by unforeseen or unplannable factors at the time of filing, including weather and tactical ATC routings. Some of these modifications might lead to a lengthening of the trajectory, while others will lead to a shortening of it;

- KEP indicator is the horizontal flight efficiency calculated using the planned trajectory according to the flight plan. The filed flight plan must always be at least as long as, if not longer than, the SCR; and
- KES is based on the shortest constrained route (SCR) available for flight planning. The SCR reflects the effect of the constraints (referring to constraints that are imposed on flight planning, e.g. route structure, airspace availability) on flight planning. It is not influenced by weather conditions or specific airline considerations, and it sets the limits within which the airlines can optimise. The SCR (if correctly calculated) would provide the measurement which is not influenced by the choices of the airspace users (see graph below).

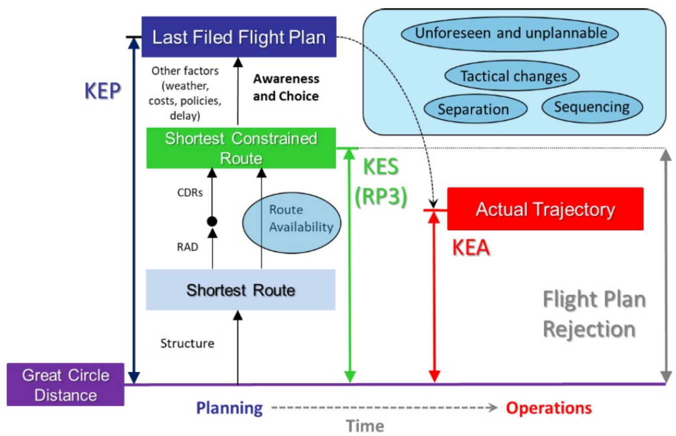

Figure 6. HFE measurements (Source: PRU)

To exclude the influence of unusual events, the ten best days and the ten worst days (for each measured area) are excluded from the computation for SES performance monitoring purpose. All trajectories are provided by the NM. The indicator considers all portions of flights traversing an airspace and compares the flown and the achieved distance.

Recently, several modifications to the calculation of horizontal flight efficiency have been proposed by the PRU. There are also ongoing efforts to translate the KEA results in terms of (excess) CO_2.

The next table summarises the difference between current and proposed methodology.

Table 2. KEA proposed modifications

Current	Proposal
The origin and destination could be at the border of the reference area instead of at the airports.	The origin and destination are always at the airports
Every entry and exit were considered.	Due to the lack of additivity, first entry and last exit are considered for an airspace
The 10 best and 10 worst days are excluded entirely.	For every day, 20% of the flights are excluded (10% highest and lowest in terms of additional total percentage). Daily values are presented as statistical distributions, as trimmed averages (central measure), with 20% of trajectories excluded (10% each end).

Note: the methodology previously excluded the ten best days and the ten worst days (for each measured area) from the computation to smooth out the influence of unusual events. The exclusion of the ten best / worst days (circa 5%) is there for major events, the other is there for outliers (and data errors). It should be noted that the higher the percentage the lesser the indicator will correspond to the reality. The data is certainly not normally distributed and is very skewed (it is measured as additional with respect to minimum, not average).

Criteria	Assessment	Score
Relevance	KEA measures HFE by achieved distance adequately, however, does not allow the determination of stakeholder accountability or isolate the impact of factors which are within / beyond the control of an ANSP (e.g., geopolitical situation, weather). Both KEP/KEA are proxies, and the inefficiency is negatively affected in all airspaces after the one in which the deviation was initiated. The reference trajectory used is the GC which is a mature reference but may still be fuel inefficient or fuel efficient as it does not incorporate meteo information such as wind. There are ongoing efforts to adapt KEA to CO_2 measure.	++
Transparency	The indicator is well documented, methodology is available and indicators replicable. As part of SES Performance Scheme KEA is also auditable.	+++
Proportionality	The indicator is centrally measured therefore, continuing with this indicator is a low-cost solution.	+++
Granularity	Can be used to measure performance per airspace / State. Could potentially be broken down per phase of flight.	++
Maturity	HFE is one of the most evaluated indicators. Large experience in measurement, data, and methodology is available. Already used in SES Performance Scheme and in ICAO Performance Framework, it can be considered mature	+++
Acceptability	Mainly accepted and applied by stakeholders within the SES Performance Scheme, however, requests for improvement are frequently made.	++

3.2.2. En-route Vertical Flight Efficiency

The PRC has developed a methodology to assess en-route Vertical Flight Efficiency (VFE). The methodology does currently not allow quantification of the total amount of vertical en-route inefficiencies in the EUROCONTROL area, nor does it identify all underlying reasons for the observed inefficiencies.

Because of the distinct nature of the different phases of flight, specific methodologies were developed for the analysis of vertical flight efficiency during climb and descent on the one hand and for the analysis of en-route vertical flight efficiency on the other hand.

Based on the assumption that flights on airport pairs with similar GCD should be able to reach similar cruising altitudes, the methodology compares the maximum filed flight levels of flights on a specific airport pair and flights on reference airport pairs with a similar GCD and without RAD (Route Availability Document) constraints.

There are several ongoing workflows related to en-route VFE:

- Development of an indicator that compares the maximum altitudes in flight plans of flights between a specific airport pair with the maximum altitudes of flights between unconstrained (in terms of RAD restrictions) airport pairs which have a similar GCD between them;
- Development of an indicator that measures the vertical deviation between top of climb (ToC) and top of descent (ToD) of an actual trajectory with that of a reference profile (representing a 90% percentile of the average en-route vertical profile of all flights of the same aircraft type between city pairs of a similar distance). This follows the approach developed for the TMA metrics [12] (see section 3.3.3); and
- Development of indicator that measures the vertical deviation between ToC and ToD points of an actual trajectory with that of a reference profile derived from BADA performance data which can then be converted to fuel burn / CO_2 using BADA performance tables.

Criteria	Assessment	Score
Relevance	These indicators measure vertical flight efficiency in the en-route phase by comparing performance to a best performer, ideal and statistical reference. These indicators provide consistency with other indicators such as the horizontal / vertical TMA metrics and the CCO / CDO indicators. VFE performance is not solely based on factors under control of the ANSPs, and may be influenced by airline decisions, as well as other factors such as weather. Development of a CO_2 module is also ongoing.	++
Transparency	The PRU indicator is well documented, methodology is available and indicators replicable. As part of SES Performance Scheme en-route VFE is also auditable. *Note: The other two indicators are still under development.	+++
Proportionality	The PRU indicator is centrally measured therefore, continuing with this indicator is a low-cost solution. *Note: Once available, the indicators under development are likely to be able to be centrally measured.	++
Granularity	Only city pair / network level at the moment. Further work is required to provide additional granularity.	+
Maturity	Development of these indicators is ongoing, some have not yet been fully tested on a wider scale.	++
Acceptability	The basic premise of each metric appears accepted by stakeholders; however, results have not yet been widely shared to fully determine the level of acceptability.	+

3.2.3. CCO/CDO indicators

The ICAO CDO Manual (9931) states that CDO is an aircraft operating technique aided by appropriate airspace and procedure design and appropriate ATC clearances enabling the execution of a flight profile optimized to the operating capability of the aircraft, with low engine thrust settings and, where possible, a low drag configuration, thereby reducing fuel burn and emissions during descent.

Reducing intermediate level-offs and deviations during climb and descent can save substantial amounts of fuel and CO_2 and reduce noise levels in the vicinity of airports. In principle, the lower the level segment, the higher the additional fuel consumption.

Current vertical flight efficiency indicators for measuring performance during climb and descent have been developed by the work of the European CCO/CDO Task Force who brought together a set of European stakeholders (mainly ANSPs and aircraft operator representatives) and used their experiences and the existing metrics used by them to agree on a harmonised definition of CCO / CDO [14]. The agreed indicator was 'average time in level flight', an operational proxy for flight inefficiency and CCO/CDO. This was a big change and improvement from other indicators which focused on a binary definition of CCO/CDO (i.e., Y/N). This was because the binary measure was not able to demonstrate operational performance improvements and it did not distinguish between a small inefficiency to maintain separation between aircraft, and a long inefficiency at high fuel flow levels due to inefficient procedures.

However, although this methodology is an improvement, it may not fully align with fuel burn measures by the Flight Data Recorders on board the aircraft as it may hide the inefficiency arising from descent segments where partial thrust is used, or it may measure inefficiencies in level segments that are flown in idle thrust.

The methodology calculates the rate of climb or descent (vertical velocity) between every pair of consecutive data points. If the rate of climb or descent between two data points is smaller than or equal to a chosen vertical velocity, that part of the trajectory is considered as level flight. A segment of the trajectory is considered as level flight when its rate of climb or descent is lower than or equal to 300 feet per minute. Level segments shorter than 20 seconds are not considered.

The objective of the methodology is to measure and observe vertical flight efficiency during climb and descent without highlighting specific reasons for the observed behaviour. More detailed case studies are needed to find out reasons (constraints put by ANSPs, airline procedures, airport constraints etc.) for particular observations.

The European CCO / CDO Task Force developed two definitions for CCO:

- Noise CCO – measures the average time in level flight from 2500ft above ground level (AGL) for that part of the climb profile below 10500ft, and
- Fuel CCO – measures the average time in level flight from 2500ft AGL to ToC.

In addition, the Task Force proposed two definitions for CDO:

- Noise CDO – measures the average time in level flight for that part of the descent profile below 7500ft to 1800ft AGL, and
- Fuel CDO – measures the average time in level flight from ToD to 1800ft AGL.

These indicators rely on the definition of a series of 4D points for measurement (described in the European CCO / CDO Action Plan [15]) and the indicator can also be converted into CO_2 using an aircraft performance model such as BADA[3]. As a reference, it is assumed that the level segment

[3] Under the auspices of the WG a CO_2 module was developed by incorporating BADA into the Advanced Emission Model (AEM) tool which enabled CCO/CDO performance to be estimated by CO_2.

would have happened at cruising altitude. The indicator is calculated as the difference between the fuel burn of the level segment at its actual altitude and at cruising altitude (with the same track distance, considering the speed profile of the aircraft at the different cruising levels).

