ALIGHT
SUSTAINABLE AVIATION

Report on field performance monitoring

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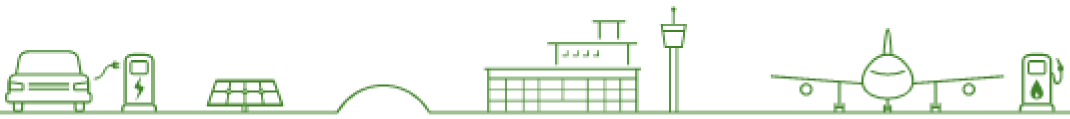
Content



1 Executive summary

This report presents the findings from field-based monitoring activities conducted under the ALIGHT project, a Horizon 2020 initiative aimed at accelerating the adoption of Sustainable Aviation Fuel (SAF) and smart energy systems at European airports. The focus of this deliverable (D3.5) is on evaluating the real-world performance of SAF at Copenhagen Airport (CPH) through a combination of short-term measurement campaigns, advanced fuel monitoring, and simulation modeling.

Key Findings

Short-Term SAF Measurement Campaign (2023):

High-resolution emissions data collected using DLR’s mobile laboratory demonstrated a consistent reduction in both total and non-volatile particle emissions—averaging 30%—when using a 34% HEFA-SPK SAF blend compared to conventional Jet A-1 fuel. NO_x emissions remained unchanged, confirming comparable combustion conditions.

FuelTrack CPH Campaign (2025):

Over 55 fuel samples and 344 aircraft plume measurements were collected, linking fuel properties to emission behavior. Significant variability in fuel composition was observed, even within ASTM D1655 limits. Lower aromatic and sulfur content correlated with reduced particle emissions, highlighting the importance of fuel quality in emission mitigation.

LASPORT Simulation Modeling:

Predictive modeling of future SAF blending scenarios (aligned with ReFuelEU Aviation targets) showed substantial reductions in SO_x and ultrafine particle emissions—up to 50% by 2050 with a 50% SAF blend. However, NO_x emissions remained unaffected, underscoring the need for complementary mitigation strategies.

Recommendations

Near-Term Actions:

- Implement strategic fuel sampling at the airport’s fuel farm export point to improve transparency and support EU MRV systems.
- Consider setting maximum aromatic content thresholds for uplifted fuel to promote cleaner conventional jet fuel use.
- Continue exploring the cost-benefit relation between targeting SAF deployment during periods of elevated air quality concern vis-à-vis the required segregated fuel infrastructure.

Long-Term Outlook:

- SAF adoption must go beyond minimum regulatory requirements to achieve meaningful environmental benefits.
- Continued monitoring and data integration are essential to refine emission models and inform policy.
- Airports should position themselves as innovation hubs, leveraging data-driven insights to guide sustainable aviation practices.

This report contributes to the development of a “Bold Vision for Airports in 2050,” offering actionable insights for stakeholders across the aviation ecosystem—from airport operators and airlines to policymakers and environmental researchers.

2 Introduction

2.1 Background

2.1.1 **The ALIGHT Project**

The ALIGHT project, “A Lighthouse for the Introduction of Sustainable Aviation Solutions for the Future” is a Horizon 2020 initiative funded by the European Union. The project brings together a consortium of 17 partners from 10 European countries, representing a diverse cross-section of the aviation ecosystem. These include major airports, technology providers, research institutions, and, since 2023, the aircraft manufacturer Airbus, whose participation adds valuable industry insight from the OEM perspective.

The strength of the consortium lies in its multidisciplinary composition and shared commitment to accelerating the aviation sector’s transition toward climate neutrality. Each partner contributes specialized expertise, enabling the project to address both the technical and systemic challenges associated with decarbonizing airport operations.

ALIGHT is structured around two core focus areas: (1) the supply, implementation, integration, and smart use of Sustainable Aviation Fuel (SAF), and (2) the development and deployment of a Smart Energy System. Together, these pillars support the overarching goal of transforming airports into innovation hubs for sustainable aviation.

2.1.2 **Primary project partners in D3.5 tasks**

This deliverable has been jointly developed by partners within the ALIGHT consortium, each contributing domain-specific expertise to ensure a comprehensive and scientifically robust assessment of Sustainable Aviation Fuel (SAF) performance under real-world conditions.

Copenhagen Airport (CPH) served as the lead beneficiary and host site for all field activities. As the primary implementation partner, CPH coordinated logistics, facilitated access to airside infrastructure, and ensured compliance with safety and operational protocols. The airport also provided critical data on aircraft movements, fuel logistics, and local air quality monitoring.

DLR – German Aerospace Center led the scientific design and execution of the measurement campaigns. DLR deployed its mobile laboratory to Copenhagen Airport, enabling high-resolution monitoring of aircraft exhaust plumes. The institute also conducted fuel sample analyses and contributed to the interpretation of emission data, drawing on its extensive experience in combustion technology and environmental diagnostics.

SAS, Scandinavian Airlines System supported the campaign through operational coordination and aircraft access. SAS facilitated fuel sampling from its fleet during overnight stays and provided aircraft performance data essential for correlating emissions with operational parameters.

BKL (Brændstoflageret Københavns Lufthavn I/S) and **DRS (Danish Refuelling Service I/S)** contributed to the fuel sampling and storage process, ensuring traceability and integrity of samples collected from the airport's fueling infrastructure. Their role was critical in linking fuel properties to observed emission patterns.

Together, these partners enabled the successful implementation of both the short-term and advanced fuel monitoring campaigns described in this report. Their collaboration exemplifies the interdisciplinary approach required to evaluate SAF deployment in complex airport environments and to generate actionable insights for future policy and operational strategies.

2.1.3 SAF and local air quality in airport

Sustainable Aviation Fuel (SAF) represents a critical pathway for decarbonizing the aviation sector and mitigating its environmental impact. Produced from renewable or waste-derived feedstocks, SAF is designed to be a drop-in replacement for conventional Jet A-1 fuel, compatible with existing aircraft engines and fueling infrastructure. Its adoption is central to achieving the EU's climate targets and reducing the carbon footprint of air travel.

Beyond its well-documented climate benefits, SAF also offers potential improvements in local air quality, particularly in airport environments where emissions from aircraft engines are released close to ground level. Studies have shown that SAF blends can reduce emissions of particulate matter (PM), sulfur oxides (SO_x), and unburned hydrocarbons, all of which contribute to air pollution and pose health risks to airport workers and nearby communities.

The relevance of SAF to airport air quality is especially pronounced during ground operations such as taxiing, idling, and takeoff, where exhaust plumes interact directly with the local atmosphere. These phases are characterized by lower engine thrust settings, which can influence the formation of non-volatile particles and gaseous pollutants. By lowering the aromatic and sulfur content of aviation fuel, SAF has the potential to reduce the formation of soot and volatile particles, thereby improving air quality in the airport vicinity.

Real-world validation of these benefits is essential. While laboratory and testbench studies provide controlled insights, they often fail to capture the complexity of operational conditions, fuel variability, and meteorological influences. Field measurement campaigns, such as those conducted under the ALIGHT project, and described in this report, are therefore crucial for quantifying SAF's impact on air quality and informing future regulatory and operational strategies.

2.2 Aims and objectives

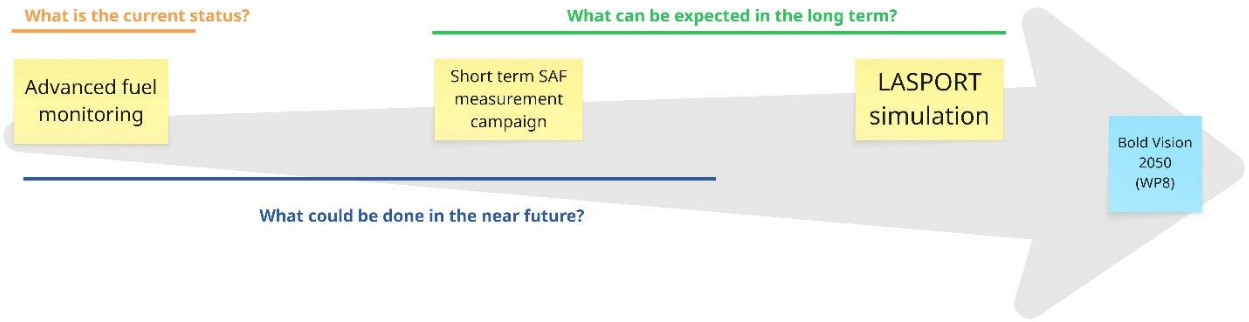
Task 3.3 and the corresponding report aim to provide a practical, demonstration-based insight into three overarching questions regarding aviation fuels and the use of SAF at airports in relation to aircraft emissions:

- What is the current status?
- What could be done in the near future?
- What can be expected in the long term?

To address these questions, three complementary activities were carried out:

1. **Comprehensive monitoring of the current fuel supply and utilization at Copenhagen Airport** - including sampling from both the fueling infrastructure and incoming flights - combined with detailed emissions measurements, to assess the current status and identify potential areas for improvement.
2. **A focused short-term SAF measurement campaign**, designed to demonstrate the impact of high blend-ratio SAF on aircraft emissions under fully operational airport conditions.
3. **Simulation studies conducted using the LASPORT software**, evaluating the anticipated impact of future SAF blending rates - aligned with the ReFuelEU Aviation mandate - on local air quality at Copenhagen Airport over the coming decades.

This report summarizes the key findings from all three activities. The results will also serve as a direct input to the development of the *Bold Vision for Airports in 2050*.



2.3 Reader's guide

Purpose

This report presents findings from field-based monitoring activities under the ALIGHT project, focusing on Sustainable Aviation Fuel (SAF) performance at Copenhagen Airport. It provides real-world data to support future policy, operational strategies, and the development of a "Bold Vision for Airports in 2050."

Intended Audience

- Airport operators and policy makers
- Environmental researchers
- Airlines and fuel suppliers
- EU aviation and climate stakeholders

Report Structure

1. **Executive Summary** – Key findings and recommendations
2. **Introduction** – Project context and SAF relevance
3. **Short term measurement Campaign**
4. **Advanced fuel monitoring Campaign: FuelTrack CPH**
5. **LASPORT Simulation** – Predictive modeling of SAF impacts
6. **Conclusions & Recommendations**
7. **References** – References, table of figure and table of tables

Use of the Report

- Inform SAF-related decisions and strategies
- Support regulatory and environmental assessments
- Guide future SAF deployment and monitoring efforts

3 Short term measurement campaign

This section provides an overview of the key findings from the SAF measurement campaign conducted at Copenhagen Airport in January 2023. Selected results were presented at the 2023 EASN Conference and the 2023 Inter Airport Europe.

A comprehensive analysis of the campaign has been submitted for in September 2025, under the title "*Operational Evaluation of Emission Impacts from Sustainable Aviation Fuel Blends via Engine Plume Measurements and Predictive Modelling at the Airport Scale*." At the time of this report's submission, the manuscript was under peer review.

3.1 Objective

The objective of the short-term measurement campaign was to generate high-resolution, real-world data on aircraft emissions during ground operations at Copenhagen Airport, with a particular focus on the influence of Sustainable Aviation Fuel (SAF) blends. This activity aimed to complement existing laboratory and testbench studies by capturing emissions under operational conditions, thereby improving the understanding of how SAF impacts local air quality.

Specifically, the campaign sought to:

- Quantify particulate and gaseous emissions from aircraft during taxiing and idle phases.
- Differentiate between total and non-volatile particle emissions to assess the contribution of soot and other combustion by-products.
- Establish baseline emission profiles for conventional Jet A-1 fuel and compare them with SAF blend scenarios.
- Evaluate the suitability of mobile laboratory instrumentation for field deployment in complex airport environments.
- Provide empirical data to support future modelling efforts and policy recommendations related to SAF implementation.

The campaign was designed to be temporally constrained but technically comprehensive, enabling a focused investigation of emission characteristics while minimizing disruption to airport operations. The insights gained from this activity serve as a critical input to the broader ALIGHT project goals of promoting sustainable aviation practices and improving environmental performance at European airports.

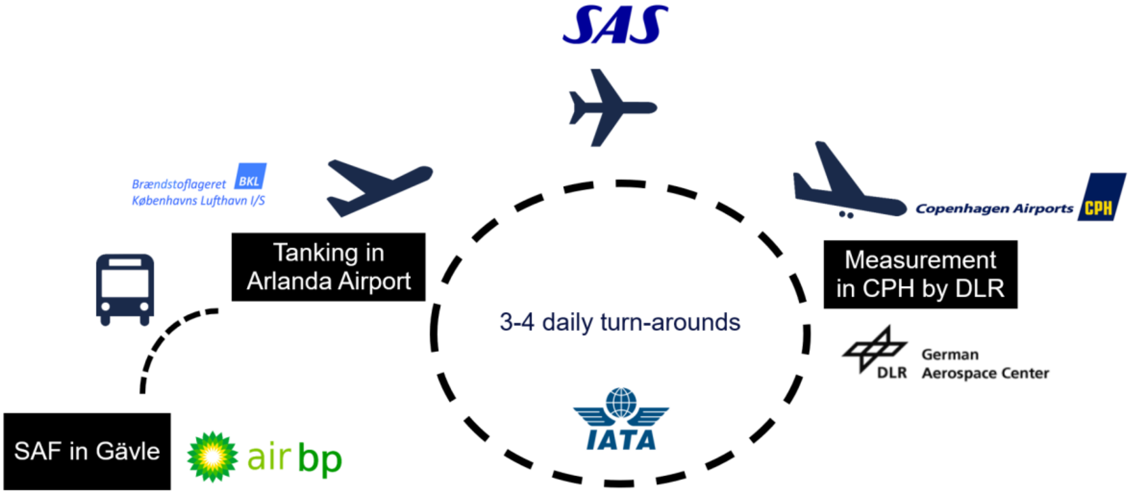


Figure 1: The schematic illustrates the key partners and the workflow of the measurement campaign

Figure 1 provides an overview of the procedure during the experimental phase with the SAF blend. The blend was not refueled in Copenhagen but instead supplied to the target aircraft at Arlanda airport in Sweden. The aircraft then operated three to four daily rotations between the two airports. Measurements with the DLR mobile laboratory were conducted in front of Pier B at Copenhagen Airport, where the aircraft was assigned a reserved gate. This setup allowed systematic monitoring of taxi-in and taxi-out events for each arrival and departure.

3.2 Methodology

The short-term measurement campaign was conducted using the DLR mobile laboratory, strategically deployed at Copenhagen Airport to capture aircraft exhaust plumes during ground operations. The methodology was designed to ensure high temporal and spatial resolution of emission data, with a particular focus on particulate matter and nitrogen oxides (NO_x), which are critical indicators of local air quality.

3.2.1 **Instrumentation and Measurement Scope**

Mobile Lab

The DLR mobile laboratory is based on a modified Volkswagen Crafter and was developed by the Chemical Analytics Department at the DLR Institute for Combustion Technology in Stuttgart, Germany. The loading space is equipped with a modular aluminum-frame structure holding custom-built instrument boxes. These boxes are fitted with vibration dampers to prevent measurement artifacts from pumps and other instruments. Highly sensitive devices such as the Engine Exhaust Particle Sizer (EEPS, TSI 3090) are additionally mounted on wire rope isolators. The infrastructure includes an independent IT system with LTE connectivity to the DLR network for 24/7 remote access, a roof-mounted air conditioning system (20–25 °C, supported by fans and temperature sensors), and a three-phase power supply. For stationary operation, a weather station (MWS 55V, Reinhardt) mounted 4 m above the vehicle records local meteorological parameters. Aerosol sampling is conducted via a PM10 sampling head (Derenda) mounted 3.5 m above ground on the vehicle roof. The sample is guided through a heated line (35 °C) to a manifold that distributes the conditioned aerosol to the connected instruments. Particle numbers, total and non-volatile as well as particle size distributions are measured with an Engine Exhaust Particle Sizer/EEPS (6–500 nm) and in parallel with a Differential Mobility Spectrometer/DMS 500 (5-1000nm) equipped with a catalytic stripper (CS10, Catalytic Instruments) to determine the non-volatile fraction. The DMS500 electrometer currents are reset daily under "zero air" conditions to avoid long-term drift. In parallel two Condensation Particle Counter /CPC systems were operated; one also equipped with a catalytic stripper to determine the total particle number in redundance.