Other CCO / CDO indicators include the median CDO/CCO altitude and the share of CDO/CCO flights by detecting level flight (vertical velocity ≤ 300 feet/min) from ToD (a defined 4D point) to 1800ft AGL (descent) or from 3000ft AGL to ToC (climb).

Criteria	Assessment	Score
Relevance	Proxy metric that measures VFE in the climb and descent phases in the absence of fuel data from airlines. CCO/CDO performance is not solely based on factors under control of the ANSPs, and may be influenced by airline decisions, as well as other factors such as weather, runway use etc. CCO/CDO definition can and is perceived differently by operational stakeholders. An optimized descent trajectory is a CDO. A trajectory reducing emissions and satisfying Airspace Users should not be disqualified by an indicator. Development of a CO_2 module is finalised.	++
Transparency	As it is based on harmonised definitions measurement of CCO/CDO indicators by all stakeholders, should be transferable when using the data of similar quality.	++
Proportionality	As implementation of CCO/CDO is usually led by controllers and airspace designers, substantial external effort should not be required. Centrally measured so continuing with this indicator is a low-cost solution.	+++
Granularity	Is currently measured by the CCO / CDO dashboard per airport, airline, and State. *Note: State measurement is based upon airport data in that State and may not fully align with individual FIRs / airspace.	+++
Maturity	Already used in SES Performance Scheme as monitoring indicator, so it can be considered mature. However, the CCO/CDO European Action Plan calls for further research activity.	+++
Acceptability	There is no agreement reached yet on a common definition for CCO/CDO indicators that satisfies both operational needs and performance measurement constraints. Although stakeholders would prefer performance based on actual fuel data, the European CCO / CDO Task Force considered this the next best option so fully accepted by experts, provided applied correctly.	++

3.2.4. ASMA and TXOT

The additional time in Arrival Sequencing and Metering Area (ASMA) provides a proxy for holding time. It is the difference between the actual ASMA transit time and the unimpeded ASMA time calculated for non-congested conditions [16]. This indicator compares actual (additional) ASMA time per Instrument Flight Rules (IFR) arrival (in minutes) in a 40NM cylinder around a destination airport, to an unimpeded ASMA time which is a reference based upon a statistical analysis of historic data observed at the airport over a reference period, averaged for groupings of similar flights arriving via each ASMA sector. The actual time measured is based upon the last entry of a flight into the ASMA cylinder and the actual landing time. Note that the new methodology considers the FIRST entry in the ASMA cylinder (unlike the current methodology that considers the last entry in the ASMA cylinder).

Additional Taxi-Out Time (TXOT) indicator provides a proxy for the average taxi delays and departure runway queuing time on the outbound traffic flow, during times that the airport is congested. The indicator is calculated based on data availability for Actual Off Block Time (AOBT) and Actual Take-Off Time (ATOT). In other words, it compares the difference between the actual take off time (elapsed time between off blocks time and take off time) and the unimpeded take off time in non-congested conditions at airports per IFR departure. The additional taxi-out time per group of similar flights is the difference between the actual taxi-out time and the median unimpeded taxi-out time. Taking the weighted average of the values for all groups produces the taxi-out additional time for the airport [17].

A consultation on an update to ASMA is currently being undertaken (e.g., how to define an appropriate reference, and to correct that holdings are erroneously being measured under KEA instead of ASMA) based on Stakeholder comments to simplify it. This exercise includes a revision of TXOT and development of Taxi-In Time indicator (TXIT). TXIT indicator should measure the difference between actual landing time (LT) (elapsed time between LT and in-block time) and the unimpeded taxi-in time in non-congested conditions at airports.

Criteria	Assessment	Score
Relevance	Measures arrival TMA performance together with taxi-out time at individual airports. For taxi times less relevant, as scope and way of measuring can be different per airport (include/exclude remote de-icing, grouping by stand or group of stands, etc.). This complicates a universal application. It is difficult to isolate the ANSP contribution, as for example taxiway maintenance (not in scope of ANSP) can negatively impact performance. Ongoing work to review and develop a CO_2 module.	++
Transparency	The indicators are well documented, methodology is available and indicators replicable.	+++
Proportionality	Measured centrally so continuing with this indicator is a low-cost solution	+++
Granularity	Applicable per airport only. Comparisons between airports can be made, however results from multiple airports cannot be easily aggregated.	++
Maturity	Already used in SES Performance Scheme as monitoring indicator, therefore it can be considered mature.	+++
Acceptability	Well accepted by stakeholders within SES Performance Scheme and Airport community.	+++

3.2.5. Excess Fuel Burn

Excess Fuel Burn (XFB) is an indicator that calculates the excess fuel burn for an airport pair / aircraft type combination based on the total actual fuel burn / total reference fuel burn, using Enhanced Tactical Flow Management System (EFTMS) trajectory data (the Current Tactical Flight

Model (CTFM) or Model 3[4] – actual route flown) from the NM. The reference fuel burn used by NM is either the 5th or 10th percentile of all fuel burn observations for a specific airport pair / aircraft type combination over a reference period (currently 2019).

The excess fuel burn for an airport pair / aircraft type combination is the total fuel burn (the "wheels up – wheels down" portion of the flight) for flights in the combination divided by total fuel burn if all flights had achieved the reference fuel burn. The Intra NM excess fuel burn is the aggregation of all combinations within the scope.

The XFB is a network indicator. Therefore, ATM Stakeholders such as ANSPs, Airlines, airports, the EUROCONTROL NM and Computerised Flight Plan Service Providers (CFSPs), share a responsibility to collaborate and contribute to reducing excess fuel burn inefficiencies as much as possible. Based on an indicator relating directly to fuel consumption and emissions, this approach suggests that ATM can influence roughly 10% of aviation's emissions in Europe which is above earlier estimates (6% average ANS-related gate-to-gate fuel burn inefficiency as compared to the unimpeded trajectory). It is important to highlight that not all ATM inefficiencies can be eliminated, and a certain flexibility in the system is required to manage constraints such as separation minima, TMA route structure, runway direction, adverse weather, avoidance of 'Danger Areas', interdependencies etc. The "benefit pool" therefore constitutes an estimated upper bound of possible savings in the respective flight phases.

It should be noted that whilst XFB can measure the fuel inefficiency based on the activity of all stakeholders, it may also be affected by parameters that are not under the control of a stakeholder e.g., wind. In addition, using a 'best performer' reference, just like a GC approach (KEP, KEA), may still be fuel efficient or inefficient under favourable conditions e.g., tailwinds. When using a PI with a best performer reference, care should be taken to identify any false improvements or impairments due to a changing reference baseline.

Criteria	Assessment	Score
Relevance	XFB provides measure of performance at the Network Level by comparing performance to a best performer reference. It is difficult to identify stakeholder accountability, as it is not limited to ANS actions (it is influenced by all ATM stakeholders such as, airport, airlines, ANSPs). It is a relative measure, based on the relationship between average performance and the top 10% / 5%, therefore does not show overall absolute improvement. It is based on theoretical fuel burn, not actual fuel burn data. It is based on a specific type of plane and city pairs. There is no CO_2 conversion at the moment.	++
Transparency	The indicator detailed description and methodology available only to NM internally. Ongoing work to make calculations transparent via FATHOM portal.	+

[4] The Current Tactical Flight Model (CTFM) or Model 3 is a flight trajectory constructed (by the ETFMS system of NM) to tactically represent a flight being flown. It refines the previous Tactical Flight Models when CPRs show a significant deviation (1 min in time, more than 400 feet in en-route phase, more than 1000 feet in climb/descent phase or more than 10 NM laterally) and/or upon message updates from ATC (DCT, level requests, FPL update).

Criteria	Assessment	Score
Proportionality	Centrally measured and delivered daily to stakeholders via a dashboard therefore using this indicator is a low-cost solution.	+++
Granularity	The indicator can only measure XFB per airport pair and aircraft type and is not recommended to be used at the individual airspace level. May be broken down into phases.	+
Maturity	A new indicator (2019), it has been validated with several stakeholders.	++
Acceptability	Appears quite accepted by operational Stakeholders.	++

3.3. Indicators that are used by individual Stakeholders and introduced by the group

The following section provides information about indicators presented to the WG that are either already in use at Stakeholder's own environment, or are under development (regardless of their maturity, e.g., concept stage up to initial testing and implementation).

For mature indicators, for which information was available, the WG used the same assessment criteria as for the ones already widely in use. For the rest, due to either limited amount of information provided to the WG, lack of time for thorough discussion within the WG, or the fact that some of these are merely concepts, only high-level description was provided, and they did not go through detailed assessment review based on criteria described before.

3.3.1. NATS - 3Di score Indicator

3Di is an indicator used in the UK that combines horizontal and vertical flight inefficiency, compared to a minimum GC track, based on the actual trajectory of each flight from its first to last radar point. The UK Civil Aviation Authority (CAA) sets annual financially incentivised performance targets for NATS on 3Di.

The 3Di indicator is a score that compares the actual flight path of an aircraft to the 'preferred profile' (or the most efficient possible flight path). There are two principal parts of the profile:

- The horizontal efficiency compares the actual radar ground track against the most direct track possible over ground, essentially calculating the additional miles flown.
- The vertical efficiency measures the amount of level flight that occurs below the airlines' requested flight level; the more time spent at a lower cruising altitude, the more penalising for a flight's 3Di score.

The score also includes working with neighbouring air traffic control providers and military airspace users to deliver more direct routes beyond UK airspace to improve the great circle route where the origin/destination are outside of the UK.

Analysis is currently being undertaken to assess to what extent this indicator can be applied to airspace outside of the UK. In the future, consideration will be taken as to whether this indicator can be adapted to become based on fuel burn or CO_2.

Criteria	Assessment	Score
Relevance	Provides an overall score for at a network / individual airspace level based on measuring multiple inefficiencies. Performance measurement focused on what ANSP controls, integrates both Vertical and Horizontal inefficiency. Filed flight plan reference might not take into consideration unconstrained trajectory requests. It is difficult to identify stakeholder accountability. It is still a proxy, not a pure reflection of ANSP efficiency. Measures performance affected by factors under ANSP control and factors outside of its control. Not possible to convert to CO_2 at the moment.	+
Transparency	The indicator detailed description and methodology available only to NATS internally and PRU. Ongoing work with PRU to make calculations transparent and applicable to other ANSPs.	+
Proportionality	Implementation requires a big investment for a new stakeholder as not currently measured centrally.	+
Granularity	Only Network/State level at the moment. Efforts are ongoing to evaluate relevance at the FAB level but currently applicable only in one State.	+
Maturity	Mature in the UK, not currently used network wide. Tested within UK but not outside. Development and refinement still in progress.	+
Acceptability	Fully validated in UK but there may be some scepticism relating to multiple variables and the applicability of different performance factors in other airspace.	+

3.3.2. MUAC – HFE and VFE indicators

The Maastricht Upper Area Control Centre (MUAC) developed a set of two HFE indicators called Route Efficiency Ratios for a single airspace:

- REDES – Route Efficiency in approaching DEStination, and
- RESTR - Route Efficiency in Straightness of Trajectory

REDES and RESTR (Figure 7) for a single airspace are calculated as a route extension (only in the considered part of the airspace) relative to the realized approach to the destination (REDES) and geographical distance between the entry and exit points from that airspace (RESTR).

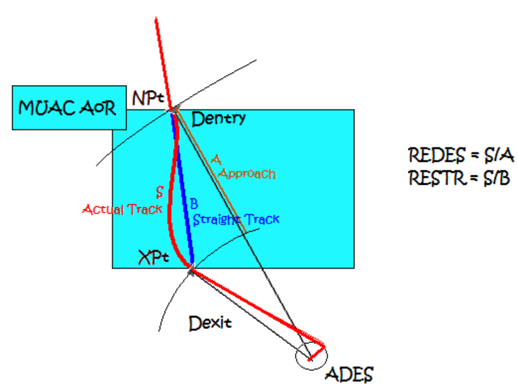

Figure 7. MUAC HFE indicators

The REDES indicator consists of two components: local extension (RESTR) and exit interface (network) extension, with the measurement starting at the entry point of the airspace, which is why the indicator doesn't include the inefficiency created in previous airspaces. REDES indicates exactly how efficiently the aircraft is using its resource (kilometres flown) for reaching its goal (getting to ADES) on a certain part of its route.

From 2009 on, MUAC monitors horizontal flight efficiency (calculated as the ratio of route extension relative to the approach of the flight to its destination as realized in MUAC airspace) both for:

- the actually flown trajectories, as REDES_actual/RESTR_actual, based on actual trajectories coming from the MUAC radar system; and
- the last filed flight plans, as REDES_planned/RESTR_planned.

Indicators are proxies as they compare the length of the en-route part of flight trajectories with a corresponding portion of the GC calculated for each flight through the MUAC airspace and its corresponding flight plan.

The advantages of using this set of ratios are twofold: first, they provide an accurate indication of the HFE achieved in a specific airspace and the gains achieved by the controllers, and can be applied to States, ANSPs, different ATC units, and secondly, they make it possible to calculate inefficiency and hence to identify the causes, relating, for example, to cross-border issues, closed airspace, as well as extreme weather conditions or natural disasters.

Finally, MUAC HFE indicators, can be also used operationally by controllers to indicate the most efficient environmental route.

Criteria	Assessment	Score
Relevance	This indicator measures HFE adequately, allows to identify inefficiency and reflect on improvements (e.g., implementation of FRA). It does not allow to determine stakeholder accountability or the factors beyond the control of an ANSP. There is no CO_2 conversion at the moment.	++
Transparency	The indicator detailed description and methodology available. it is not replicable at the moment.	+
Proportionality	The indicator can be easy centrally measured without big investments. The indicators can be used operationally by ATCOs.	++
Granularity	The indicators can be used to measure performance per airspace/State/ATC/airline etc. However, this still has to be implemented.	++
Maturity	Mature in MUAC, not currently used network wide. MUAC has been using the indicators since 2009. Tested within MUAC but not outside. Development and refinement still in progress.	++
Acceptability	Fully validated within MUAC only.	+

MUAC has developed a set of VFE indicators based on the same principles as HFE indicators. The vertical flight inefficiency (excessive fuel burn) is calculated as a difference between the reference (optimal) vertical profile and the flown/planned trajectories. The fuel burn calculations are done using simplified BADA tables.

MUAC VFE is considering assumptions and points compared to current CCO/CDO metrics, i.e. considers distance between actual ToD and optimal ToD in MUAC and between actual ToD and optimal ToD outside MUAC.

Two reference profiles have been developed for the climbing phase:

- Internal (reflects internal inefficiencies): the calculation of ToC_{MUAC} starts at the entry point to the MUAC airspace;
- Including interface component: ToC_{opt} is defined starting from ADES.

Two reference profiles have been developed for the descending phase:

- Internal (reflects internal inefficiencies): the calculation of internal ToD (ToD_{MUAC}) is defined by the exit point from MUAC airspace;
- Including interface component: ToD_{opt} is defined by ADES.

The same approach (difference in the fuel burn between the reference trajectory from_ADEP/to_ADES and from_entry/to_exit points for internal component and real/filed tracks) could be used for combined horizontal and vertical flight efficiency. A reference trajectory could be based on fuel burn data including meteorological data and climate function which reflects non-CO_2 emissions.

The reference trajectory defined in this way could be calculated to create the optimal profile for every moment of the flight in real time. Controllers could use this trajectory operationally to provide the most efficient environmental route to airlines.

3.3.3. EUROCONTROL - Horizontal and vertical TMA indicators

Horizontal and vertical TMA indicators [13] [19] measure the horizontal and vertical deviations for arrivals, from a selected horizon (typically 50NM, up to 200NM) down to final, using two types of reference trajectory (best flown (blue) and ideal (orange)) to identify airspace and operations related inefficiencies (Figure 8). They measure deviation from reference, "best flown" specific to each airport (operations) and "ideal" common to all airports (airspace).

The ideal trajectory represents a flyable trajectory with no constraints (Figure 8) - a shortest direct route from the entry at 50NM to the intercept point. Ideal is defined for an airport, runway, and flow as an unconstrained trajectory (horizontal direct to final, vertical continuous descent). The best flown trajectory (or best performer) represents the best possible trajectory integrating the local constraints; therefore, it is incorporating any horizontal extension or level-offs resulting from airspace (e.g., traffic segregation) or environmental constraints. Best flown is defined for an airport, runway, and flow as a percentile of the flown times and altitudes (resp. 10^{th} and 90^{th}).

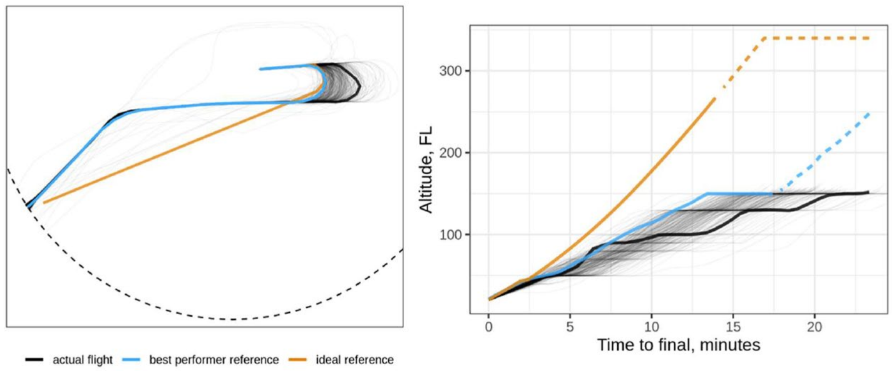

Figure 8. TMA indicators: ideal and best performer references (horizontal left, vertical right)

Similarly, there is a fuel burn deviation indicator, representing the fuel burn in excess compared to a reference. Two references are considered: a best performer defined statistically (10^{th} percentile of the fuel burn, per aircraft type, runway, and flow) and an ideal (calculated using the ideal 3D reference and appropriate aircraft model as input of the BADA 4.2 fuel calculation tool). The speed profiles are computed using a wind archive to reconstruct a true airspeed. These two references (represented by horizontal lines in Figure 9 with best performer in blue, ideal in orange) enable an estimation of the respective contribution of airspace and operations on the excess fuel burn.

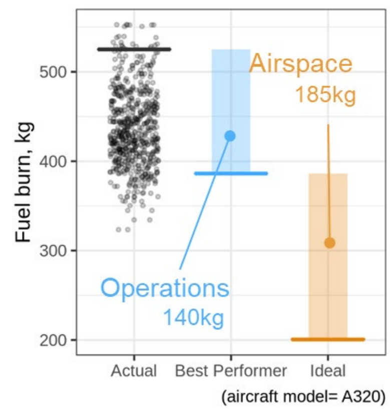

Figure 9. TMA indictors: fuel burn, with airspace and operation excess fuel burn

Figure 10 shows how the principles of ideal vs best performers may be applied to other indicators, such as the level-off for CDO, to quantify the contribution of airspace vs operations. The current version of the level-off indicators corresponds to a comparison to an ideal profile with no level-off. A best performer (e.g., define as a percentile) may contain one or several level-off segments, typically for downwind flows. The airspace related inefficiencies would be reflected by the time level-off of the best performers, while the operations related inefficiencies by the differences between each flown profile and the corresponding best performer.