Figure 2: View inside the equipped mobile lab – shown is an example of the mounted instruments

In addition, combustion gases are monitored: CO_2 and H_2O (LI-COR LI-7200) as well as NO and NO_2 (Eco Physics CLD64). All instruments connected to the same manifold record data continuously at 1 Hz.

A detailed list of all instruments operated is summed up in the following table.

Particles	Particle number concentration (total) of particles between 4 nm and 3 µm	TSI Condensation Particle Counter (CPC) 3752
	Particle number concentration (non-volatile) of particles between 2.5 nm and 3 µm	TSI Condensation Particle Counter (CPC) 3776
	Particle size distribution (total) 6-523 nm	TSI Engine Exhaust Particle Sizer (EEPS)
	Particle size distribution (non-volatile) 5-1000 nm	Cambustion DMS500
Gaseous species	CO_2	LICOR LI-7200RS
	H_2O	LICOR LI-7200RS
	NO	Ecophysics CLD64
	NO_2	Ecophysics CLD64
	NO_x	Ecophysics CLD64
Weather parameters	Wind direction	Reinhardt weather station MWS55
	Wind speed	Reinhardt weather station MWS55
	Humidity	Reinhardt weather station MWS55
	Temperature	Reinhardt weather station MWS55
	Dew point	Reinhardt weather station MWS55

3.2.2 **Measurement Strategy**

The measurement campaign was structured in two phases: a reference phase using conventional Jet A-1 fuel and a SAF blend phase, with the reference phase accounting for approximately one third of the total measurement time. The focus of the campaign was on a single aircraft, SE-ROU. SE-ROU is an Airbus A320-251N operated by Scandinavian Airlines System (SAS). Delivered in late 2019, it is equipped with two CFM LEAP-1A26 engines and configured for around 180 passengers. The aircraft is mainly used on short- and medium-haul routes within Scandinavia and across Europe. As illustrated in Figure 1, this aircraft typically performed three to four daily turnarounds between Copenhagen and Arlanda airports, where it was refueled with SAF. Measurements focused on aircraft taxiing phases, where emissions are released close to ground level and have the greatest potential to the local environment

Aircraft plumes were sampled during taxi-in and taxi-out operations, with the mobile lab positioned to intercept exhaust flow under prevailing wind conditions. The campaign was scheduled to coincide with periods of stable traffic and favorable meteorological conditions to maximize data quality and representativeness.

Data acquisition was synchronized across all instruments, and real-time monitoring allowed for immediate validation of plume detection. Background measurements were also taken to establish reference conditions and isolate aircraft-specific contributions.

3.2.3 Data Processing

Raw data were post-processed to derive emission indices per kilogram of fuel burned. The emission index method normalizes the measured particle number concentration to the corresponding CO_2 signal. Since CO_2 is a direct tracer of the combustion process, this approach enables conversion to mass-specific emissions (kg per kg of burned fuel). The methodology is described in detail in ICAO Annex 16 and was adapted here for ambient sampling conditions. By accounting for variations in the CO_2 signal, for example due to plume dilution under changing meteorological conditions, the method allows comparison of plumes that have been identified as valid. Detailed description of all steps can be found in the paper. As an overview this included:

- Identification of plumes that are caused by SE-ROU and isolated them from other plumes
- Correction for ambient dilution and meteorological variability.
- Differentiation between volatile and non-volatile particle fractions.
- Determination of the Emission index for the identified movement

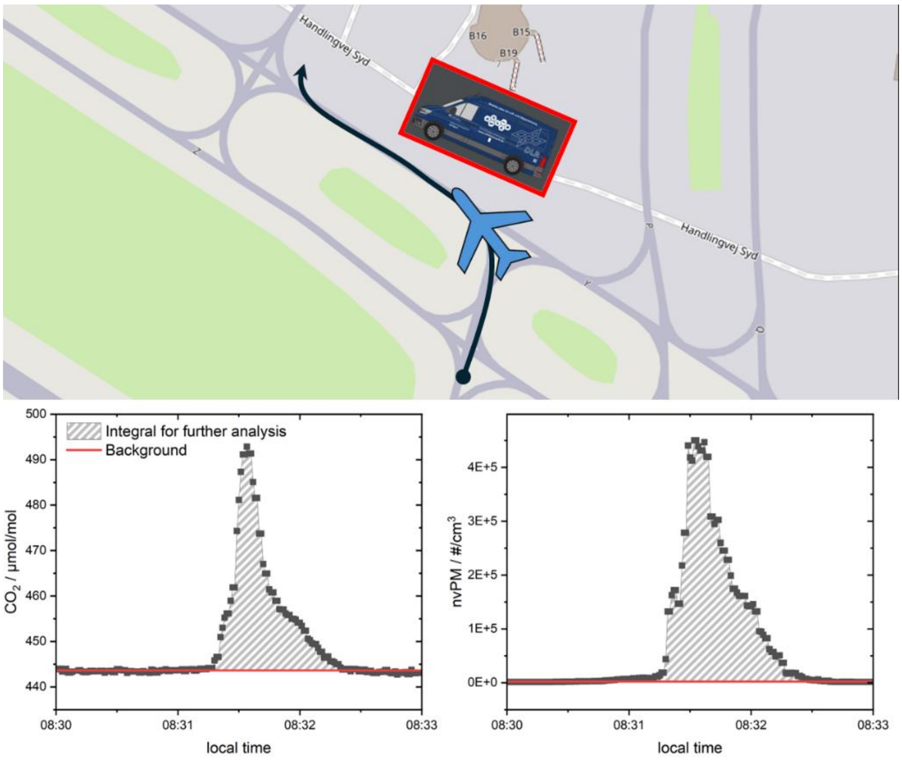


Figure 3: An example of an isolated non-volatile particle peak and the corresponding CO_2 signal is shown.

Figure 3. An example of an isolated non-volatile particle peak and the corresponding CO_2 signal is shown. By combining aircraft position data obtained from Flightradar with the measured aerosol and meteorological data, the observed signal can be unambiguously attributed to the target aircraft.

3.3 Results and discussion

3.3.1 Results

Optimal meteorological conditions, with prevailing winds between SE and W, were present during approximately three quarters of the campaign. During the reference phase, around 70% of the target aircraft's flight operations could be included in the analysis. In the SAF blend phase, about 60% of the detected peaks were clearly and validly attributed to the target aircraft. Figure 4 presents a statistical evaluation of particle number concentrations normalized to the CO_2 signal, including total particle number, non-volatile particle number, and measured NO_x values. Considering the values within the 25–75% interquartile range, the spread of particle number concentrations is noticeably larger for Jet A-1 compared to the SAF blend.

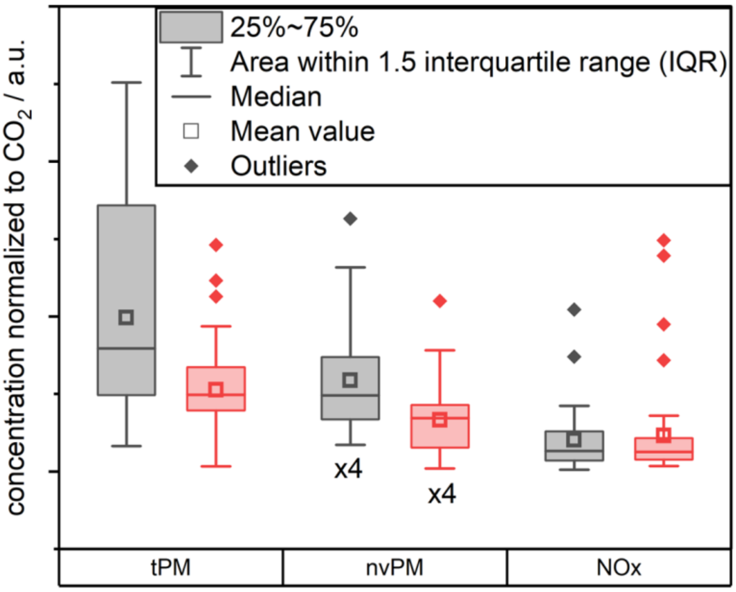


Figure 4: Statistical evaluation of the valid measurement values. Reference measurements with Jet A-1 are shown in gray, while SAF blend measurements are highlighted in red.

Figure 4: statistical evaluation of the valid measurement values. Reference measurements with Jet A-1 are shown in gray, while SAF blend measurements are highlighted in red. The statistical evaluation of the processed data also shows a clear reduction in both non-volatile particle number and total particle number when SAF is used. The reduction potential achieved through the use of the SAF blend can be quantified at an average of 30%, both for the non-volatile particle fraction and for the total particle number. These values are in line with other published numbers, like the study from Durdina et al (1). They found a reduction of non-volatile particle mass by about 35% and of about 20% of non-volatile particles numbers when using a similar SAF blend containing 30% HEFA-SPK at idle engine settings corresponding to a taxi movement of the aircraft. The identical NO_x values demonstrate that combustion conditions remained unchanged, confirming that the two fuels are directly comparable.

The short-term measurement campaign successfully captured a series of aircraft exhaust plumes during taxiing operations at Copenhagen Airport. Despite the limited duration of the campaign, the dataset includes high-resolution measurements of both particulate and gaseous emissions under real-world conditions.

Key findings include:

- **Particle Emissions:** Time-resolved particle size distributions revealed distinct plume signatures for both total and non-volatile particles.
- **Gaseous Emissions:** NO_x concentrations were consistently low across all measured plumes, reflecting the reduced engine thrust settings typical during taxiing. CO_2 and H_2O concentrations were used to validate plume detection and estimate fuel burn rates.
- **Meteorological Influence:** Wind speed and direction played a critical role in plume dispersion and detection efficiency. The campaign benefited from stable meteorological conditions, which enabled consistent sampling and minimized data distortion.
- **Instrument Performance:** The mobile laboratory demonstrated robust performance in the airport environment, with all instruments operating reliably throughout the campaign. The setup proved effective for capturing transient plume events and provided a strong foundation for subsequent data analysis.

3.3.2 Discussion

The resulting dataset provides a robust foundation for evaluating the environmental performance of aircraft operating at Copenhagen Airport and assessing the potential benefits of SAF deployment.

One of the key findings of this campaign, in addition to the demonstrated reduction potential, is the high variance observed in the reference measurements with Jet A-1 especially for the total particles, compared to the consistent results obtained with the SAF blend. This variability can be attributed to differences in Jet A-1 batches and compositions, including variations in sulphur levels.

Table 1: Differences between the fuels used during the campaign

	Conventional Reference	SAF blend
Composition	100 % Jet A-1	34% HEFA-SPK, 66% Jet A-1
Total aromatics % [vol/vol]	17.2 – 19.9	12.2
Hydrogen content % [kg/kg]	13.80 – 14.14 [1]	14.34 [2]
Sulphur % [kg/kg]	0.050 – 0.191	0.046
Specific energy [MJ/kg]	43.296 – 43.321	43.539

1 ASTM D3343 correlation; 2 ASTM D7171 measurement (1H NMR)

The parameters summarized in Table 1 highlight, among other aspects, the differences between the fuels. In particular, they show the high variability in aromatic and sulfur content of the Jet A-1 fuels available in Copenhagen and Arlanda during the measurement period.

4 Advanced fuel monitoring campaign: *FuelTrack CPH*

This section provides an overview of the key results and findings from the *FuelTrack CPH* campaign conducted at Copenhagen Airport in May 2025. As the campaign took place toward the end of the ALIGHT project and involved the analysis of a large and complex dataset, only selected results are included in this report. The full set of findings will be published through subsequent scientific publications.

4.1 Objective

Due to variations in crude oil sources and refining processes, conventional aviation fuels exhibit natural variability in physical properties—such as aromatic content, sulfur content, and density. These differences exist within the airport's fuel distribution system, among aircraft fueled at other airports, and within individual fuel uplifts. Although always within the ASTM D1655 specification limits, such variations have been shown to influence combustion characteristics and pollutant formation in jet engines.

With the increasing adoption of Sustainable Aviation Fuel (SAF) blends, this variability is expected to grow further, owing to the broader specification limits of neat SAF (ASTM D7566) and differences in feedstocks and production pathways. A detailed understanding of fuel property variation at the aircraft level is therefore essential for accurately assessing local emissions and the mitigation potential of SAF.

Currently, these exact fuel properties remain unknown at the aircraft level due to the complexity of airport fuel distribution systems and the absence of mandatory fuel quality monitoring per aircraft.

The FuelTrack CPH measurement campaign was designed to address this gap by directly linking detailed fuel property data from individual aircraft and the fueling infrastructure with high-resolution emission measurements during taxiing operations. This unique dataset aims to bridge the knowledge gap between controlled testbench measurements and real-world airport operations.

To achieve this, the high-level objectives were to:

- Monitor fuel properties at the aircraft level by collecting fuel samples from arriving and departing aircraft during turnaround at CPH
- Conduct chemical analyses of the collected fuel samples

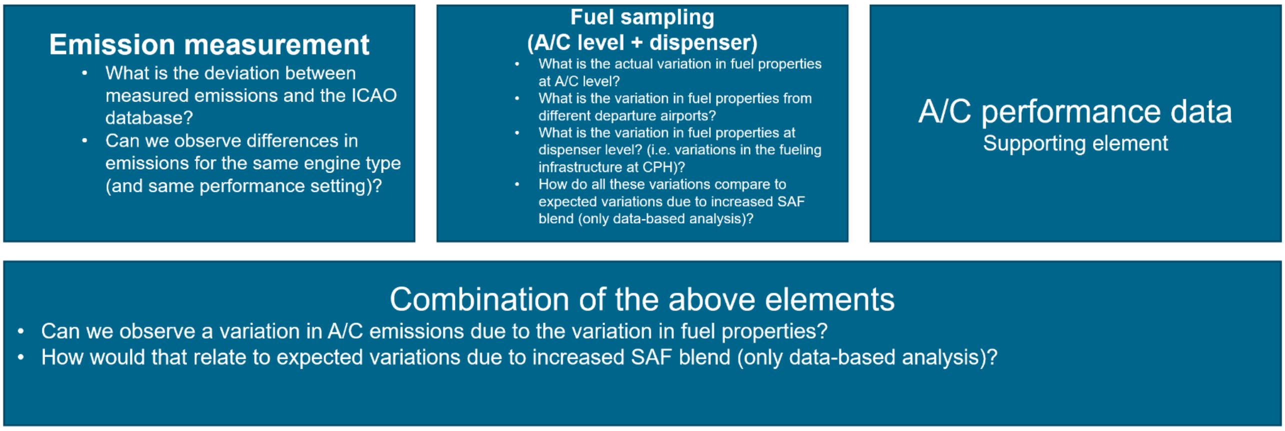
- Complement fuel data with detailed emission and local air quality measurements at locations exposed to aircraft exhaust during taxi
- Identify correlations between fuel properties and measured emissions
- Compare observed jet fuel variations with typical SAF blend properties and extrapolate potential impacts

The campaign's measurement framework consisted of three core, interlinked components:

- **Emission measurements** at strategic apron locations to capture aircraft exhaust plumes during taxi
- **Fuel sampling** from arriving aircraft and airport fueling infrastructure
- **Aircraft performance data** during taxi to determine engine thrust settings, fuel flow, and other relevant parameters

The aforementioned impact of fuel property variations on emissions can be analyzed by combining the three core components of the measurement campaign. Each component contributes a crucial piece of the overall picture, enabling a detailed assessment of how fuel characteristics influence aircraft emissions under real operational conditions.

The guiding questions behind each element of the campaign's measurement framework are summarized in the following structural diagram:



Emission measurement

- What is the deviation between measured emissions and the ICAO database?
- Can we observe differences in emissions for the same engine type (and same performance setting)?