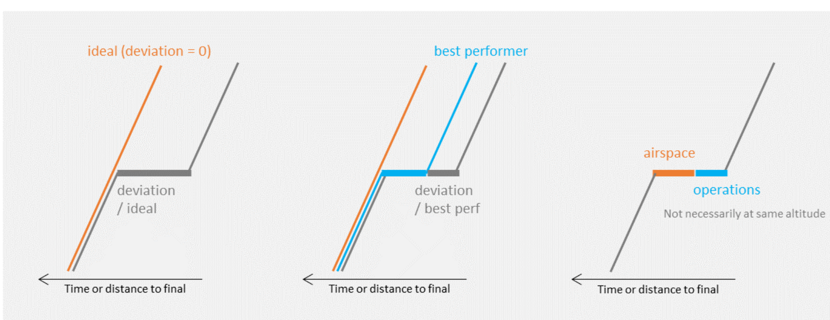

Figure 10. Horizontal and Vertical TMA indictor

Criteria	Assessment	Score
Relevance	Measures performance of both horizontal and vertical flight efficiency, and fuel in excess, comparing the trajectory to both an ideal and best performer reference which represent airspace and operations respectively. However, this is relative measurement, and it is difficult to reflect absolute changes. Conversion to CO_2 is ongoing.	++
Transparency	The indicator detailed description and methodology available through scientific papers. Indicator not replicable by Stakeholders at the moment.	+
Proportionality	Although it can be centrally measured, due to the variability of airport requirements, could be costly to implement at both network level and for individual stakeholders	+
Granularity	Only at individual airport level but variations are being discussed for other phases of flight.	++
Maturity	In development, applied to the top 27 airports.	+
Acceptability	Appears quite accepted by operational stakeholders especially as can measure performance compared to a best performer reference.	++

3.3.4. ENAIRE - “Directs” Indicator

This indicator uses flight plan data and radar tracks to identify “directs”, which are defined as: deviations in the horizontal plane present in the radar track compared to the planned trajectory included in the activated flight plan. Those deviations are:

- Flight plan way points that the flight does not cross;
- Change of heading between flight plan waypoints;
- Change of heading around flight plan waypoints.

This allows detection of Directs, false Directs and Vectors. By means of post-process it is possible to remove false detections and concatenate sequential directs.

When focusing on ‘directs’ only this indicator seems to provide what it promises. The reverse conclusion that any not given ‘direct’ should be seen as an inefficiency could also be covered by Excess Fuel Burn and/or HFE but can be questioned.

Figure 11. ENAIRE Direct index visualisation

3.3.5. ENAIRE - Holding Monitoring Indicator

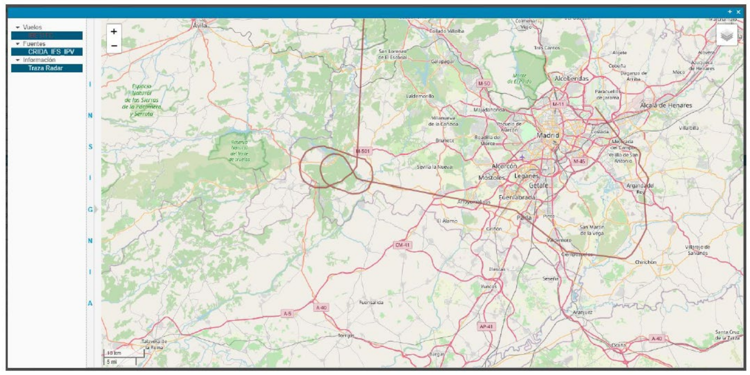

Figure 12. ENAIRE Holding detection

The second proposal from ENAIRE concerns measurement of environmental implications of holding. Indicator is based on Radar Tracks data, which includes detection of intersections within radar track (T > 60 s; Horizontal size < 25NM).

Holding is detected when intersection is compliant with a holding point defined in AIP. The holdings are detected by the intersection of the radar track by itself near a waypoint designated as a holding. The intersections are detected separately for each flight, and each circuit is identified independently. Therefore, for each flight it is possible to flag which one made a holding and if yes, the number of circuits done during the holding, with the information of the time and flight level.

This indicator could create a wrong impression at sites where holdings are flown as kind of "longitudinal holding" where transition arrival routes are replacing holdings; therefore "no holding" only delivers incomplete results.

3.3.6. DSNA - ACROPOLE indicators

Acropole PI aims at measuring performance in terms of fuel efficiency and identifying the several constraints effects and potential gains. Acropole uses machine learning models to enhance radar plots with fuel flow consumption as a pre-processing step. The way consumptions or fuel flow are computed is independent to the definition of the indicators.

Each trajectory is clustered by flows for each phase (departure, arrival, en-route, gate to gate) to enable consistent statistical comparisons. Large historical data (4 years period) is used to define refences among flows and aircraft types such as the 5^{th} and 95^{th} percentiles and the means for consumption or distance. (NB: to deal with underrepresented aircraft types or bias, proxy aircraft fuel flow models may be used).

Several indicators are being developed on those references:

- The wind corrected fuel score is computed on each flow and for each aircraft type using the wind corrected consumption references (mean, 5th and 95th percentile). The coefficient is an equivalent to the statistical standardization formula (value minus mean divided by standard deviation) map to [0,1] and reflects whether a trajectory was efficient in terms of fuel compared to the observed distribution. The score is usually between 0 and 1 (it could be above or below for values with more than 3 standard deviations from mean consumption). The 5th percentile corresponds to a score close to 0.25, mean consumption equal to 0.5 and the 95th percentile close to 0.75. The associated indicator is the mean aggregation over a period, the lower the better.

- The overall, lateral and profiles potential gains indicators aim at measuring potential gains for each trajectory compared to an achievable wind corrected fuel consumption reference (5th percentile) in terms of overall consumption, lateral deviation and speed and altitude profiles. Both indicators are aggregated in (kg) by summing the positive values over period to obtain an overall potential.
- The wind deficit indicator is computed to measure wind impact by comparing observed and wind corrected consumptions. Similarly, the indicator is aggregated in (kg).
- The lateral and profiles structural effects indicators compare the wind corrected fuel consumption for two references. An achievable reference (5th percentile within flow), and an ideal reference (direct trajectories for lateral deviation, and best profiles (5th percentile observed over all flow in similar phase) for speed and altitude profiles).

3.3.7. Optimal Trajectory Indicator (KEO)

Vueling, with help of ENAIRE, has proposed a concept which is supported by Airlines for Europe (A4E). The proposed solution is to measure environmental performance via concept of Optimum Trajectory. Two proposed indicators are measuring fuel burn (3D) and CO_2, as (Figure 13):

- Optimum Trajectory (replacing GC distance) – which is including: actual environmental conditions (Wind/Temperature/Relief etc.) and actual aircraft capabilities (influence of weight), and excluding: any other constraints (RAD, airspace closures, Cumulonimbus clouds);
- Constrained Optimum Trajectory (equivalent of optimum available flight plan) - which is including: Optimum Trajectory plus and all known constraints (RAD, airspace closures, etc.), and excluding: Air Navigation charges.

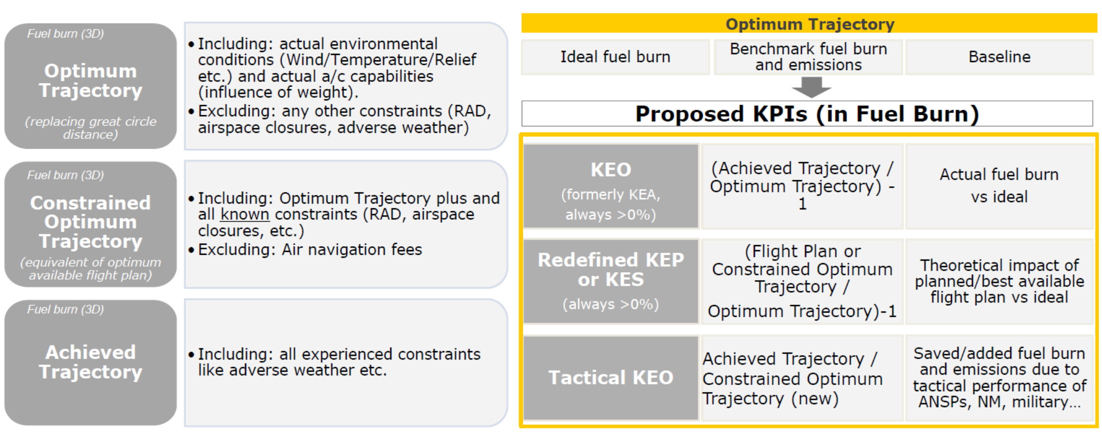

Figure 13. KEO (Source presentation given by Vueling)

3.3.8. The Six Reference Trajectories

The six (6) reference trajectories have been developed within the EASA/EUROCONTROL ATM/ANS Transparency Working Group to be able to compare fuel burn/CO_2 for each flight trajectory. Comparisons amongst trajectories could provide insights on the level of the inefficiencies, and potentially an indication of the (shared) stakeholder contribution.

The six trajectories are as follows (Figure 14):

- T1 – flight plan trajectory: based on the Filed Tactical Flight Model (FTFM) or Model 1[5] data, flight plan as filed by the operator;
- T2 – actual trajectory: based on CTFM or Model 3 data, actual trajectory flown;
- T3 - theoretical City Pair Optimal: trajectory with minimum CO_2 achievable;
- T4 - realistic City Pair Optimal: trajectory based on "realistic" trajectory (5th / 10th percentile). It may include impact of RAD restrictions, airspace users' choices and tactical ANSP interventions;
- T5 - dynamic Flight Optimal: trajectory using Shortest Constrained Route (SCR) at the time of flight. The SCR is a profile generated by the NM path generation tool and is the Integrated Initial Flight Plan Processing System (IFPS[6]) compliant route (available CDRs open and Route availability document (RAD) compliant);
- T6 - dynamic Flight Optimal+: this trajectory is the dynamic Flight Optimal, modified/optimised for meteorological conditions (e.g. wind).

T3 and T4 are considered 'fixed' reference trajectories (as they are static for each aircraft type/city pair combination) , whilst T5 and T6 are considered 'flexible' reference trajectories (as they take into account the actual circumstances and conditions at the time of flight).

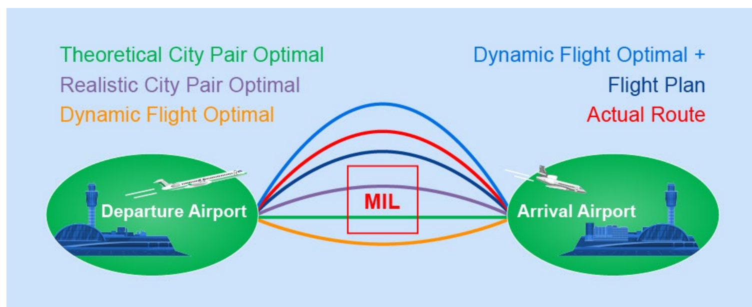

Figure 14. Six trajectories

Approach consists of two steps: (1) for each flight, define a set of trajectories: reference trajectory, Flight Plan and Actual Route; (2) for each trajectory, calculate fuel burn/CO_2. Results for these trajectories can be compared, in order to deduce (shared) stakeholder contribution. They can be expressed in various ways e.g., per city pair or ECAC wide, or expressed in terms of average/total CO_2 (savings/losses).

[5] The Filed Tactical Flight Model (FTFM) or Model 1 is a flight trajectory constructed (by the ETFMS system of NM) from the last filed flight plan.

[6] IFPS is a centralised service of the Network Manager Operations Centre (NMOC) designed to rationalise the reception, initial processing and distribution of flight plan data related to instrument flight rules (IFR) flight within the ICAO EUR Region known as the IFPS Zone (IFPZ). Flight plans and associated update messages may be submitted as individual messages. The IFPS shall check all messages received or changes thereto for: compliance with all format and data conventions; completeness and accuracy. The IFPS shall take action to ensure that the flight plan is acceptable to air traffic services

Some challenges with regards to the methodology need to be tackled, in order to further develop this, such as answering following questions:

- How to apply methodology on State/ANSP level?
- How to take into account different phases of flight: e.g., how to apply the methodology per sector or within TMA or en-route airspace?
- How to take into consideration additional weather impact?

3.3.9. Partitioned indicator of efficiency

The Partitioned Indicator of Efficiency (PIE) has been developed to construct a robust metric for efficiency analysis and to provide the opportunity to isolate inefficiency spillage between multiple areas. This indicator introduces an approach that can be used for combining the horizontal, vertical and time component of efficiency while considering user preferred baseline for comparison. It may use a static baseline (SPIE) or a dynamic baseline (DPIE)

This indicator that can be used to address both the currently measurable (e.g., HFE) and overlooked parts of the current ANS performance framework in the environment/efficiency KPA. Efficiency is calculated by decomposing the flight path and reconstructing an indicator to reflect the unbiased performance and the potential spillages between areas. The procedure involves the methodology for the calculation of the Network Partitioned Efficiency Index (NPEI), Local Partitioned Efficiency Indicator (LPEI), Absorbed Deviation (ADEV), Transferred Deviation (TDEV) and Given Deviation (GDEV). The analysed use-case describes the application of the indicators on operational flight data within the ECAC area.

The new PEI approach offers breaking down flight segments into approach and deviation components. Considering that an ideal optimal path to destination changes its direction at every new flight point, it must be calculated at every reported position of the aircraft. The two measures are always expressed in a reference system based in the flights origin with an x axis pointing towards the flights destination. This allows for calculation of the distance flown along the great circle and distance flown along the perpendicular line to the great circle starting from its instant optimal path to its actual flown path.

Another benefit of the new approach is that different parameters (indicators GDEV, ADEV and DEV) can be used to assess the transfer of deviation from one to another area. This can show whether an area had low efficiency due to absorbing deviation or due to adding deviation on top of what it already has received from the previous area.

4. Conclusion and recommendation

The main task of Pillar-1 WG was to demonstrate how Providers identify environmental inefficiencies under their responsibility, or where responsibility is shared, and how they measure environmental performance based upon certain criteria (existing or to be developed).

Whilst there is a range of metrics and indicators that could be used, **Pillar-1 prioritised emissions linked to CO_2 emissions**. This conclusion was supported by the results of questionnaire and interviews with the WG, although it must be noted that not all partners agreed to this approach. This decision was also in line with the efforts conducted by the European Commission (EC) to achieve the ambitious goal of climate neutrality by 2050 and calls for the EU to ensure a deep decarbonisation of the air transport sector through various measures such as the EU Aviation Green Deal and the Long-Term Aspirational Goal (LTAG) adopted by ICAO Member States in October 2022. By prioritising metrics linked to CO_2, the group ensured that the most scientifically reliable parameter that influences climate change is assessed and used to measure ANSP contribution to the Destination 2050 and the European industry's net zero emissions goal.

4.1. Conclusions

The number of solutions and measurements were discussed and assessed by the WG, including the ones currently in use, and the ones developed and presented by different Stakeholders, regardless of their **maturity** phase (in use, under development or concept phase). Each measure was mapped against HLP and phase of flight to provide visibility where the **gaps in environmental performance measurement** exist.

> *The current widely used environmental indicators are mainly time- or distance- based. Measures of fuel burn / CO_2 emissions are rarely available.*

Gap analysis performed to identify gaps in environmental performance measurement (from gate-to-gate perspective) identified many areas in both vertical and horizontal plane of flight trajectory where environmental performance is not measured. Figure 15 shows results of this exercise for the current widely accepted and used environmental PIs.

Overall, gap analysis showed that currently **widely used environmental indicators** are mainly focused on individual flight phases and **are either time- or distance-based PIs** (as operational proxies for flight efficiency). These measurements indeed could be subsequently converted into fuel burn (and ultimately to CO_2); however, analysis results show that current widely used **indicators rarely present environmental efficiency in terms of fuel burn or CO_2 emissions**. At the moment a good alternate to HFE-KEA is still unavailable. Lastly, at the moment, **there are no environmental PIs that provide gate-to-gate view** of environmental performance.

HLP		Network Performance (NP) How ANSPs manage traffic strategically across the airspace network (partly dependent on CNS infrastructure)				Operational Tactical (OT) How ANSPs manage traffic tactically - ATCO level (partly dependent on airspace design)				Airspace / CNS infrastructure How ANSPs have optimised airspace or decided to use CNS infrastructure (partly dependent on key traffic flows and geography)			
Dimension		H	V	3D	F/CO2	H	V	3D	F/CO2	H	V	3D	F/CO2
Phases	TAXI OUT					X				X			
	DEPARTURE / CLIMB		X								X		
	CRUISE	X	X			X							
	DESCENT / ARRIVAL		X		X	X				X	X		X
	TAXI IN												
	W/U - W/D			X	X								
	G2G												

Figure 15. Indicators assessed mapped to HLP and phase of flight

Several concepts and indicators presented by Stakeholders (either in the concept stage or in the development phase) have potential to fill in the gap in the current performance measurement. Once these become more mature, they should be re-assessed and tested in terms of usability through regular monitoring. In general, all indicators where the level of maturity does not yet suffice should be assessed once maturity improves, or they have moved beyond concept stage.

Detailed mapping results for both widely-used and indicators presented by different Stakeholders (in use, under development or concept only), are available in Annex IV – Widely used ENV indicators per HLP and phase of flight and Annex V – Stakeholders' ENV indicators per HLP and phase of flight, where additional information, such as exact cross reference to assessed indicators as well as their maturity level can be found.

Both currently widely used, as well as indicators presented by individual Stakeholders were also assessed based on their **suitability** to be used in the regulatory environment (R) and/or in operations/industry (O). This is very important to be clearly identified, as some operational indicators would fail to measure their intended purpose when moved into regulatory environment.

Summary of assessment results (for both currently widely used and presented to the WG), presenting indicator maturity, suitability, and mapping per HLP are presented in Table 3.

Table 3. Indicators maturity and suitability

Indicators		**HLP**			**Maturity level**	**Suitability**
No.	**Name**	**NP**	**OT**	**AI**		**Regulatory / Operations**
1	**KEA**	X	X		**In use**	R / O
1A	*KEA update*		X		**Under development**	R / O
2	**VFE ER**				**In use**	
2A	*VFE ER (PRU)*	X			**In use**	R / O
2B	*VFE ER (INO)*		X		**Under development**	R / O
2C	*VFE ER (BADA)*	X		X	**Under development**	R / O
3	**CCO / CDO (time)**	X		X	**In use**	R / O
3A	*CCO / CDO (CO2)*	X		X	**In use**	R / O
3B	*CCO / CDO (median)*			X	**In use**	R / O
3C	*CCO / CDO (share)*			X	**In use**	R

Indicators		HLP			Maturity level	Suitability
No.	Name	NP	OT	AI		Regulatory / Operations
3D	*CCO / CDO (Intermediate levels)*			X	In use	R / O
4	**ASMA**		X	X	In use	R / O
4A	*ASMA (CO_2 conversion)*		X	X	Under development	R / O
4B	*ASMA (PRU consultation)*		X	X	Under development	R / O
5	**TXOT**		X	X	In use	R / O
5A	*TXOT revision*		X	X	Under development	R / O
5B	*TXOT (CO2)*		X	X	Under development	R / O
6	**XFB**	X			In use	O
7	**NATS 3Di**	X			In use	R / O
7A	*3Di (CO_2)*	X			Under development	R / O
7B	*3Di (Borealis analysis)*	X			Under development	R / O
7C	*3Di (Single airspace)*	X			Concept	R / O
8	**MUAC**					
8A	MUAC HFE	X	X		In use	R / O
8B	MUAC VFE		X		In use	R / O
9	**ECTL TMA PIs**		X	X	In use	R / O
9A	*TMA PIs (CO_2)*		X	X	In use	R / O
9B	*TMA PIs (CDO)*			X	In use	R / O
9C	*TMA PIs (Intermediate levels)*			X	In use	R / O
10	**ENAIRE**					
10A	*ENAIRE Direct*		X		Under development	R / O
10B	*ENAIRE Holding monitoring*		X		Under development	O
11	**DSNA ACROPOLE**	X			Under development	O
12	***KEO***	X	X		Concept	R / O
13	**6-Trajectories**					
13A	*Theoretical city pair optimal*	X			Concept	N/A
13B	*Realistic city pair optimal*	X			Concept	N/A
13C	*Dynamic flight optimal*	X			Concept	N/A
13D	*Dynamic flight optimal +*	X			Concept	N/A
13E	*Ref vertical profile for 13A*				Concept	N/A
13F	*Definitions for 13C and 13D*				Concept	N/A
14	**TXIT**		X	X	Under development	R / O
14A	*TXIT update*		X	X	Under development	R / O
15	**Partitioned indicator**	X			Concept	N/A

None of the current environmental PIs fully satisfies all criteria set by the WG.