Fuel sampling (A/C level + dispenser)

- What is the actual variation in fuel properties at A/C level?
- What is the variation in fuel properties from different departure airports?
- What is the variation in fuel properties at dispenser level? (i.e. variations in the fueling infrastructure at CPH)?
- How do all these variations compare to expected variations due to increased SAF blend (only data-based analysis)?

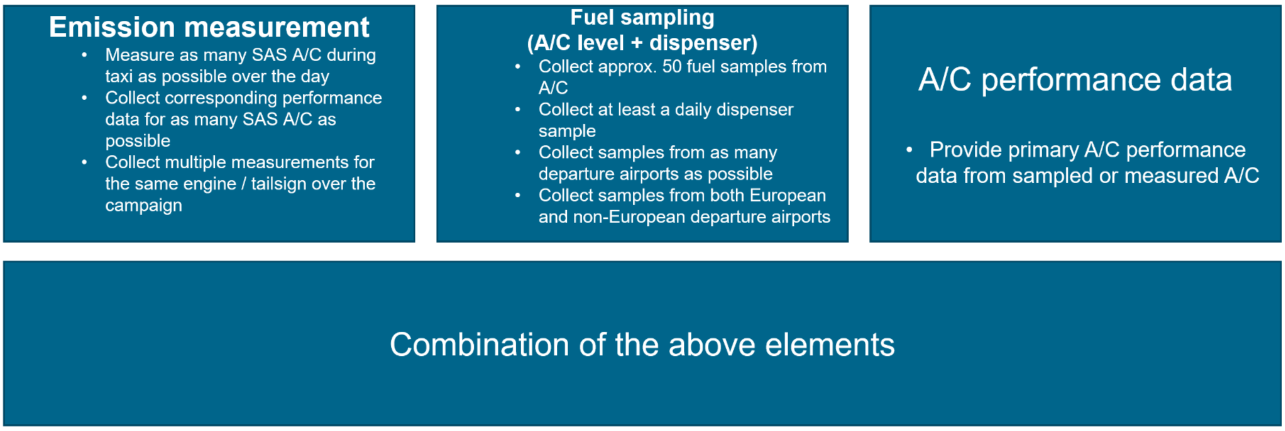
A/C performance data
Supporting element

Combination of the above elements

- Can we observe a variation in A/C emissions due to the variation in fuel properties?
- How would that relate to expected variations due to increased SAF blend (only data-based analysis)?

Figure 5: Diagram used for measurement framework. (1 of 2)

4.2 Methodology



Emission measurement

- Measure as many SAS A/C during taxi as possible over the day
- Collect corresponding performance data for as many SAS A/C as possible
- Collect multiple measurements for the same engine / tailsign over the campaign

Fuel sampling (A/C level + dispenser)

- Collect approx. 50 fuel samples from A/C
- Collect at least a daily dispenser sample
- Collect samples from as many departure airports as possible
- Collect samples from both European and non-European departure airports

A/C performance data

- Provide primary A/C performance data from sampled or measured A/C

Combination of the above elements

Figure 6: Diagram used for measurement framework. (2 of 2)

4.2.1 Planning of the advanced fuel monitoring campaign

4.2.1.1 Airport considerations

Advanced fuel monitoring activities at the aircraft level require close coordination with airport stakeholders, as well as adherence to strict safety, operational, and logistical requirements. This section outlines key factors that must be addressed when planning and executing fuel sampling and associated measurements at airports.

Role of the airport

The airport acts as both a facilitator and gatekeeper for fuel monitoring activities. Its role includes coordinating access to aircraft stands, ensuring safe and compliant operations in the airside environment, and liaising with relevant internal departments and third-party partners. The airport also provides crucial infrastructure support (e.g., access to storage and electricity) and enforces procedures that govern all airside activities.

Weather

Weather conditions significantly influence the planning and execution of airside fuel sampling. Rain or strong wind may limit the relevance of sampling positions or compromise the integrity of local air quality (LAQ) samples. Unusual temperature variations may also require additional cooling or heating of measurement devices, as extreme temperatures can lead to equipment malfunctions and reduce data quality. In cases of unanticipated weather conditions, measurements may need to be postponed, requiring flexibility in both sampling locations and campaign duration.

In preparation for the campaign, Copenhagen Airport (CPH) conducted a detailed mapping of historical wind directions, existing weather and LAQ data collection points, and the types and frequencies of data collected. During this process, it became evident that increasing the frequency of data collection—particularly for black carbon (BC) measurements—could introduce noise into the dataset. This insight was based on discussions with Force Technologies, who advised that higher sampling rates may compromise data integrity due to equipment limitations. As a result, CPH also assessed the trade-offs between improved temporal resolution and potential data distortion, ensuring that measurement strategies were optimized for both accuracy and reliability.

Safety

Safety is a primary concern during fuel sampling operations. All activities must comply with airport fire safety regulations, especially when handling flammable liquids like Jet A-1. Personnel must wear appropriate personal protective equipment (PPE) and receive prior safety briefings. Equipment brought airside requires inspection and approval to ensure it meets local airport safety and fire standards. Sampling must not interfere with aircraft turnaround processes, and all personnel must remain within designated safety zones.

Involved airport partners

Successful implementation of fuel sampling and monitoring depends on collaboration with several airport departments and stakeholders. For the long-term measurement campaign, CPH identified the following airport stakeholders.

- **Electricity & Facilities:** The instruments and equipment used during the campaign required a stable power supply. Temporary access to airside power outlets was arranged and verified in advance. Furthermore, it was assessed that some equipment benefitted from housing in existing facilities. The ILS shelter was identified as a suitable location for the installation of measurement equipment. However, this required the establishment of a new wall opening to accommodate the routing of hoses and cables.
- **Airport Security**: All external personnel (e.g., lab technicians) and equipment must be registered through the airport's security system and undergo relevant entry inspection. For CPH this included temporary ID issuance, escorted access and a special vehicle inspection.
- **Airport Safety**: European airports are responsible for maintaining strict safety procedures. In CPH this was formalized through two applications, a safety assessment and a location permit (covering location specific safety aspects). The safety concerns covered prior to commencing with measurements were; fire risks regarding pressurized containers for testing equipment and flammable liquids, fuel storage, height, interference with electronic equipment such as instrumental landing system (ILS) equipment, 24/7 vehicle access for security personnel.
- **Aircraft stand allocation team:** The airport's stand allocation and disposition team was consulted on a daily basis to identify suitable stands for sampling that avoid conflict with scheduled traffic and maintenance activities, such as construction using heavy machinery influencing LAQ. Stands relying on aircraft-roads near LAQ monitoring equipment were prioritized.
- **Fuel sampling and storage:** ALIGHT Partner SAS (local maintenance team) and into-plane service providers supported the fuel sampling process. This involved coordination with refueling schedules. The fuel samples were stored at the airport fuel farm in coordination with the ALIGHT partner BKL.

This coordination was essential to ensure that sampling could occur without disrupting airport operations, while maintaining the integrity and safety of all involved parties. Early engagement with airport partners, formalization of procedures, and alignment with turnaround schedules were critical for the success of the advanced fuel monitoring campaigns.

4.2.1.2 Airline considerations

By participating in the FuelTrack campaign, SAS was able to contribute with a variety of aircraft and engine models, collecting fuel samples and providing flight data.

JOB INSTRUCTION CARD

An essential aspect of the campaign involved a detailed fuel sampling procedure, as outlined in a Job Instruction Card (JIC). This JIC, adhering to AMM Airbus Maintenance Manual guidelines, provide engineering orders for extracting and storing fuel samples. A detailed, standardized procedure for safely and accurately collecting fuel samples from aircraft ensures that the collected samples are representative of the fuel in use, free from contamination, and suitable for analysis.

The JIC provides step-by-step instructions on the sampling process, including the tools and equipment needed. It details the method for accessing the fuel system, handling fuel samples, and ensuring clean and contamination-free procedures.

The JIC includes safety protocols to protect personnel and equipment. It aligns with requirements and manufacturer guidelines to ensure compliance.

Data Recording: Instructions for documenting sample details, such as aircraft registration, date, location as necessary, and conditions are included. This involve logging sample data using QR codes as a tracking method.

SAS **Job Instruction Card**	Number: **28-1045**	Revision: **00**
	Issue Date:	
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TITLE: A320 Fuel Sampling _ALIGHT PROGRAM

Revision Highlights:

Revision 00: Original issue.

1. REASON

ALIGHT is a part of EU sponsored project, which involves to have 50 fuel samples done (in CPH) during a two week period. The fuel sampling measurement campaign focuses on aircraft emissions and fuel quality.

2. REFERENCES

- Airbus AMM TASK 12-32-28-281-003-A
- EO (SAS-12-1025)

FLIGHT DATA REPORT

By using aircraft equipped with advanced sensor technology, SAS was able to contribute with monitored real time data such as fuel flow, engine temperatures, engine exhaust gas temperature (EGT), engine thrust, aircraft mass, weather/ambient data, and GPS position.

To retrieve and report flight data effectively, the following equipment and systems are necessary:

Flight Data Recorder (FDR): Also known as the "black box," records crucial flight parameters such as speed, altitude, fuel flow, engine temperatures, and control settings. It is essential for post-flight analysis and accident investigation.

Quick Access Recorder (QAR): This device provides more accessible data storage compared to the FDR, capturing detailed flight parameters that can be quickly downloaded after flights for operational analysis.

Aircraft Communications Addressing and Reporting System (ACARS): ACARS is a digital datalink system used for transmitting short messages between the aircraft and ground stations, including flight performance and maintenance data.

Aircraft Condition Monitoring System (ACMS): This system collects and manages data from various aircraft sensors and systems, providing information on engine performance, system health, and other metrics.

Integrated Modular Avionics (IMA): This architecture allows for streamlined processing of data across various systems, enhancing real-time monitoring and reporting capabilities.

Data Management Software: To collect, process/prepare data for transmission or post-flight downloading.

4.2.1.3 Operation plan

Fuel sampling during the campaign was planned to focus on aircraft operated by the ALIGHT partner SAS. To gain a better understanding of the turnaround process for SAS aircraft at CPH, assess the feasibility of fuel sampling at the aircraft level, and identify suitable positions for emissions measurements, a scouting visit to CPH was conducted in January 2025.

It became evident during this visit that, due to technical and safety considerations, fuel sampling during regular turnaround at the aircraft stand was not feasible. This limitation was primarily due to the requirement that fuel temperature in the aircraft tanks must exceed 0 °C before the fuel drain port can be safely opened. As a result, sampling efforts were redirected toward SAS aircraft staying overnight at CPH, or aircraft undergoing extended maintenance stays in the SAS hangar, allowing sufficient time for the fuel to warm above the threshold temperature.

The general campaign plan was therefore to identify aircraft staying overnight, measure their emissions during taxi-in on their last scheduled arrival into CPH, collect fuel samples overnight, and then measure emissions again during taxi-out of their first scheduled departure the following day.

An analysis of the planned SAS schedule for the two-week measurement period showed that between five and ten SAS aircraft were expected to stay overnight at CPH each night—providing a sufficient pool of candidates for fuel sampling. These overnight stays also covered a variety of aircraft types, including the Airbus A320neo, A350, A319, and A330 (A333). An example of such a scheduling analysis is shown in Figure 7.

Based on this planning, it was decided to concentrate fuel sampling on a set of “focus aircraft” that were expected to have multiple overnight stays during the campaign. This strategy allowed for repeated emissions measurements on the same aircraft and engine types, improving consistency and data quality.

The five designated focus aircraft were:

- OY-KBR – A319
- OY-KBO – A319
- SE-ROB – A320neo
- SE-ROX – A320neo
- SE-RSF – A350

Given potential changes to the flight schedule, the specific aircraft subject to fuel sampling were identified and confirmed on a daily basis, with highest priority given to the focus aircraft.

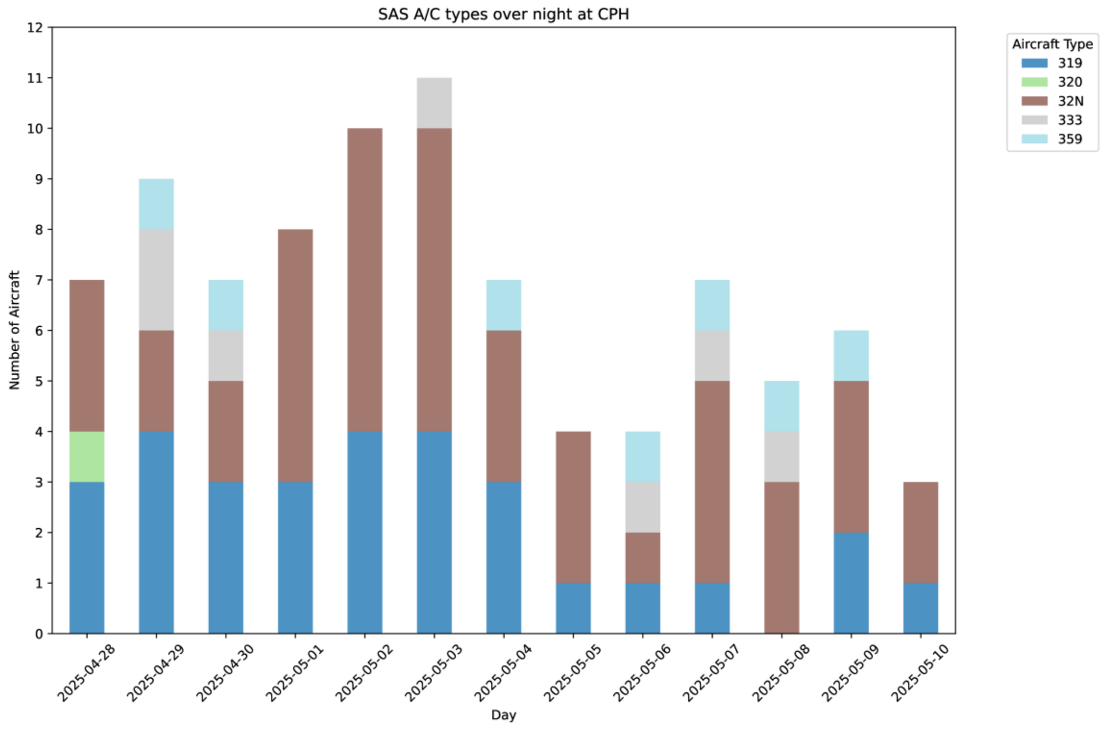


Figure 7: SAS A/C types over night at CPH

4.2.2 Execution of the advanced fuel monitoring campaign

4.2.2.1 Emission measurements and data processing

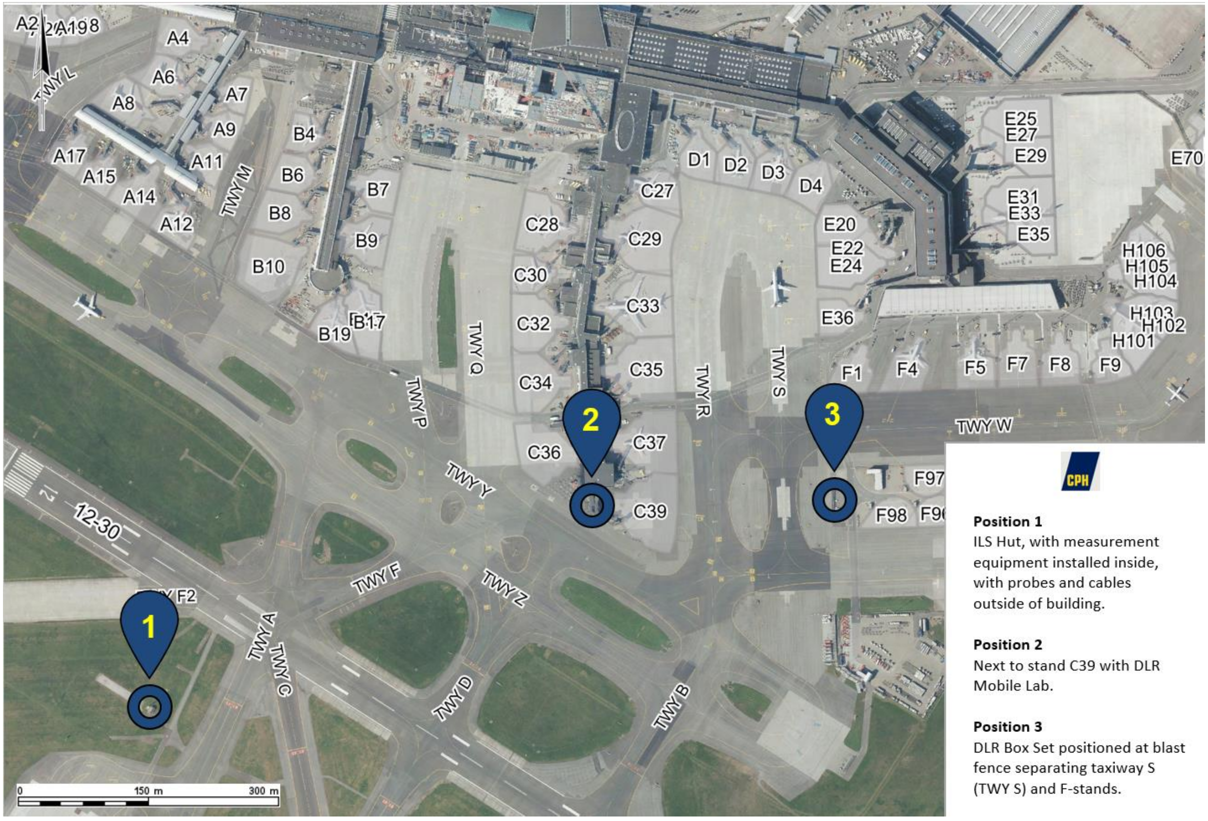
Similar to the short term measurement campaign (see Chapter 3) the DLR mobile was employed at CPH to analyze aircraft exhaust plumes. With its state-of-the-art instrumentation it was able to monitor air quality parameters like particle number concentration and size distributions for both total and non-volatile particles as well as carbon black mass concentrations and gaseous components as CO_2 and NO_x. The DLR mobile lab was operated from 28th April to 12th May 2025 close to gate C39 (see Fig. 8 and Fig.9.