A single perfect indicator capturing the environmental performance fully under the control of an ANSP has not been found. Each of the assessed indicators has a specific ability to measure different contributions to the pool of ATM inefficiencies shared by all operational stakeholders. Furthermore, none of the current environmental PIs in use satisfies all criteria set by the WG. Results of PIs assessment show that **very limited number of environmental indicators (fully) satisfies ANSP needs**, especially considering ability to identify share of responsibilities. The WG also finds that current indicators still have a limited capability to improve operations, and that additional work on improvements is needed.

Potential improvements to currently widely used PIs (such as KEA, CCO/CDO, and XFB) as well as the ones in use by individual Stakeholders or under development (such as the new EUROCONTROL TMA indicators or 3Di score) should be further investigated. Moreover, interesting concepts are being developed that could help in the future for both performance measurement and improvement of operations. For example, indicators based on Machine Learning (e.g., Acropole indicators) or indicators based upon the real fuel burn data from airlines (e.g., KEO) deserve a high level of attention and should be further developed in particular by adapting the methodology to the ECAC dimension. Lastly, the new set of indicators that would include MET data and airline fuel burn is clearly missing and should be developed and tested.

The environmental gains can only be achieved if the partners are working together – and more importantly - take their responsibilities.

The WG also believes that unfortunately, due to the absence of research on environmental performance measurement, at the moment there is **no environmental indicator that is fully satisfying regulatory or operational needs**. The WG believes that the research on ATM/ANS environmental performance indicators is not yet complete.

European ANSP have a strong need for a commonly agreed new set of indicators in respect to both the European regulation and the new policy measures put in place in a view of decarbonisation of the air transport sector. With best measurements ultimately in place, the WG highlighted that at the end, most of the environmental gains can only be achieved if the partners are working together – and more importantly - take their responsibilities.

4.2. Recommendations

The proposed recommendations aim to help the ANSPs to improve their environmental disclosure and identifying areas where they can contribute to aviation industry strategic decarbonisation goals. Based on the review and assessment of the current and future indicators undertaken by the group, two sets of recommendations have been established: 1) a set of high-level "Strategic Recommendations" and 2) "Technical Recommendations" providing suggestions/proposals for improvement and future work.

4.2.1. Strategic recommendations

Recommendation	Key message
A set of indicators is needed to demonstrate the environmental performance of ANSPs.	It has been demonstrated that the environmental performance of ANSPs cannot be measured by only one single indicator. The Working Group members advise the use of a set of indicators depending on the area of inefficiency. As an example, an indicator designed to measure the efficiency of the overall network should not be applied to measure the efficiency of the airspace around an airport. Two tables provided (Annex IV and Annex V) map existing indicators to the phase of flight that will help to guide stakeholders to choose the relevant indicators to be used for their specific needs.
Engagement with other stakeholders is key to identify the fuel optimal trajectory.	It is important to engage with aircraft manufacturers and airspace users to better identify the fuel optimal trajectory to be used as a reference for measuring fuel burn or CO_2 emissions. For instance, while a metric considering great circle distance may still be applied in some local circumstances, "best performer" reference trajectories may also help to take into account interdependencies such as wind or airspace users' choices. However, the Working Group found that the best ideal reference could be the (updated) fuel-optimised trajectory as computed by the aircraft Flight Management System or fuel optimal trajectory based on data from advanced flight planning systems used by airlines' dispatchers which are provided by CFSPs. Access to operational data like actual take-off weight or fuel flow will help to improve fuel modelling computations and therefore the efficacy of ATM/ANS environmental indicators.
Alignment of the KEA and the ASMA indicators and their parameters is needed.	The revision of the KEA indicator should be aligned with the revision of ASMA indicator in consultation with stakeholders to accurately record inefficiencies in the area around airports. *Note: the development should be aligned with all relevant groups.
Interdependencies need to be better addressed, including military activities.	There is a need to better address the interdependencies between the different environmental impacts (for example noise, local air quality and non-CO_2 emissions) and with the other performance areas such as capacity, safety, and costs-efficiency. These other performance areas should be seen, all together including the environment, as enablers to drive environmental improvements of stakeholders involved, by finding the best synergies between all of them. Within the current geopolitical context, military activities are increasing and may have an impact on the performance of civil ANSPs (such as limited airspace or closure of airspaces due to safety or security reasons), and the impacts of those activities need to be better quantified.

4.2.2. Technical Recommendations

Recommendation	Key message
The possibility to decompose KEA into a "local" and a "network" component should be further investigated.	KEA on the European network level is already close to optimal and in some circumstances, flying the shortest distance could lead to additional fuel burn. However, the local component could be a useful measure/PI of the actual HFE/track extension through a local airspace. The possibility to decompose KEA into a local component (track extension) and the network contribution (ENTRY/EXIT interface) should be further investigated.
Future indicators should better consider the impact of weather (especially wind).	The fact that KEA is not considering the impact of wind strength and direction has also been identified as a weakness of the indicator. It should be noted that wind is an external factor for trajectory management and has a significant impact on fuel consumption and therefore should be better considered in flight efficiency measurement. More generally, any future indicator should consider MET data to better reflect the realities of flight efficiency.
Mapping of indicators to ATM/ANS environmental performance should continue.	There is both the need and the option for new indicators to fill existing gaps in the measurement of the environmental performance identified. Based on identified gaps in environmental performance measurement, new indicators should be developed to satisfy each HLP. Several concepts and indicators presented by Stakeholders in the course of this work (some of which are still in the development phase) have the potential to fill in the gaps identified. These new indicators (such as KEO or Acropole) should be tested and monitored to check their usability and usefulness. Ideally, mapping between the existing indicators and the HLP/phase of flights should be repeated regularly.
Existing TMA indicators require more work to meet requirements.	TMA performance indicators developed by EUROCONTROL (section 3.3.3) should be further developed, monitored and tested to reach a sufficient maturity to satisfy Operational-tactical and Airspace Infrastructure HLPs.
Excess Fuel Burn indicator should be further monitored and promoted.	The Network Manager Excess Fuel Burn indicator is a promising option for a Network level performance indicator, and it should be further monitored and tested to reach a level of maturity to satisfy the Network HLP.
Conversion of CCO/CDO indicators to fuel burn should be further monitored and promoted	The work that has been done by the European Continuous Climb Operations and Continuous Descent Operations (CCO/CDO) Task Force is fully supported by the Working Group members. However, the results of the conversion of these indicators into fuel burn should be further tested, monitored and assessed.
Non-CO_2 impacts are required to complete the picture about climate impact.	Non-CO_2 impacts were out of the scope of Pillar 1 report. However, Working Group members emphasize the need to address the climate impact of their operations including to need to find truly comprehensive climate indicators and to define a climate optimised trajectory.
KEO development should be completed at European level.	The KEO metric developed by ENAIRE in collaboration with the Vueling airline appears to be a promising indicator for the future. However, work needs to be completed to assess its implementation at European scale.
Airlines should share data with ANSPs allowing them to identify the fuel optimal trajectory.	In the future, optimal trajectories will be directly shared from the aircraft to the air traffic controller via Extended Projected Profile (EPP)/4D trajectory. Meanwhile, there is a need to improve ANSPs fuel modelling capabilities and proxies to give ANSPs the possibility to know what the fuel optimal trajectory is.

5. Acronyms

Acronym	Definition
A4E	Airlines for Europe
ADEV	Absorbed Deviation
AEM	Aviation Emission Model
AGL	Above Ground Level
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AOBT	Actual Off Block Time
ASMA	Arrival Sequencing and Metering Area
ATC	Air Traffic Control
ATM	Air Traffic Management
ATOT	Actual Take-Off Time
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation Services Organisation
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
CFSP	Computerised Flight Plan Service Providers
CH4	Methane
CNS	Communication, Navigation and Surveillance
CO_2	Carbon Dioxide
CTFM	Current Tactical Flight Model
DSNA	Direction des Services de la Navigation Aérienne
DPIE	Dynamic Partitioned Indicator of Efficiency
EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EEA	European Economic Area
ENAIRE	El gestor de Navegación Aérea de España
ETFMS	Enhanced Tactical Flow Management System
EU	European Union
FAB	Functional Airspace Block
FDR	Flight Data Recorder
FMS	Flight Management System
FIR	Flight Information Region
FTFM	Filed Tactical Flight Model
GC	Great Circle
GCD	Great Circle Distance
GDEV	Given Deviation
GHG	Green House Gasses
HFE	Horizontal Flight Efficiency
IFR	Instrument Flight Rules
IFPS	Integrated Initial Flight Plan Processing System
IFPZ	IFPS Zone
KPI	Key Performance Indicator
LPEI	Local Partitioned Efficiency Indicator

Acronym	Definition
LT	Landing Time
HLP	High Level Principles
NATS	UK National Air Trafic Services
NM	Network Manager
NMOC	Network Manager Operations Centre
NPEI	Network Partitioned Efficiency Index
MUAC	Maastricht Upper Area Control Centre
O_3	Ozone
PI	Performance Indicator
PIE	Partitioned Indicator of Efficiency
PRC	Performance Review Commission
RAD	Route Availability Document
REDES	Route Efficiency in approaching DEStination
RESTR	Route Efficiency in Straightness of Trajectory
RP4	Reference Period 4
SCR	Shortest Constrained Route
SES	Single European Sky
SESAR	Single European Sky ATM Research
SPIE	Static Partitioned Indicator of Efficiency
TDEV	Transferred Deviation
TMA	Terminal Manoeuvring Area
ToC	Top of Climb
ToD	Top of Descent
ToR	Terms of Reference
TXIT	Taxi-In Time
TXOT	Taxi-Out Time
VFE	Vertical Flight Efficiency
WP	Work Package
WG	Working Group
XFB	Excess Fuel Burn

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Annex I - Work Group Members

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BOREALIS	Francois Huet	**EUROCONTROL**	David Brain
BULATSA	Marin Petrov	**EUROCONTROL**	Eric Perrin
CANSO	Eduardo Garcia	**EUROCONTROL**	Gerard Boydell
CANSO	Johnny Pring	**EUROCONTROL**	Hamid Kadour
CROCONTROL	Amela Jericevic	**EUROCONTROL**	Ilona Sitova
CROCONTROL	Tomislav Mihetec	**EUROCONTROL**	Karim Zeghal
DFS	Fabio Ramos	**EUROCONTROL**	Laurent Tabernier
DFS	Gregor Thamm	**EUROCONTROL**	Marylin Bastin
DFS	Osman Saafan	**EUROCONTROL**	Nicolas De Brabanter
DSNA	Alain BOURGIN	**EUROCONTROL**	Pascal Hop
DSNA	Bertina Ho-Mock-Qai	**EUROCONTROL**	Pierre-Louis Dugenet
DSNA	Sophie Baranes	**EUROCONTROL**	Philippe Merlo
EANS	Jaan Tamm	**EUROCONTROL**	Dr Rainer Koelle
EASA	Dietmar Bloemen	**EUROCONTROL**	Robin Deransy
EASA	Emanuela Innocente	**EUROCONTROL**	Sam Julienne Peeters
EASA	Fabio Grasso	**EUROCONTROL**	Stefano Mancini
EASA	Kai Bauer	**EUROCONTROL**	Dr Tamara Pejovic
EASA	Luc Tytgat	**FABEC**	Jean-Michel Edard
EASA	Mara Dame	**HUNGAROCONTROL**	Peter Szekacs
EASA	Rowan Powel (Observer)	**IAA**	Declan Mangan
EASA	Vincent Taverniers	**IAA**	Joe Ryan
ENAIRE	Alicia Alcubilla	**LFV**	Patrik Bergviken
ENAIRE	Gema Haro	**LFV**	Olivier Petit
ENAIRE	Jose Antonio Aznar	**LVNL**	Emil Schot
ENAIRE	Patricia Ruiz Martino	**LVNL**	Leo HOOGERBRUGGE
ENAV	Giuseppe Gangemi	**NATS**	Andrew Burke
ENAV	Giuseppe Romano	**NATS**	Dr Jarlath Molloy
ANALux	Yves Becker	**PANSA**	Grzegorz Zacharczuk
		PANSA	Krzysztof Jemiolo
		PANSA	Tomasz Gromski
		SESAR JU	Philippe Lenne
		SKEYES	Alexander Vanwelsenaere
		SKEYES	Francine Carron
		SKEYES	Bertrand Gallez
		SKYGUIDE	Thierry Bregou
		SKYGUIDE	Valery Michon

Annex II – List of Questions

Q1a: What methodologies/tools do you use to measure ENV performance?

Q1b: What ATM-related environmental impact assessments have you undertaken?

Q2: What can an ANSP do to reduce the environmental impacts of their operations?

Q3a- What metrics do you use to measure ENV performance?

Q3b: What forms the basis of these metrics e.g. distance, time, delays, statistical from a baseline, others….)?

Q6a: Have you tried to quantify the ANS contribution to your ANSP environmental performance and if so, what was the outcome?

Q6b- What would be the appropriate scope / phase of flight measuring ANS performance (e.g. Gate to Gate, Wheels up/down, segments of flight…)

Q10: What factors or principles should be considered when developing / agreeing on the use of metrics? (e.g. relevance, applicability, data availability etc.)?

Q11: In addition to CO2 (which has been defined as our main priority for pillar 1), what other ENV metrics need also to be considered?

Note: Question numbering does not follow sequence due to questionnaire development and sorting during the time.

Annex III – Questionnaire Results

The questionnaire was sent to the members of the WG on the 27th November 2020. A more focused questionnaire update was shared with the WG Members in January 2021, which also included an additional three questions that were proposed by DSNA. Between these two questionnaire versions, 19 responses (representing 16 ANSP 1 FAB and 2 Alliances) were received. Hence it can be stated that the results represent view of the majority of the WG.

Q1a: What methodologies/tools do you use to measure ENV performance?

The responses to this question did not really show a clear picture. Out of 25 institutions/ANSPs asked ten did not come up with a response. Six use their own bespoke systems/methods and the rest is totally divers. It is difficult if not impossible to see any trend here other than a lot of own solutions and standards.

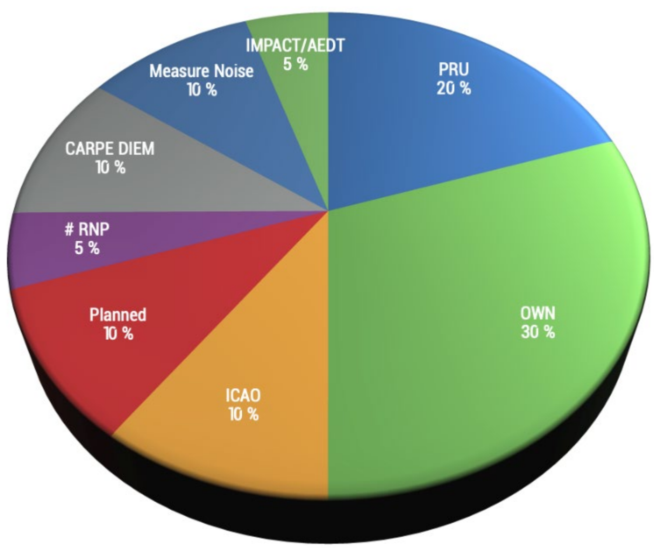

Figure 16. Q1a responses

Q1b: What ATM-related environmental impact assessment have you undertaken?

Eleven responses are missing on this question, majority of responses indicate that customized or bespoke solutions are used. Some ANSPs use the PRU documentation / guidance for their internal assessments (four). All other responses are quite different and some are not fully clear or kept on a very generic level.

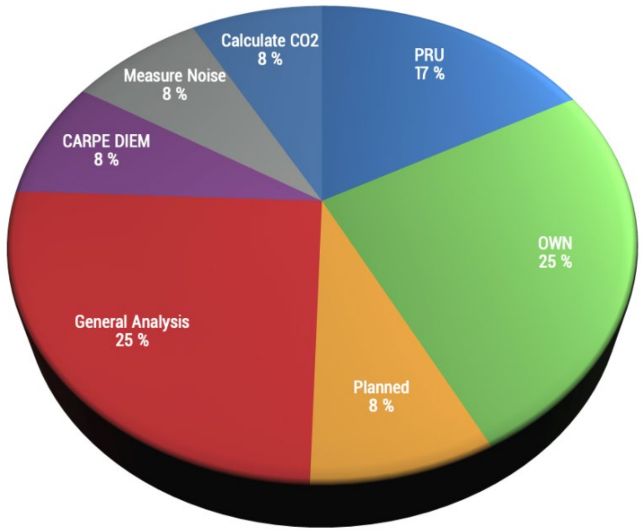

Figure 17. Q1b responses

Q2: What can an ANSP do to reduce the environmental impacts of their operations?

While Q1a and Q1b resulted in no clear picture of methods and assessment options – it even more showed the opposite – Q2 gave a different picture. Still there are lots of options for ANSPs mentioned just once, some others have been listed multiple times.

Improving the vertical and horizontal efficiency of flights was top listed followed by FRA which is basically tightly connected.

CCO/CDO enabled by ANSPs was mentioned six times and the options to improve SIDs and/or procedure design in general – also with PBN support – 5 times. This procedure option showed another interesting aspect as it was proposed to reduce noise by flying around sensitive areas on one side and making these procedures shorter to reduce gas emissions on the other side. No surprise here as this conflict can be observed again and again.

Next, training of ATCOs together with best possible tools on hand was also listed as a measure of reducing ANSP’s impact of their operations.

Finally improving civil-military cooperation and increase in capacity were listed.

It is interesting though that options like FRA, CCO/CDO and others which are very well know now in the aviation industry are not listed in all answers.

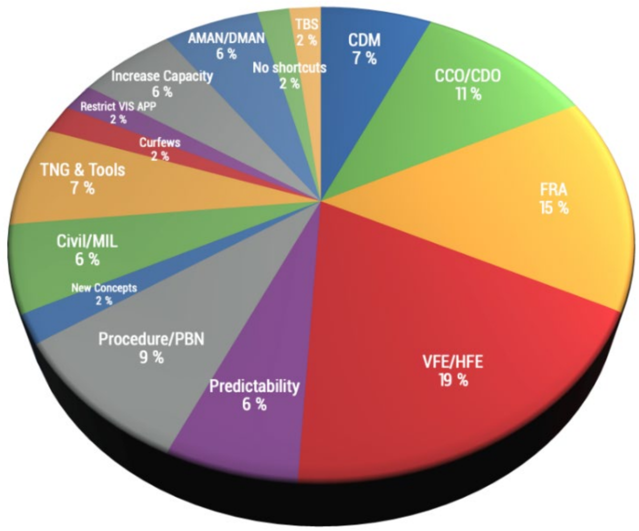

Figure 18. Q2 responses

Q3a- What metrics do you use to measure ENV performance?

Q3b: What forms the basis of these metrics e.g. distance, time, delays, statistical from a baseline, others….)?

Question three was originally divided into two parts but as the answers were partially combined the summary is as well.

Again here the PRU standards as HFE/VFE/KEA were listed quite frequently (seven times out of 15 responses in total). Also metrics and basis coming with CCO/CDO is used repeatedly. The ways of counting are site specific – either percentage of flights or total.

Additional distance flown was listed four times – partially with various wordings. From ASMA to track length to distance.

Quite interesting here is that the number of completed RNP AR approaches has been mentioned twice and also the number of noise complaints is taken as a metrics.

All together again a quite divers response even though as VFE/HFE/KEA was mentioned by 28% of units asked.

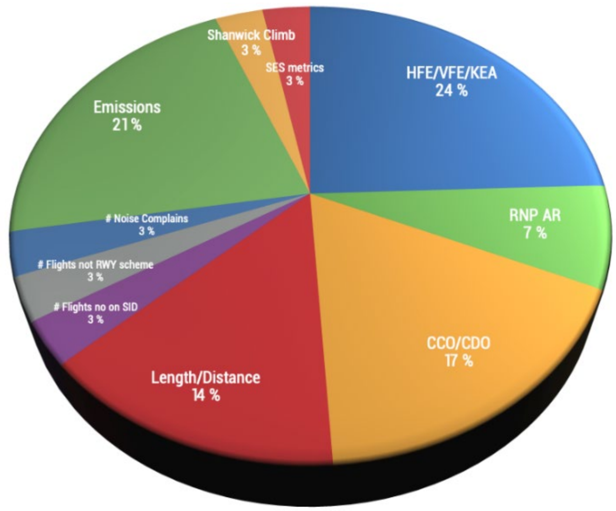

Figure 19. Q5 responses

Q6a: Have you tried to quantify the ANS contribution to your ANSP environmental performance and if so, what was the outcome?