In addition to the mobile laboratory, further instrumentation was deployed at strategic locations around the airport during the campaign. At the Instrument Landing System (ILS) hut (Position 1, figure 9), located near the runway where most taxi-out operations pass, instruments were installed to record total particle number concentrations and non-volatile particle number concentrations, complemented by CO_2 measurements for validation of the particle data. These measurements were supported by a Partector operated by CPH. The Partector is a handheld device developed by Naneos that provides estimates of particle size distribution as well as particle number concentration.

A third measurement site was established in the area of a blast fence between Pier C and F. This site served as an additional monitoring point for Taxiway R, S and W and enabled the recording of target data even under non-preferential wind conditions, albeit at reduced intensity. For this purpose, a box equipped with handheld instruments was mounted behind the blast fence. The setup included a total particle number counter and two Partectors (one operated by DLR, the other by CPH). One of the Partectors was combined with a unit for removing the volatile particle fraction. The measurements were complemented by recording the CO_2 signal.

All measurement sites were operated continuously (24/7) and were accessible at any time via remote access.

Figure 8: DLR mobile lab during the FuelTrack campaign operating close to gate C39. Taxiways Y and Z of Copenhagen Airport can be seen in the background with a departing SAS aircraft taxiing to the runway.



Position 1
ILS Hut, with measurement equipment installed inside, with probes and cables outside of building.

Position 2
Next to stand C39 with DLR Mobile Lab.

Position 3
DLR Box Set positioned at blast fence separating taxiway S (TWY S) and F-stands.

Figure 9: Aerial photo 2024 of Copenhagen Airports Kastrup (cutout) with marked stands, taxiways and positions of sampling equipment.

4.2.2.2 Fuel sampling and analysis

As described in the previous section, fuel samples were collected by SAS Technical Services from SAS aircraft staying overnight at CPH, following their last scheduled arrival. Additional samples from the fueling infrastructure were taken by DRS during refueling operations prior to the aircraft's first scheduled departure from CPH. An overview of the sampling process is shown in Figure 10.

All collected samples were stored by BKL at the CPH fuel farm throughout the duration of the campaign. Upon completion of the two-week measurement period, the full set of samples was transported to DLR in Stuttgart for chemical analysis.

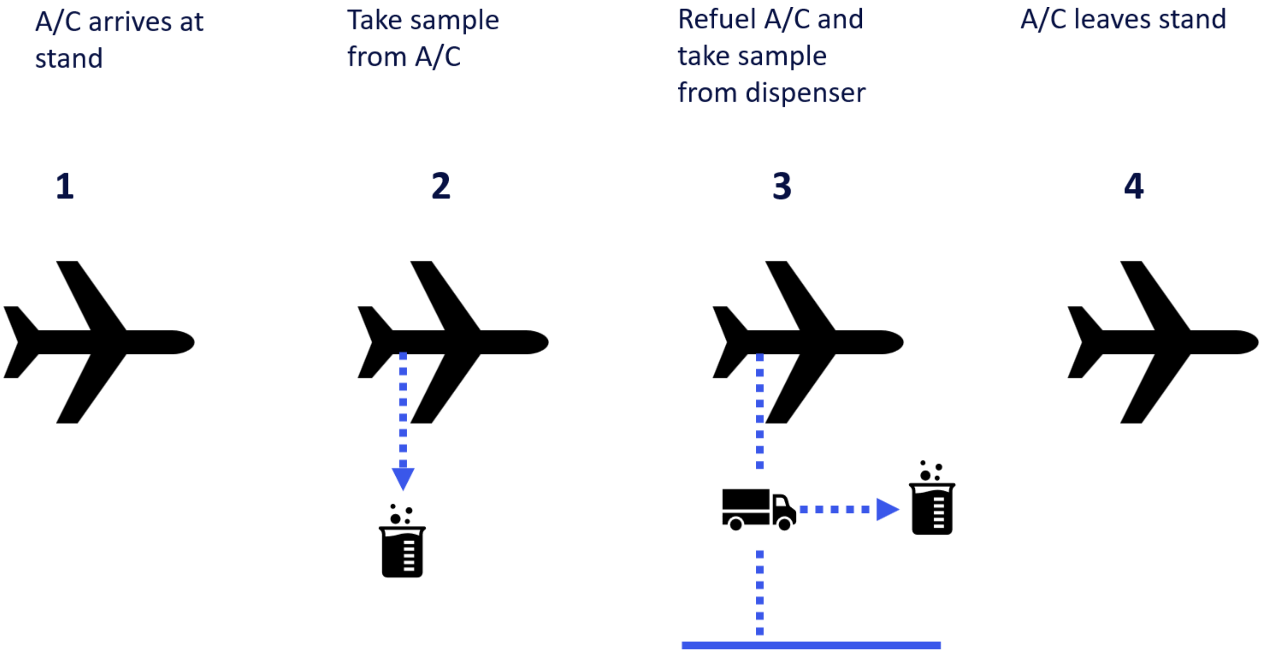


Figure 10: Fuel sampling process diagram.

Figure 11: Fuel sampling from the dispenser of DRS during the FuelTrack CPH campaign. (1 of 2)

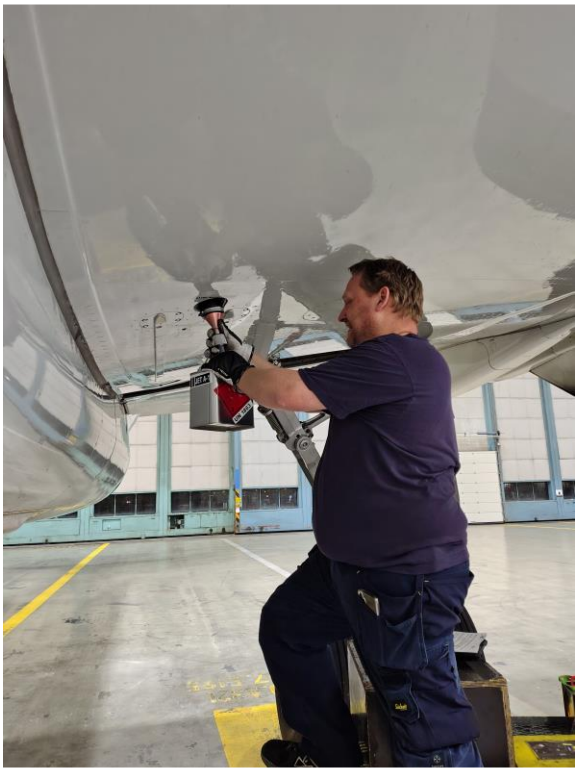


Figure 12: Fuel sampling from the dispenser of DRS during the FuelTrack CPH campaign. (2 of 2)

Fuel analysis:

For all samples collected from aircraft, the complete set of fuel properties required by ASTM D1655 was analyzed by an external, certified laboratory. Specific energy was determined using the high-precision method ASTM D4809, based on calorimetric bomb measurements.

In addition, for all samples—both from aircraft and dispensers—further analyses were carried out at the DLR in-house laboratory. These included infrared spectroscopy, hydrogen content via 1H-NMR, aromatic content, density, and refractive index measurements. It should be noted that for the dispenser samples, only the in-house measurements were performed; the full ASTM D1655 property set was not analyzed for this group.

4.2.2.3 Considerations

Despite facing multiple challenges during the FuelTrack CPH campaign, it can be considered a great success due to the careful planning in advance and dynamic adaptations during the campaign. One major challenge were the unusual weather conditions regarding both wind conditions and temperature. Fig.13 illustrates wind rose plots from CPH in general (left) and compares this with the short term (middle) and FuelTrack CPH (right) campaign. It becomes clear that the wind with a predominant direction of south-west was as it could be expected for the short term measurement campaign. However, during the FuelTrack CPH campaign very unusual wind direction of north and north-west were present hindering the measurements. Therefore, the campaign needed to be prolonged to acquire a sufficient amount of data. The temperature was quite high for that time of the year as well leading to the necessity to install additional cooling devices to keep the LAQ measurement equipment running smoothly.

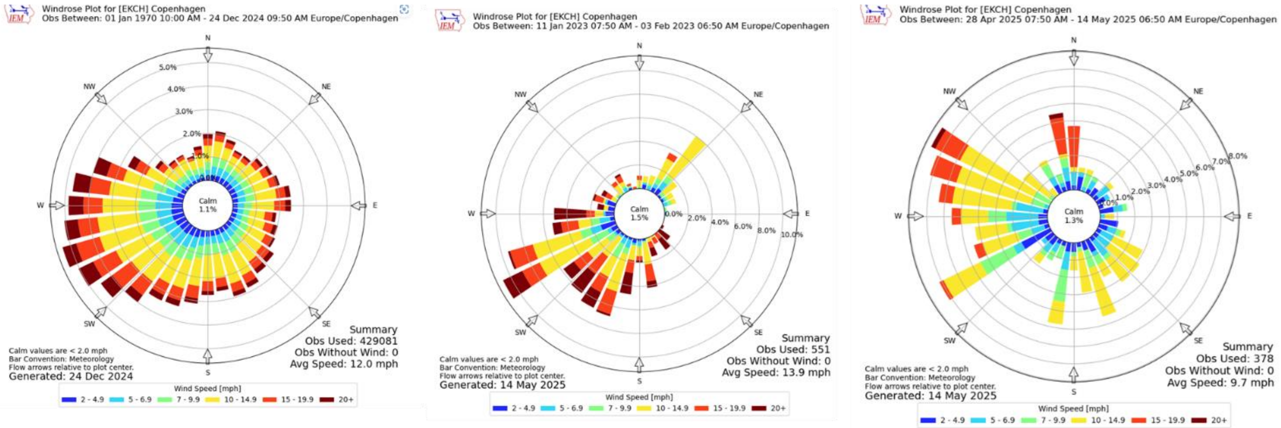


Figure 13: Windrose plots for Copenhagen Airport from 1970 to present (left), the short term measurement campaign (middle), and FuelTrack CPH campaign (right).

It had to be prevented that the measurement campaign interfered with the regular operation of CPH as well as SAS flight movements. On the other hand, requests for e.g. taking fuel samples or asking for a specific taxiway for a specific aircraft were necessary to make the campaign a success. Here, daily planning meetings with all participants were useful to adapt according to dynamically changing operation plans and weather conditions.

4.3 Results and discussion

4.3.1 **Results**

Fuel sampling

The fuel sampling component of the campaign was successfully executed, with a total of 55 fuel samples collected over the two-week measurement period—equivalent to approximately 3 to 4 samples per night. This exceeded the original expectation of 30 to 40 samples, highlighting the efficiency and consistency of the sampling process and the commitment of all involved partners. The collected samples represent incoming flights from 27 airports worldwide, including 15 flights originating from outside Europe. Samples were obtained from 16 different SAS aircraft, covering four aircraft types across the Airbus A320, A319, A330, and A350 families. Due to SAS operating the A319 with two different engine configurations, a total of five distinct engine types were represented in the sample set. A summary of key statistics, such as aircraft types, origin airports, and engine configurations, is provided in Figure 14.

As shown in Figure 15 European airports were well represented in the sampling campaign. However, the requirement that fuel sampling could only be conducted on aircraft staying overnight limited the inclusion of certain destinations—such as Paris—due to the constraints of the SAS flight schedule.

Figure 16 illustrates the global distribution of sampled origin airports, which included key intercontinental destinations such as the US East Coast (Boston), US West Coast (San Francisco, Los Angeles), and Asia (Bangkok, Tokyo). Notably, Tokyo emerged as the single most frequent origin, with the highest number of collected samples during the campaign. This was due to the consistent overnight layovers of aircraft operating on that route, which made sampling feasible after each arrival.

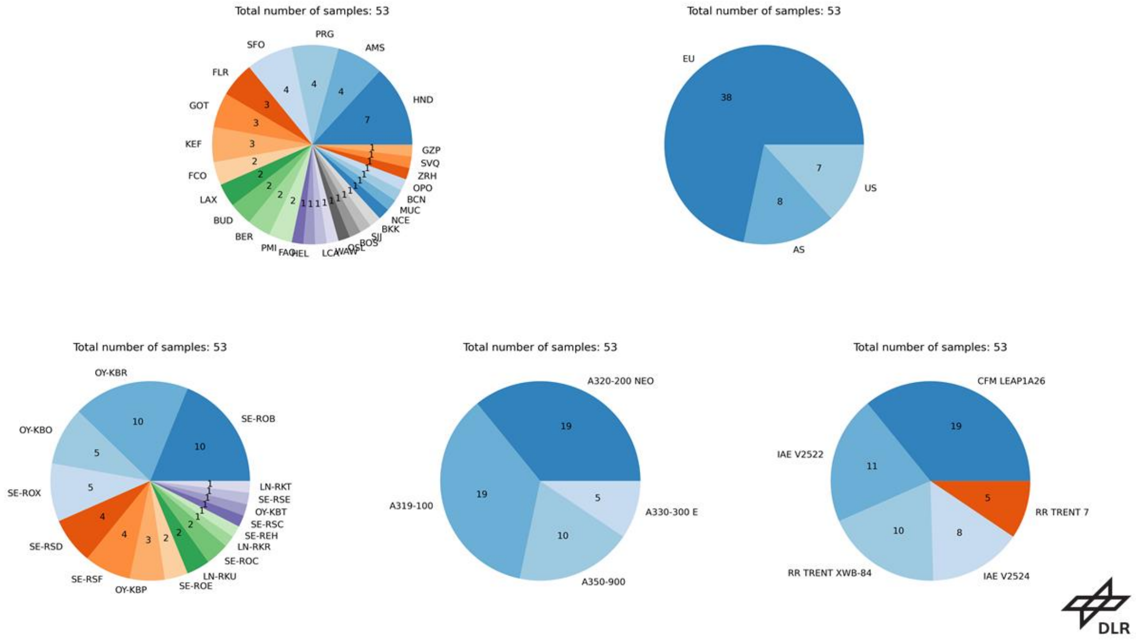


Figure 14: summary of key statistics; aircraft types, origin airports, and engine configurations.

Figure 15: European airports of origin for flights from which fuel samples were taken.