Much clearer picture here. There have been some attempts to quantify the ANSP impact but with little or no success. Only one respond showed a clear YES with nine clear NOs. One respond stated that this should happen in future.

It is not so difficult to say that there is almost no information about how big or small the ANSP contribution is.

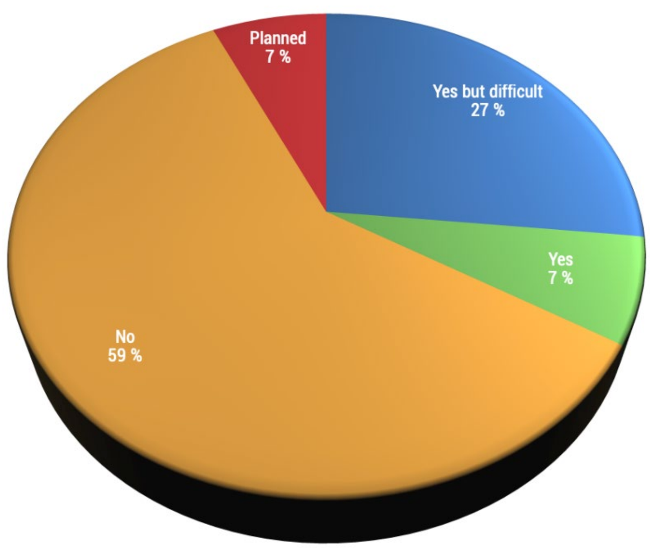

Figure 20. Q6a responses

Q6b: What would be the appropriate scope / phase of flight measuring ANS performance

This part of the questions resulted in two clearly identified scope definitions. Nine times the Gate To Gate version was mentioned and in addition dedicated segments (based on local setup and requirements).

Respecting the number of answers in total this can be considered a clear response.

Other responses referred to noise and assigned vertical limits, again the VFE/HFE combination and finally the possible negative impact on the emission side when respecting noise in the trajectory creation.

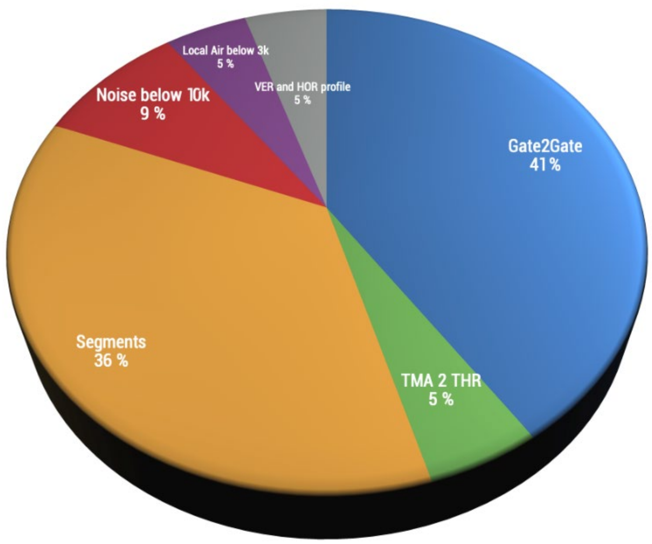

Figure 21. Q6b responses

Q10: What factors or principles should be considered when developing / agreeing on the use of metrics?

This one appears to be the easiest to answer. 11 out of 15 respondents asked for Usefulness / Quality / Relevance when agreeing on metrics. This is a clear statement.

The second most mentioned criteria addresses obviously a very practical topic. Access to data. What is the use of best metrics when data are not or only very difficult to get.

Other criteria mentioned were the option to see whether or not the ANSP is directly responsible, if fuel burn is indicated, if the metrics is understandable, comparable, if weather is considered and if an ADS-B crosscheck would be feasible.

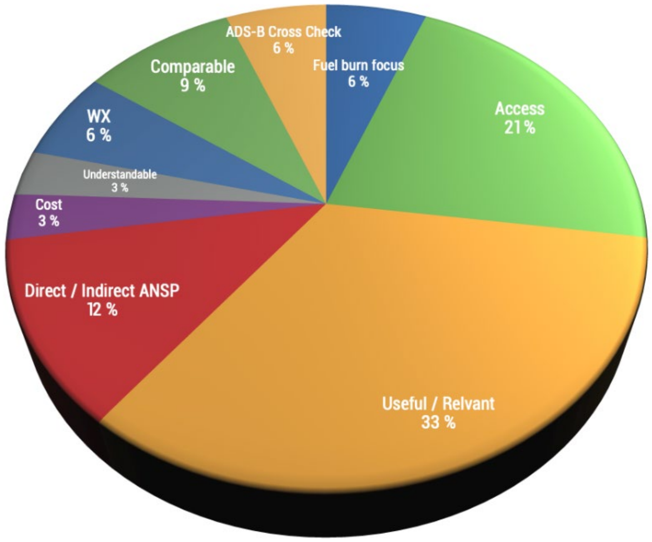

Figure 22. Q10 responses

Q11: In addition to CO2, what other ENV metrics need also to be considered?

The last question finally got as a result of its content a wide variety of answers. Three proposals were mentioned multiple times:

- Noise in general – four times
- Non CO2 emissions – three times
- Implementation of RNP approaches – twice

Other ideas mentioned:

- Re-work of KEA
- A Distance-to-Go metrics
- Speed aspects
- Availability of ENV education
- Re-work of KEA indicator
- Tactical performance
- General impact on climate change
- Green energy
- Taxi times
- Multiple options for airspace design
- Express fuel used in miles

Annex IV – Widely used ENV indicators per HLP and phase of flight

HLP	Network Performance (NP)				Operational Tactical (OT)				Airspace / CNS infrastructure			
	How ANSPs manage traffic strategically across the airspace network (partly dependent on CNS infrastructure)				How ANSPs manage traffic tactically (ATCO level) (partly dependent on airspace design)				How ANSPs use CNS infrastructure -ground/space based (partly dependent on key traffic flows and geography)			
Dimension	H	V	3D	Fuel/CO2	H	V	3D	Fuel/CO2	H	V	3D	Fuel/CO2
Phases												
TAXI OUT					5				5			
DEPARTURE / CLIMB		3								3		
CRUISE	1	2A			1							
DESCENT / ARRIVAL		3		3A	4				4	3, 3B, 3C		3A, 3B
TAXI IN												
W/U - W/D			6	6								
G2G												

Indicators		HLP			Maturity Level
No.	Name	NP	OT	AI	
1	**KEA**	X	X		In use
2	**VFE ER**				In use
2A	*VFE ER (PRU)*	X			In use
3	**CCO / CDO (time)**	X		X	In use
3A	*CCO / CDO (CO2)*	X		X	In use
3B	*CCO / CDO (median)*			X	In use
3C	*CCO / CDO (share)*			X	In use
4	**ASMA**		X	X	In use
5	**TXOT**		X	X	In use
6	**XFB**	X			In use

Annex V – Stakeholders' ENV indicators per HLP and phase of flight

HLP	Network Performance (NP) How ANSPs manage traffic strategically across the airspace network (partly dependent on CNS infrastructure)				Operational Tactical (OT) How ANSPs manage traffic tactically (ATCO level) (partly dependent on airspace design)				Airspace / CNS infrastructure How ANSPs use CNS infrastructure -ground/space based (partly dependent on key traffic flows and geography)			
Dimension	H	V	3D	Fuel/CO2	H	V	3D	Fuel/CO2	H	V	3D	Fuel/CO2
Phases: TAXI OUT					5A			5B	5A			5B
DEPARTURE / CLIMB				7A						3D		
CRUISE	1A, 8A, 15	2B, 2C		2C, 7A	1A, 8A, 10A, 15	2B, 2C				2C		2C
DESCENT / ARRIVAL				7A	4B, 9, 10B	8B, 9		4A, 9A	9, 4B	3D, 9, 9B, 9C		4A, 9A
TAXI IN					14, 14A				14, 14A			
W/U - W/D			7	7A, 12				12				
G2G			12	12								

Indicators		**HLP**			**Maturity level**
No.	**Name**	**NP**	**OT**	**AI**	
1	**KEA**	X	X		In use
1A	*KEA update*	X	X		Under development
2	**VFE ER**				In use
2B	*VFE ER (INO)*	X	X		Under development
2C	*VFE ER (BADA)*	X	X	X	Under development
3	**CCO / CDO**	X		X	In use
3D	*Intermediate levels*			X	Under development
4	**ASMA**		X	X	In use
4A	*CO2 conversion*		X	X	Under development
4B	*PRU consultation*		X	X	Under development
5	**TXOT**		X	X	In use
5A	*TXOT revision*		X	X	Under development
5B	*CO2 conversion*		X	X	Under development
7	**NATS 3Di**	X			In use
7A	*Conversion to CO2*	X			Under development
7B	*Borealis analysis (score)*	X			Under development
7C	*Single airspace application*	X			Under development
8	**MUAC**				In use
8A	*HFE*	X	X		In use
8B	*VFE*		X		In use
9	**TMA indicators**		X	X	In use
9A	*TMA PIs (CO2)*		X	X	Under development
9B	*TMA PIs (CDO)*			X	Under development
9C	*TMA PIs (Intermediate levels)*			X	Under development
10	**ENAIRE**		X		Under development
10A	*ENAIRE Direct*		X		Under development
10B	*ENAIRE Holding monitoring*		X		Under development
11	**DSNA ACROPOLE**	X			Under development
12	***KEO***	X	X		Concept
13	**6-Trajectories**				
13A	*Theoretical city pair optimal*	X			Concept
13B	*Realistic city pair optimal*	X			Concept
13C	*Dynamic flight optimal*	X			Concept
13D	*Dynamic flight optimal +*	X			Concept
13E	*Ref vertical profile for 14A*				Concept
13F	*Definitions for 14C and 14D*				Concept
14	**TXIT**		X	X	Under development
14A	*TXIT update*		X	X	Under development
15	**Partitioned indicator**	X	X		Concept

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