Figure 16: Worldwide airports of origin for flights from which fuel samples were taken

Figure 17 provides a summary of key fuel properties, including total aromatics, hydrogen content, sulfur content, and net heat of combustion. Red shaded areas indicate the specification limits for Jet A-1 as defined by ASTM D1655. Aggregated data across the respective fuel samples are presented as boxplots, with orange lines indicating median values.

The *FuelTrack* boxplots represent the 55 fuel samples collected from arriving flights, while *CPH* refers to samples taken directly from fuel dispensers at Copenhagen Airport during the campaign. As a reference for global fuel property distributions, values from the 2006 CRC World Fuel Survey (20) are included.

It should be noted that not all ASTM D1655 properties were analyzed for the CPH dispenser samples; specifically, data for net heat of combustion, sulfur content, and freezing point are not available for this group.

In general, the *FuelTrack* samples exhibited a more favorable range for most properties compared to the CRC data—characterized by lower aromatic and sulfur content, and higher net heat of combustion based on median values. Notably, the CPH dispenser samples showed an even lower aromatic content and higher hydrogen content, indicating that during the campaign period, slightly higher fuel quality was available at Copenhagen Airport compared to that of the incoming flights.

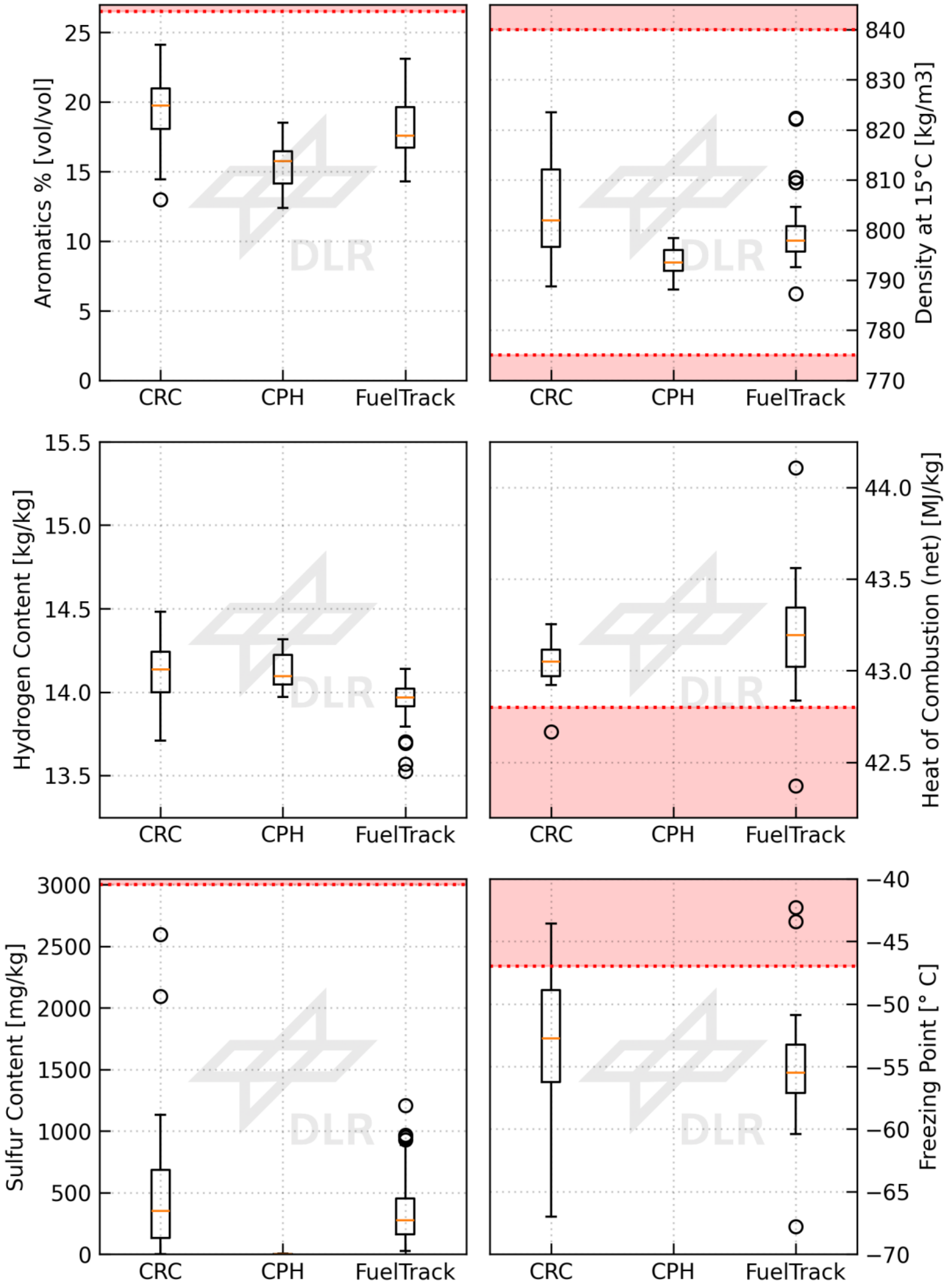


Figure 17: Overview of key the distribution of key fuel properties. CRC=CRC world fuel survey (2006), CPH=Copenhagen Airport dispenser, FuelTrack=samples from arriving flights

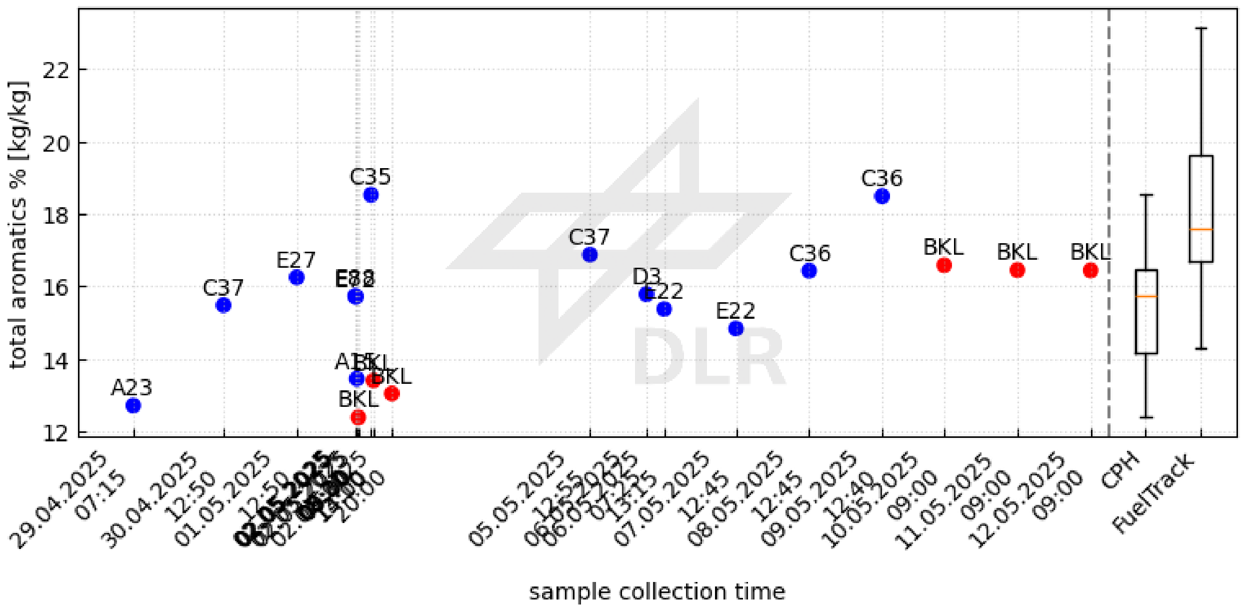


Figure 18: detailed view of the CPH dispenser samples with total aromatics over time.

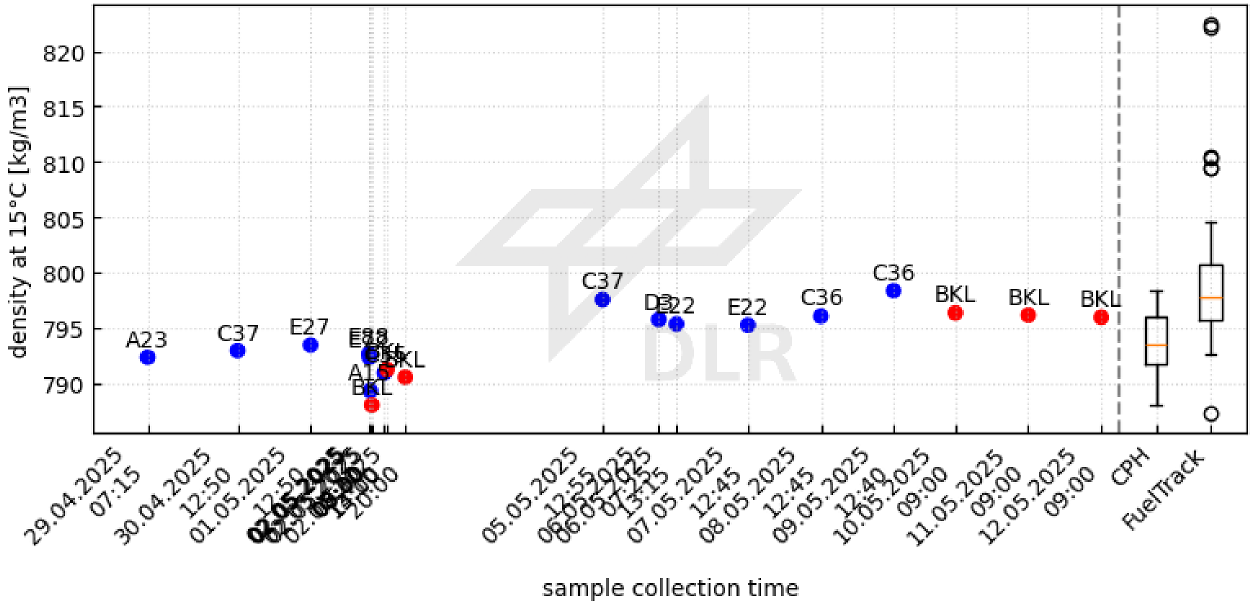


Figure 19: detailed view of the CPH dispenser samples with density over time.

A more detailed view of the CPH dispenser samples is provided in Figures 18 and 19, which show total aromatics and density over time for the dispenser samples collected during the campaign. Each data point corresponds to the time and location (aircraft stand) at which the sample was taken. Annotations indicate the specific aircraft stand where refueling—and thus dispenser sampling—occurred. Red dots mark samples taken directly at the main export point from the BKL fuel farm, upstream of the airport's underfloor pipeline distribution system.

While density varies within a relatively narrow range of approximately 10 kg/m³, total aromatics exhibit a more pronounced variation over time. This is particularly evident on 02.05.2025, when multiple dispenser samples were collected within a short time frame, showing noticeable differences between aircraft stands. Interestingly, the three samples taken directly at the BKL fuel farm over the final campaign weekend (the last three red dots) show nearly constant values for both aromatics and density.

Two main factors could explain the observed variations in fuel properties within the fueling infrastructure. First, due to the complexity and branching of the underfloor pipeline system, the timing and routing of fuel delivery may vary between stands. Fuel dispensed simultaneously at different stands may not originate from the same section of the system, depending on the local consumption dynamics. This could account for the significant stand-to-stand differences observed on 02.05.2025.

Second, the BKL fuel farm is supplied with fuel batches from the Provestenen import storage and harbor facility, located approximately 5 km north of the airport. Fuel is imported by ship to Provestenen and released via pipeline to the BKL fuel farm based on real-time demand from the CPH hydrant system. Therefore, variations in fuel properties at the dispenser level may also result from newly received batches, buffer tank switching, or blending effects occurring at the BKL facility.

In essence, the journey of fuel from the point of import at Provestenen to the aircraft wing is governed by a complex and dynamic system in which different batches are constantly mixed and commingled.

To further investigate this aspect, Certificates of Analysis (CoAs) for fuel batches imported to Provestenen during the first half of 2025—corresponding to the period of the FuelTrack campaign—were collected and reviewed. A CoA provides a set of measured fuel properties to confirm compliance with ASTM D1655 specifications.

Key data from these CoAs are presented in Figure 20, alongside values from the CPH dispenser samples and historical CoAs for batches imported to the BKL fuel farm during 2020–2021, collected at the beginning of the ALIGHT project. Since hydrogen content is not included in standard CoAs, this property was estimated using the ASTM D3343 correlation, based on total aromatics, density, and the distillation curve—parameters available from the CoAs.

As expected, the dispenser samples align with the range of the 2025 BKL batch data, confirming that all observed values originate from batches imported during the relevant time frame. Notably, in terms of aromatic content, the dispenser samples collected during the FuelTrack campaign predominantly reflect the lower end of the range found in the 2025 BKL data. This suggests that, during the two-week observation period, the airport fuel supply was likely influenced by one or more batches with unusually low aromatic content.

However, due to the complexity of the airport's fuel distribution system and the continuous mixing of multiple batches, a definitive link between a specific imported batch and the fuel ultimately uplifted to an aircraft cannot be established.

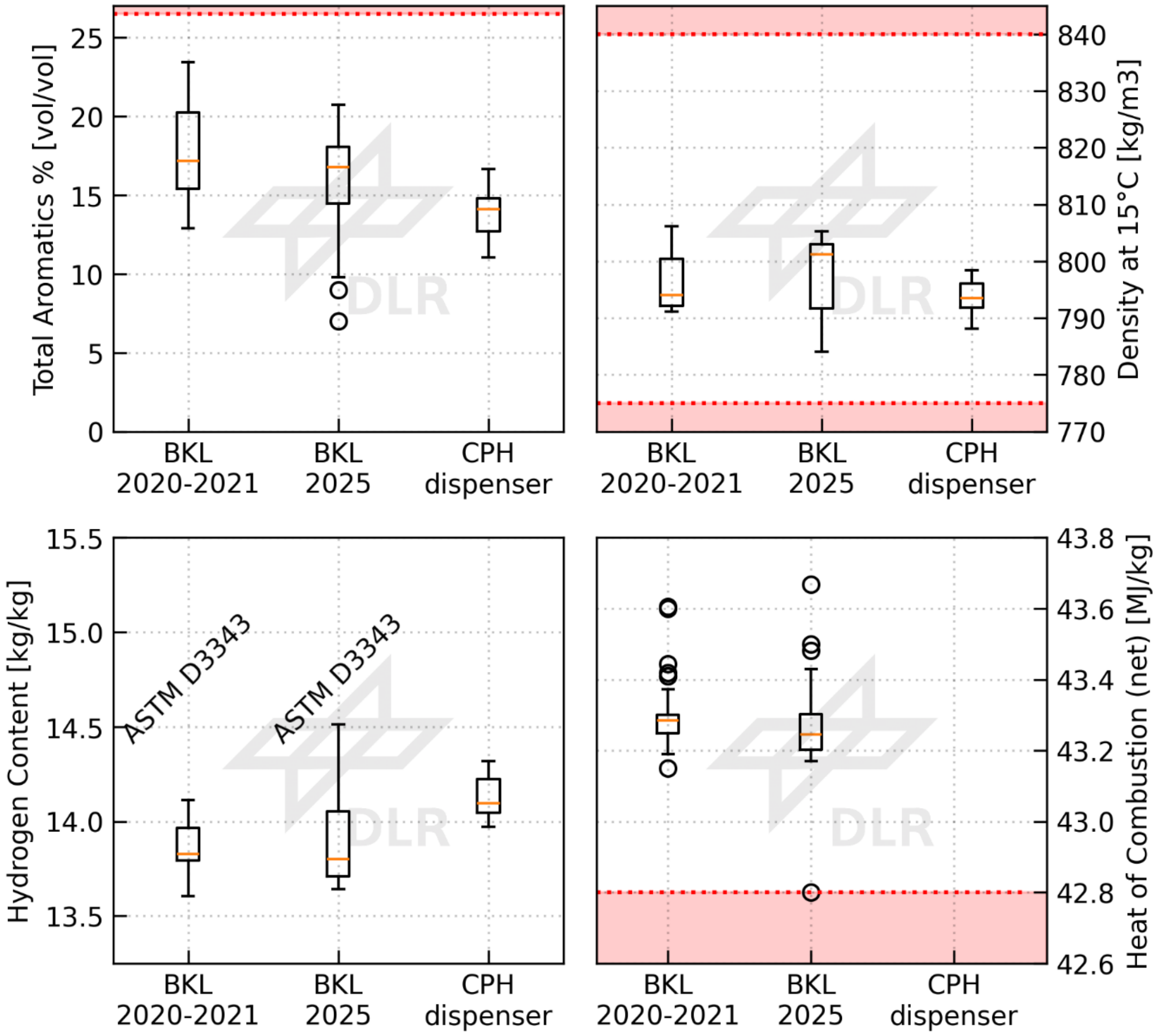


Figure 20: Overview of the distribution of key fuel properties based on CoAs from BKL fuel depot and the CPH dispenser.

During the emission measurements, a total of 344 aircraft plumes originated from SAS Core aircraft were analyzed by the DLR mobile lab. Despite the challenging conditions discussed in Chapter 4.2.2.3, this exceeds the short term measurement campaign by a factor of 3 underlining the comprehensive data set obtained during the FuelTrack CPH campaign. Aircraft-type specific emission indices for non-volatile and total particle numbers per kg fuel burned obtained during the measurement campaign are presented in Figures 21 and 22, respectively. The rather similar values among all aircraft types indicate that no particularly high-polluting aircraft type is operated by SAS. However, the large scattering of the data even among the same aircraft types emphasize the importance and influence on the fuel composition and properties. The aircraft fleet operated by SAS provides a representative cross-section of the traffic at airport CPH. Alongside modern medium-range aircraft such as the A320-200neo and A321-200neo equipped with the latest engine technologies, the fleet also includes older models in the same range class, such as the A319-100 and A320-200, powered by engines that have been in service for decades and undergone various technological upgrades. This combination allows a direct comparison of emissions across different technological generations of engines. Long-haul operations are likewise well represented, with aircraft including the A330-300 and the A350-900 in the widebody class. These models cover both earlier long-haul engine concepts and the most recent technology platforms currently in service. The presence of both categories provides valuable insight into the effects of aircraft and engine age on emission behavior under real operating conditions. The fleet is complemented by smaller regional aircraft types such as the Embraer E195, which represent an important share of short-haul operations and contribute to a broader coverage of aircraft sizes and mission profiles. In addition to turbofan-powered aircraft, the turboprop-based ATR72-600 is also operated, extending the analysis to propeller-driven regional aircraft and enabling comparison of emission characteristics across fundamentally different propulsion concepts. Overall, the fleet composition observed during the campaign offers an excellent basis for assessing the variability of aircraft emissions across a wide range of aircraft and engine types, from state-of-the-art designs to legacy platforms, and from regional to intercontinental operations.

A first inspection of the statistical evaluations shown in Figures 21 and 22 reveals that both the non-volatile and the total particle number–based emission indices allow differentiation between individual aircraft classes, although no clear overall trend is evident. Notable is the variability observed for the newer engine classes such as the A320-200neo and A321-200neo (Figure 22). For these aircraft, the statistical dataset will be examined in greater detail in subsequent analyses, including additional evaluation parameters such as peak quality and particle size distributions.

The highest variability is observed for the ATR72-600, which can be attributed to plume dispersion effects caused by the turboprop (turboshaft) engine technology. This variability is not as pronounced in the non-volatile emission indices (Figure 21), although a few outliers toward higher values are present. In terms of variance, the modern engines again stand out for the non-volatile fraction, indicating the need for further in-depth and time-intensive analyses.

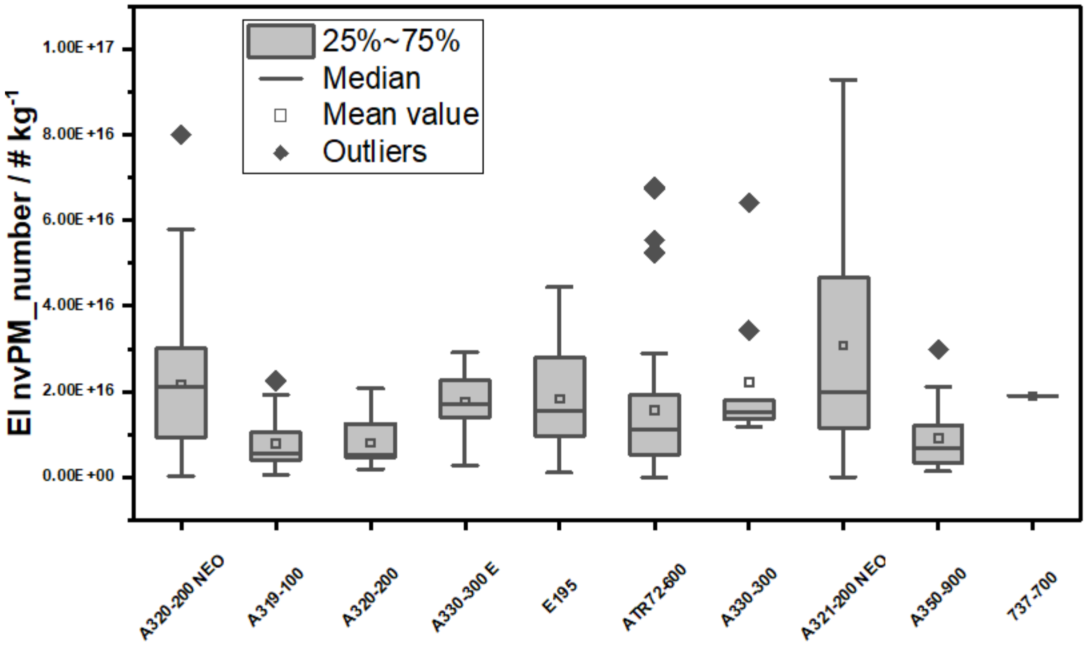


Figure 21: Statistical evaluation of the analyzed and validated aircraft movements during the fuelTrack campaign for the non-volatile particle fraction, expressed as emission index (particle number per kg of fuel), shown as a function of aircraft class.

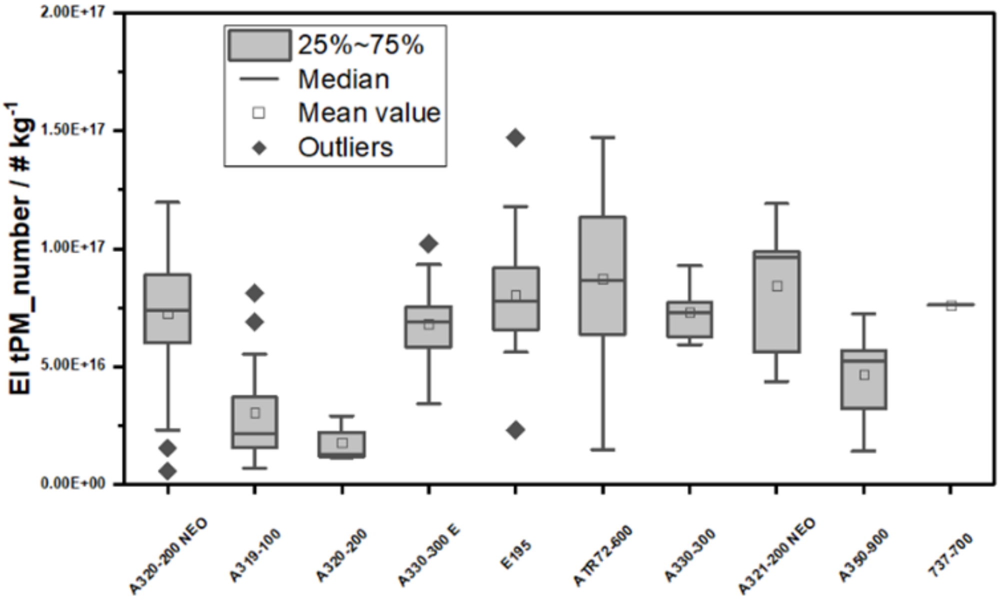


Figure 22: Statistical evaluation of the analyzed and positively validated aircraft movements during the fuelTrack campaign for the total particle fraction, expressed as emission index (particle number per kg of fuel), shown as a function of aircraft class.

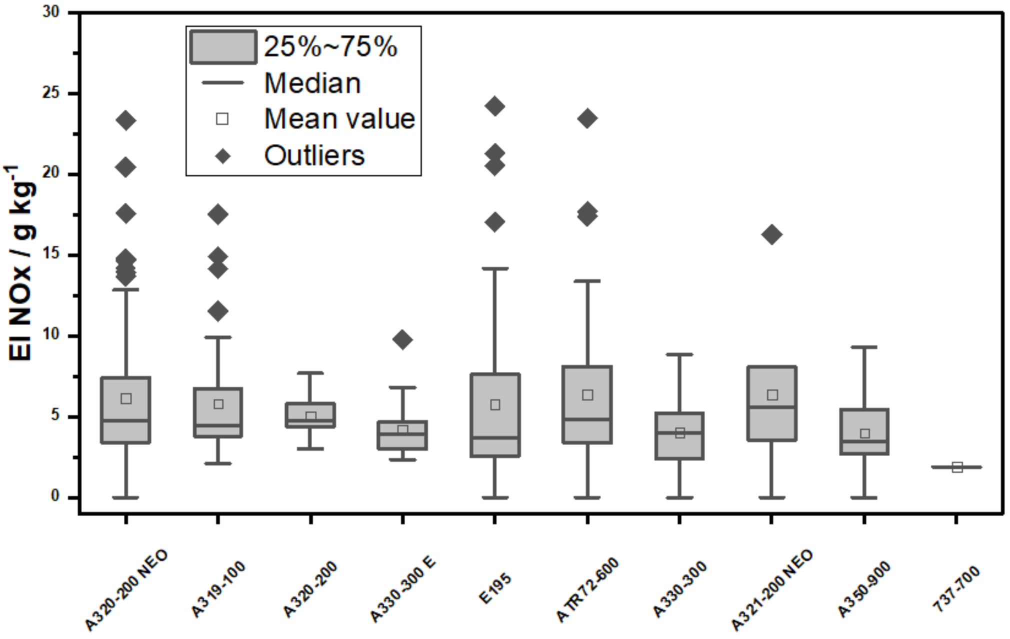


Figure 23: Statistical evaluation of the analyzed and positively validated aircraft movements during the fuelTrack campaign for the exhaust gas nitrogenoxid/nitrogendioxid, expressed as emission index (particle number per kg of fuel), shown as a function of aircraft class.

The measurements show that NO_x emission indices were consistently low, averaging around 5 g per kg of fuel burned, across all investigated aircraft types. This uniformity indicates that during taxiing operations engines were operated at low thrust settings, resulting in reduced combustion chamber temperatures and, consequently, low NO_x formation. These operating conditions are in line with the aircraft operation data provided by SAS, which further corroborates the interpretation.

While these results confirm expectations for ground-level operations, they also highlight the limitations of aggregated NO_x indices for detailed assessments. To better understand the underlying processes, further analyses will be necessary. These include a more direct correlation of NO_x emissions with specific engine types, a decomposition of the overall NO_x signal into its NO and NO_2 fractions, and an evaluation of the influence of ambient conditions, such as ozone concentration. Such extended analyses will provide deeper insight into both the variability of ground-based emissions and the robustness of the applied methodology.

It must be noted that, to determine the number of particles emitted at the airport, these indices must be multiplied by the amount of fuel burned.

Comparison of arriving/departing aircraft

Based on a more generalized approach, Fig. 24 compares the obtained values of the categories departing, arriving and transiting aircraft with the last category being quite rare. Slightly lower values are found for the departing aircraft. This is in line with the finding of the fuel analysis showing lower aromatics and higher H content for the dispenser samples compared to the aircraft samples. However, this effect is expected to be smaller in the emission measurement, since still a small fraction of the fuel from the previous airport is being burned during taxiing out to the runway.

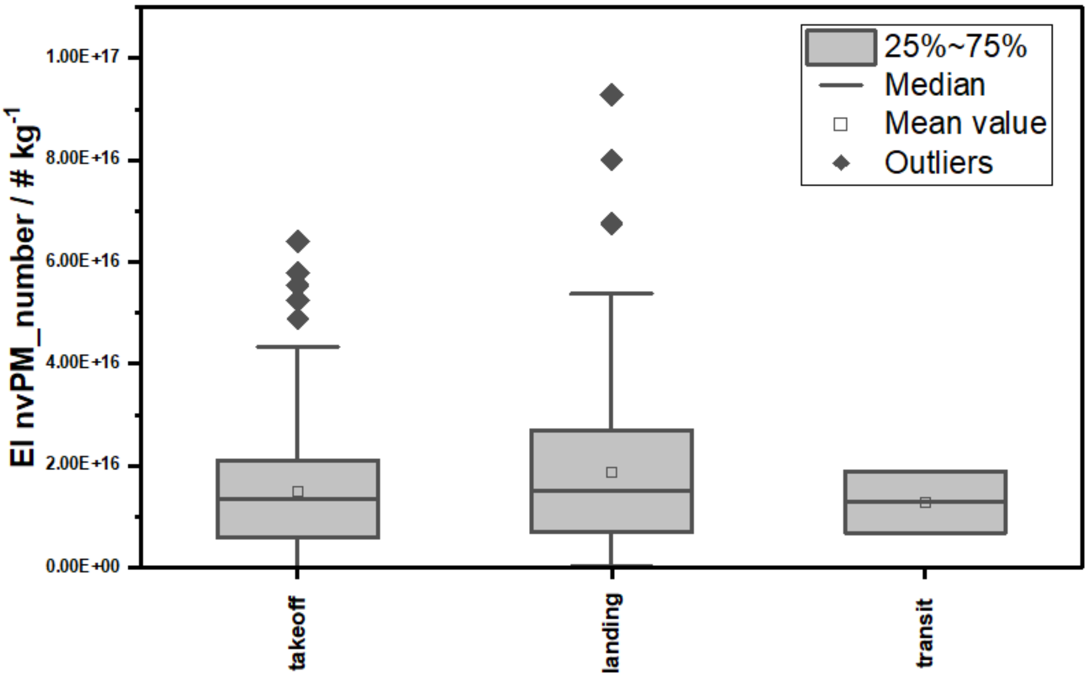


Figure 24: Statistical evaluation of all validated aircraft movements categorized by takeoff, landing, and transit, presented as emission indices of the non-volatile particle fraction.

For more detailed evaluations, these aircraft movements will need to be further differentiated; the current figure represents the aggregate of all validated flight operations. Since potential differences are expected to arise primarily from variations in fuel composition and engine type, only more time-intensive analyses will be able to reveal and illustrate possible trends.

Comparison of different departure airports

Fuel samples could only be collected directly at airport CPH. An additional approach to assess potential fuel-related influences is to trace the aircraft that landed at CPH back to its departure airport and correlate the corresponding fuel characteristics. To discuss the influence of the fuel composition, the further part is focusing on two aircraft types: A320-200 neo and A350-900. The first one was chosen, since it is the most commonly used aircraft type by SAS and the latter, since the widebody aircraft often correspond to transatlantic flights and therefore are likely to present a higher variety in the fuel composition.

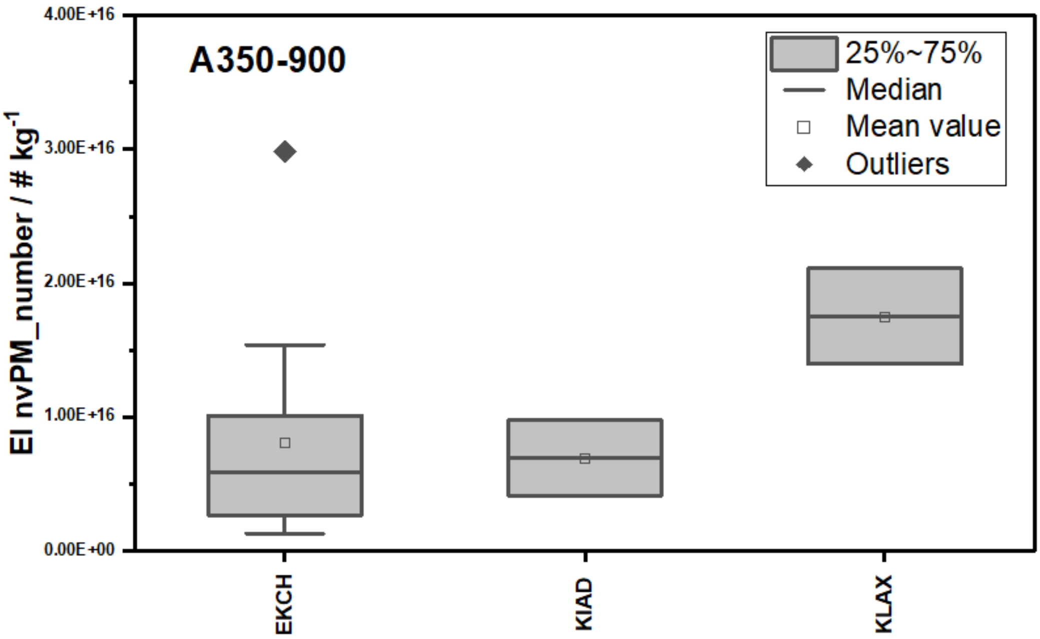


Figure 25: Statistical evaluation of the A350-900, categorized by departure airport, presented as the non-volatile particle emission index (particles per kg of fuel burned).

For the A350-900, the fuel composition is generally similar across the majority of operating airports. However, analysis indicates that California, specifically LAX, appears as an outlier, with fuels that are associated with comparatively higher emissions. This highlights the potential influence of regional fuel variability on emission characteristics for long-haul operations.

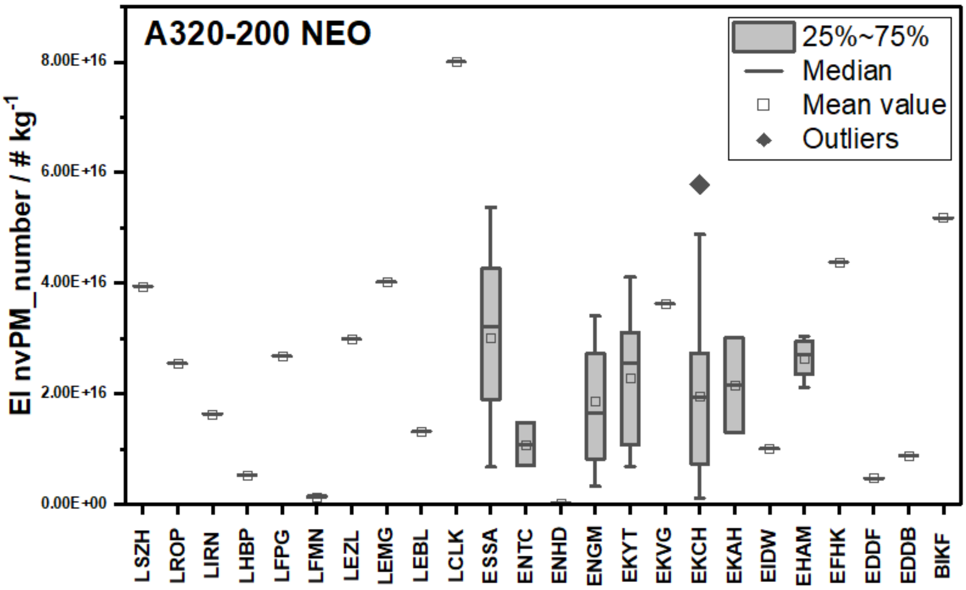


Figure 26: Statistical evaluation of the A320-200 neo, categorized by departure airport, presented as the non-volatile particle emission index (particles per kg of fuel burned).

The A320-200neo operates across many airports; however, sufficient statistical coverage is available for only a limited number of locations. Overall, the fuel used by these aircraft is fairly consistent, reflecting a predominantly Europe-centered supply. This relative uniformity in fuel composition helps reduce variability in emissions attributable to fuel differences, simplifying comparisons across different flight operations for this aircraft type.

A preliminary assessment of the data indicates that, in addition to the statistically well-represented airports ESSA (Stockholm Arlanda), ENTC (Tromsø), ENGM (Oslo Gardermoen), EKYT (Aalborg), EKCH (Copenhagen), EKAH (Aarhus), and EHAM (Amsterdam Schiphol), several further airports exhibit noteworthy deviations. Specifically, LHBP (Budapest), LFMN (Nice), ENHD (Haugesund), and EDDF (Frankfurt) show emission indices below the interquartile range (25–75%) defined by the reference airports, whereas BIKF (Keflavík) and LCLK (Larnaca) exceed this range. These findings, however, must be interpreted with caution due to the limited statistical sample size available for these locations. When combined with long-term observational studies, this approach has the potential to provide a more robust and comprehensive statistical characterization. As emphasized in earlier evaluations, the present results should be regarded as a first assessment, which will benefit from further data integration and more advanced cross-analysis in subsequent studies.

Combining fuel and emission data

Figure 27 presents the emission index for non-volatile particle number as a function of the aromatic content of the corresponding fuel sample, for selected flights where both emission measurements and fuel samples were available.

The aircraft SE-ROB (Airbus A320neo) was sampled three times under varying aromatic content levels. A clear trend is observed: the emission index increases with rising aromatic content, demonstrating that the influence of fuel quality on particle emissions is detectable under real operational conditions.

In comparison, samples from A319-class aircraft show slightly higher emission indices overall, which can be attributed to the older engine technology used on these aircraft relative to the more modern engines of the A320neo.

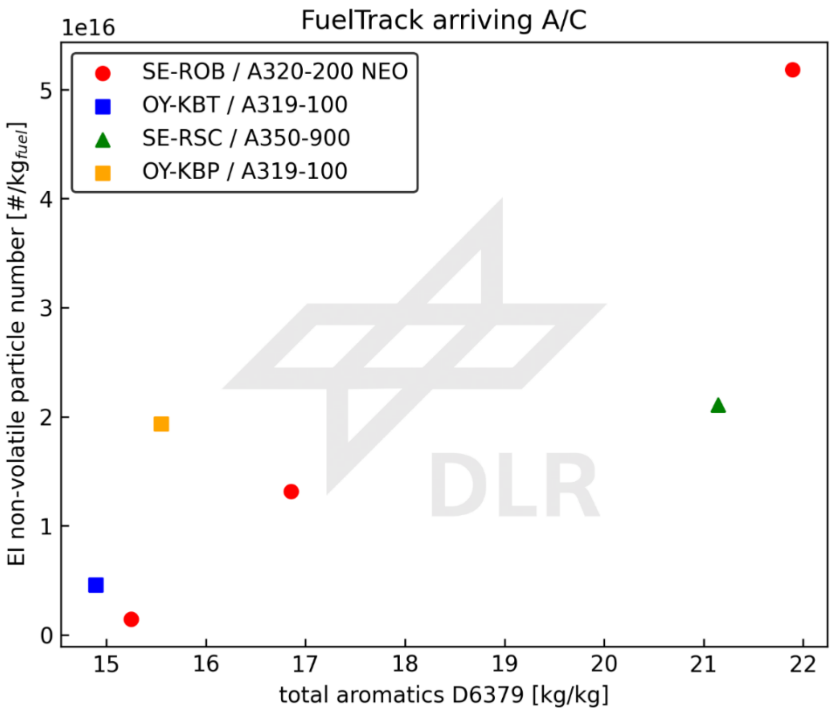


Figure 27: emission index for non-volatile particle number over total aromatics for aircraft with both emission measurements and fuel sample.

4.3.2 Discussion

Data-Driven Assessment of Fuel-Driven Emission Variability

The results from the fuel sampling confirm that there is significant variation in fuel properties, both among the aircraft samples and the dispenser samples. Similarly, the emission measurements revealed variation in emissions even for the same aircraft and engine types, suggesting that these differences may, at least in part, be driven by variability in fuel properties.

To explore this aspect further, the digital platform for aviation fuels developed under ALIGHT Task 3.5 was used to support a data-driven evaluation of potential emission impacts linked to fuel variation. Figure 28 illustrates a correlation between the relative change in non-volatile particle mass emission index (EIn) and the hydrogen content of the fuel, across different normalized engine thrust settings ($\hat{F}$), as developed by Teoh et al. This correlation is based on a combination of test-bed engine data and real-world aircraft emission measurements. The distribution of hydrogen content from the aircraft fuel samples is shown as a boxplot along the x-axis.

Since taxi operations typically occur at low engine thrust settings—including idle—analysis focused on the lowest thrust levels for which the correlation is available: 10%, 20%, and 30%, with 10% being the most representative for typical taxi conditions. Based on the hydrogen content of each fuel sample, theoretical changes in EIn can be derived relative to a reference fuel with 13.8 mass percent hydrogen content. These estimated changes are marked by red dots along each thrust-setting curve.

Figure 29 presents the results for all 55 aircraft fuel samples at the three considered thrust settings. At 10% thrust, predicted variations in EIn range from approximately +30% to -32%, solely based on differences in hydrogen content.

This simplified theoretical evaluation therefore already indicates that the observed variation in fuel hydrogen content could lead to substantial differences in particle mass emissions—even within the same aircraft and engine type—highlighting the importance of fuel composition in real-world emission behavior.

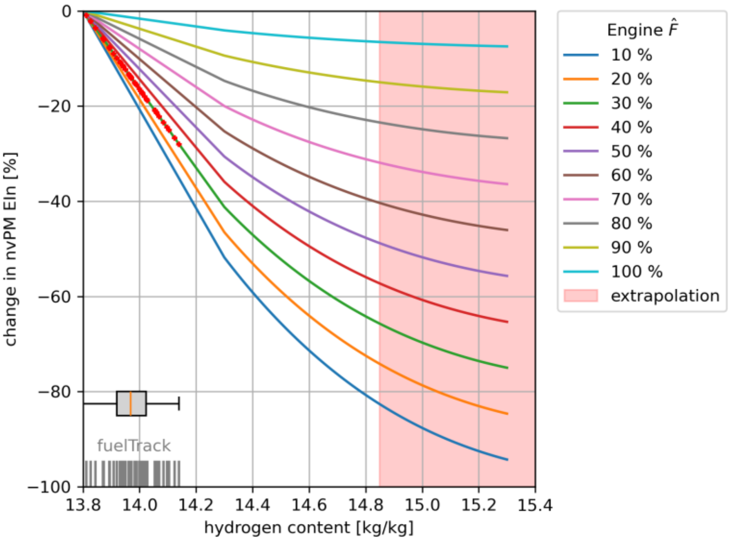


Figure 28: correlation between the relative change in non-volatile particle mass emission index (EIn) and the hydrogen content of the fuel, across different normalized engine thrust settings ($\hat{F}$), as developed by Teoh et al.

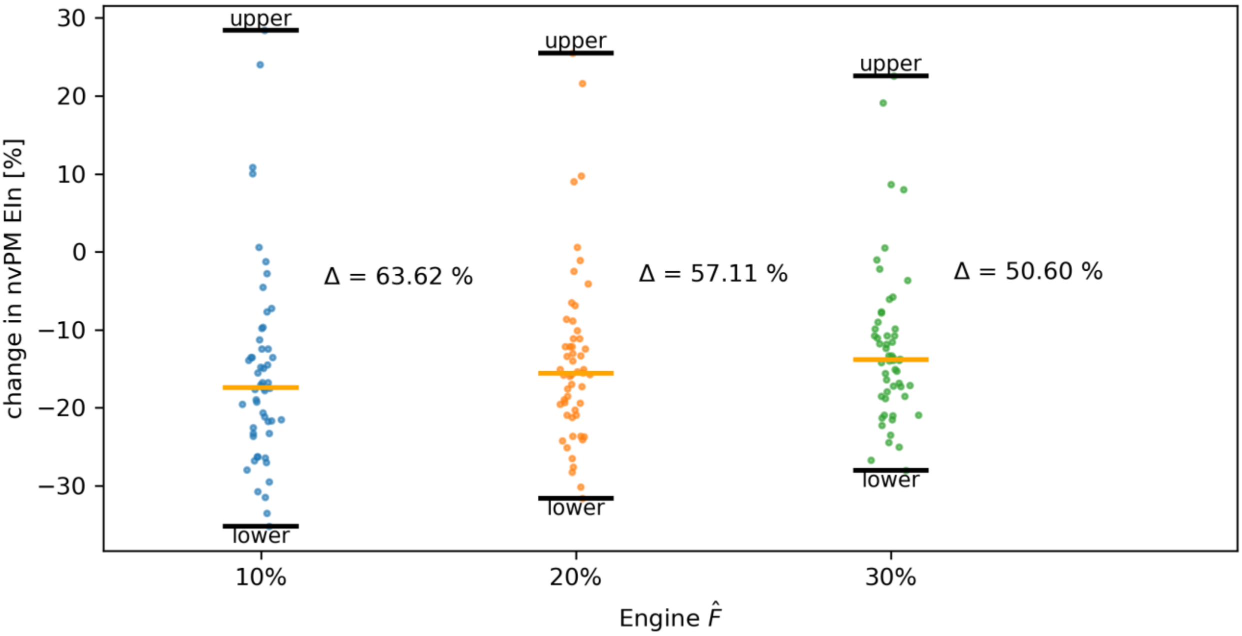


Figure 29: bandwith of change in nvPM emission index for the fuel samples at three thrust settings.

Potentials of future SAF blending

Although the FuelTrack campaign did not directly involve SAF blends, the fuel property data obtained from the CPH hydrant system sampling enables a theoretical assessment of the potential impact of increasing SAF blend ratios over the coming years. For this purpose, it was assumed that conventional jet fuels available at Copenhagen Airport during the campaign were blended with neat HEFA SAF, following the ReFuelEU trajectory for future minimum blending requirements.

Figures 30 and 31 present the resulting trends for total aromatics and hydrogen content, respectively. Blue boxplots indicate the property ranges of the simulated blends based on the CPH dispenser sample data. For comparison, black boxplots represent the corresponding properties derived from the CRC world fuel survey data. On the far right of each figure, values from the unblended aircraft samples collected during the campaign are shown. Dashed green lines indicate the aromatics and hydrogen content of the SAF blend used during the short-term SAF measurement conducted in February 2023.

Based on the hydrogen content of the modeled blends, changes in the non-volatile particle mass emission index (EIn) were estimated using the correlation approach outlined in the previous section. Figure 32 shows the predicted change in EIn relative to the conventional fuel baseline (0% SAF), based on the median values across all CPH dispenser samples. Results are provided for three different engine thrust settings.

At a 10% thrust setting and a projected 34% SAF blend in 2040, an approximate 35% reduction in EIn is predicted—closely aligning with the findings from the short-term SAF measurement campaign in 2023.

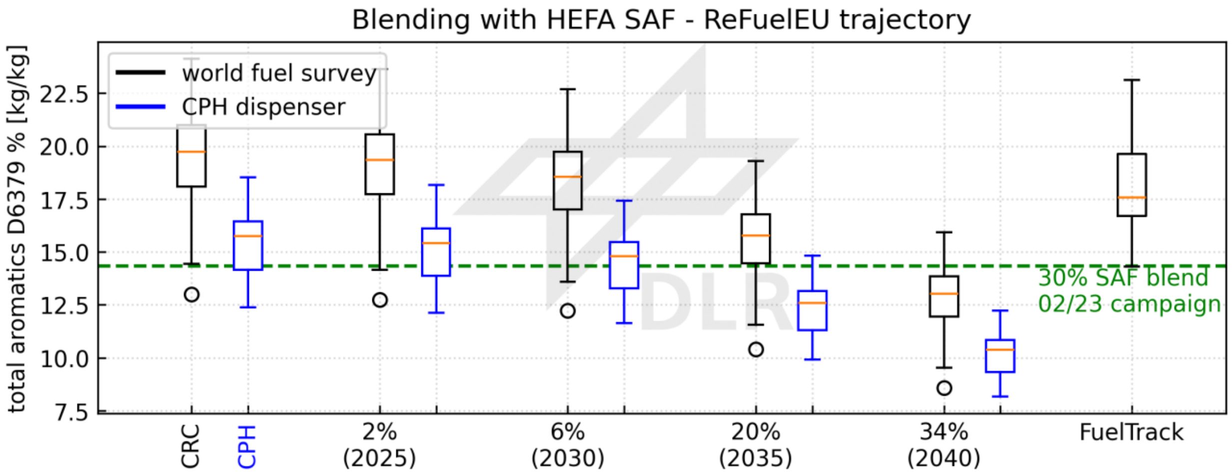


Figure 30: modelled trends for total aromatics when blending CPH fuel samples with SAF over the ReFuelEU trajectory.

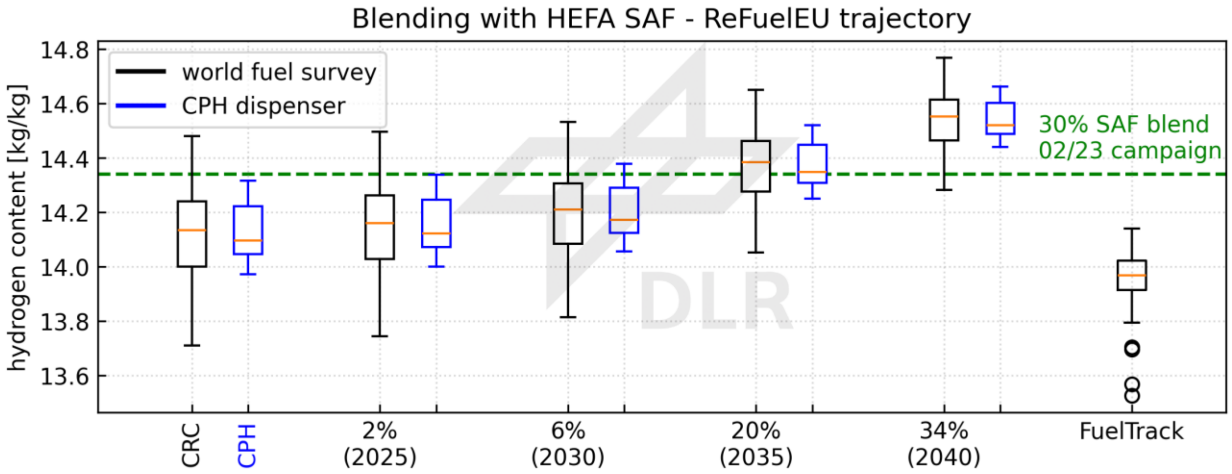


Figure 31: modelled trends for hydrogen content when blending CPH fuel samples with SAF over the ReFuelEU trajectory.

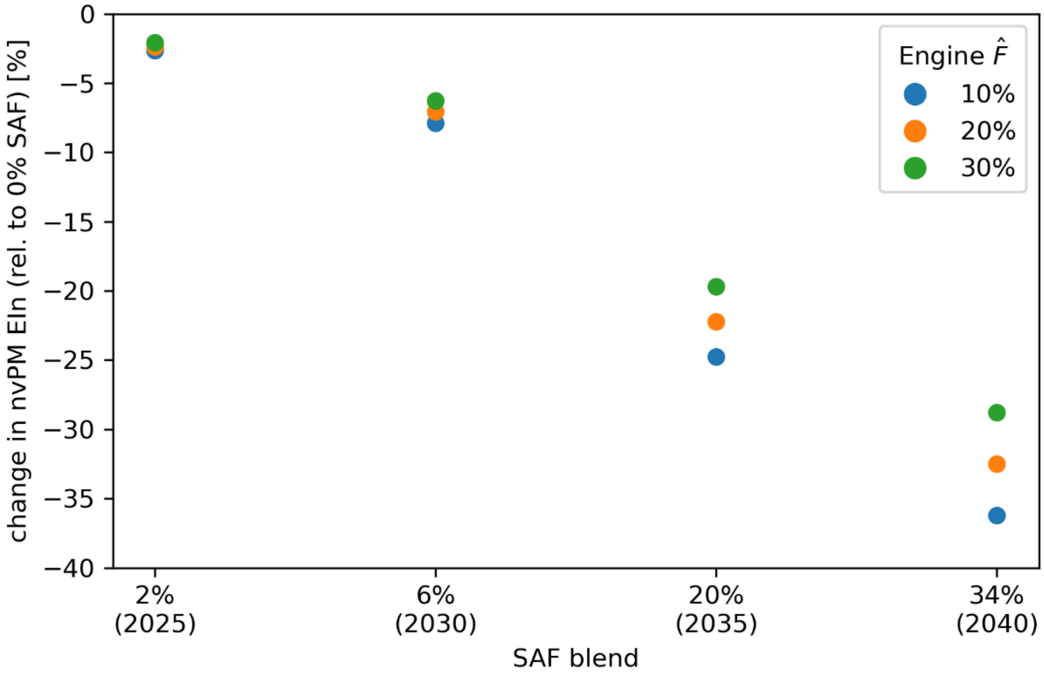


Figure 32: modelled change in nvPM emission index over the ReFuelEU trajectory.

5 LASPORT Simulation

5.1 Objective

Sustainable alternative jet fuels (SAJF) can reduce pollutant emissions from aircraft engines. In this task, which was carried out in the context of the EU Horizon 2020 project ALIGHT (Smart Airport Lighthouse), emission and dispersion calculations were carried out for Copenhagen Airport with the dispersion model system LASPORT. It was investigated how SAJF blends reduce the annual emissions and concentrations due to aircraft main engines and auxiliary power units (APU) at and around the airport.

Airport data were provided by Copenhagen Airport, meteorological data were taken from the Meteoblue database. Following the proposal of Copenhagen Airport, emission reductions were calculated from the Report 41 of the Airport Cooperative Research Program (ACRP 41) (2) for the substances SO_x , CO, and nvPM (ultrafine particles, mass and number).

The emission reductions provided in ACRP 41 refer to fleet-averaged emissions and were therefore applied in the form of overall emission reductions. As concentration is proportional to emission, the effects of emission reduction on concentration were simply derived by an according reduction of the aircraft-induced concentrations. They were calculated as annual averages for the given base case.

5.2 Methodology

Copenhagen Airport was set up with the model system LASPORT. Airport layout and aircraft traffic data were provided by Copenhagen Airport. Meteorological data were not provided and extracted from the commercial data service Meteoblue.

5.2.1 LASPORT

LASPORT (LASAT for Airports) is a program system for the calculation of emissions and concentrations at and around an airport (3), (4). It is the standard model tool of the German Airport Association and has been applied in various national and international projects (e.g. (4), (5), (6), (7). It has been approved for use in ICAO/CAEP (8) and complies to ICAO document 9889 (9).

Aircraft can be modelled individually as moving emission sources with a time resolution down to 10 seconds (monitor mode) or based on more generalised information on aircraft traffic which is then mapped on an hourly basis to stationary systems of line sources (scenario mode). In this task, the computationally more efficient scenario mode was applied, it provides sufficient detail for the task.

Aircraft are grouped into more generalised categories (aircraft groups) and for each category the number of annual movements, their distribution on runways and position areas, and their average time courses are specified. Fuel flows and emission indices are provided for every LTO segment, where the LASPORT default values were applied. These are based on the ICAO engine emission databank (ICAO EEDB), ICAO document 9889 and a typical fleet mix at a medium size airport (ZRH).

Other sources (e.g., APU, GPU, GSE, landside and airside motor traffic) can be modelled as point, line, area, or volume sources with time-dependent emissions. In this task, only APU were considered as they are the only other SAJF consuming device beside the aircraft main engines. APU emissions are located at the apron areas which were modelled as area sources. APU emissions were determined for each hour by the number of aircraft at the position area, the airport-provided running times, and the specifications provided in ICAO document 9889.

LASPORT applies the Lagrangian particle model LASAT as dispersion core. LASAT conforms with the standard VDI 3945-3 (particle model) (10) and has been the basis for the development of the German regulatory model AUSTAL, the official reference model of the Technical Instruction on Air Quality Control (TA Luft) (11) (12). LASAT is also applied as dispersion module in more complex software systems like LASPORT and LASAIR.

Typical results from LASPORT are the annual emission inventory of an airport, the near-ground concentration distributions according to EU regulations (e.g., annual means and maximum daily means) and the time series of concentrations (usually hourly means) at given monitor stations.

5.2.2 Airport layout and aircraft movements

Figure 33 shows the basic layout of Copenhagen Airport with the two parallel runways 22R/04L and 22L/04R and the shorter runway 30/12. The apron (position) areas are marked in red and the net of taxiways in green. The departure routes were assumed to be straight lines which is a reasonable assumption in this context.

Figure 34 shows the number of annual LTO (landing-takeoff cycles) and their distribution over the aircraft groups. Aircraft type examples are:

- Large: A380, A343, B748
- Medium: A359, B763, B789
- Small: A319, A320, A321, B738
- Regional: E190, CRJ9, F900
- Business: C25A, E50P, E55P
- Turboprop: DH8D, AT45, D328
- Piston: C172, PA28, DA62

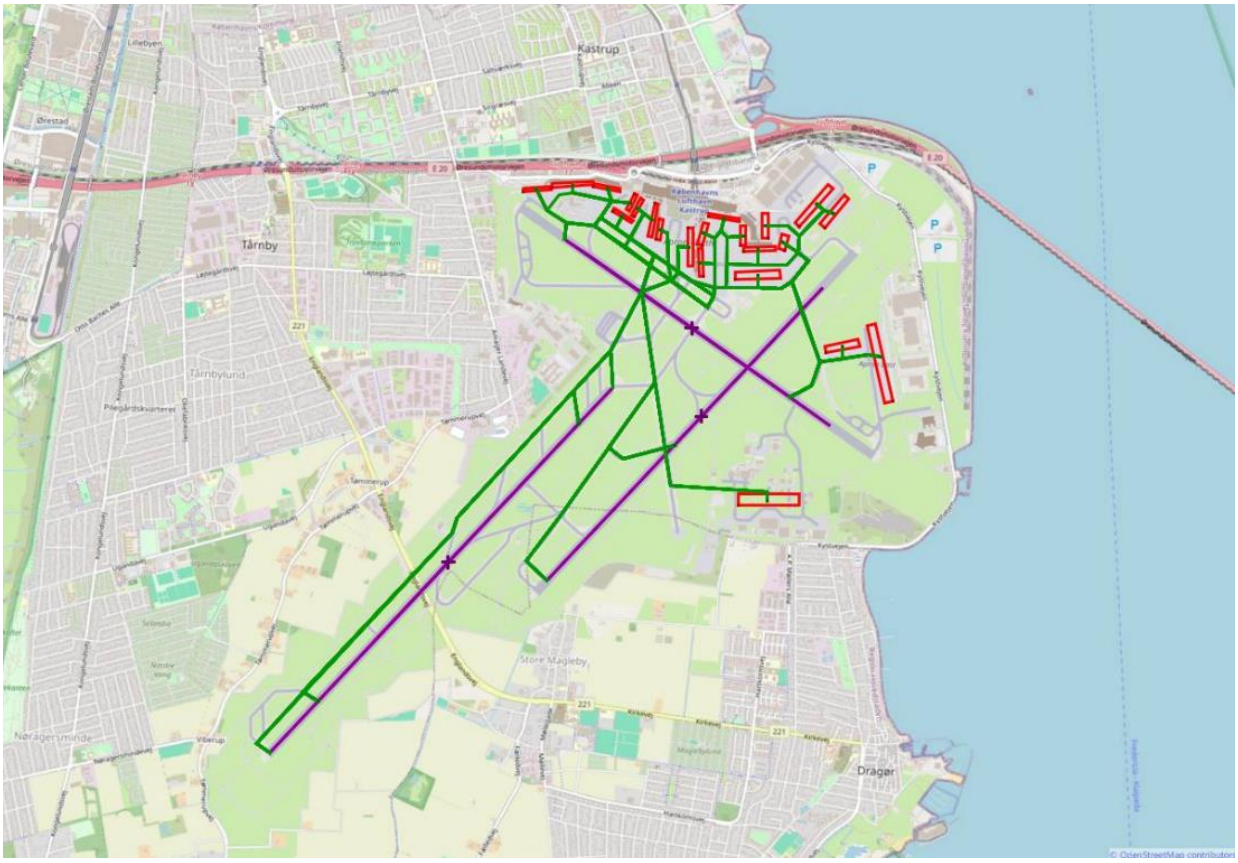


Figure 33: LASPORT layout of Copenhagen Airport with runways (magenta), position areas (red), and taxiways (green). (background: OpenStreetMap and Contributors)

The dominant aircraft group is Small which constitutes about 67% of all movements. Helicopter movements were neglected.

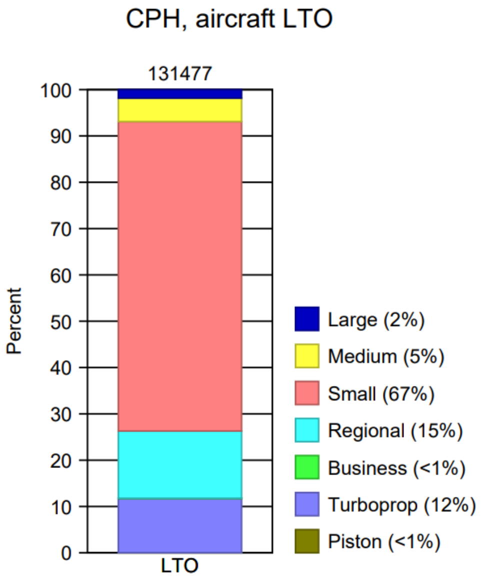


Figure 34: Annual landing-takeoff cycles (LTO) per aircraft group and in total

Figure 35 shows the distribution of movements over the arrival and departure runways. Main arrival runway is 22L and main departure runway is 22R across all aircraft groups.

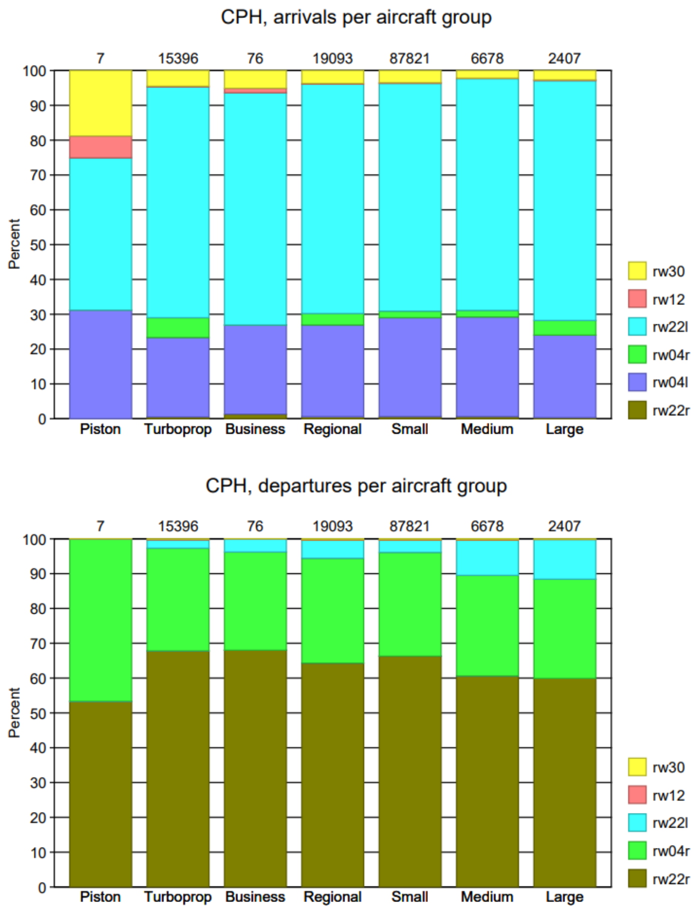


Figure 35: Distribution of arrivals and departures over the runways

5.2.3 **Meteorology**

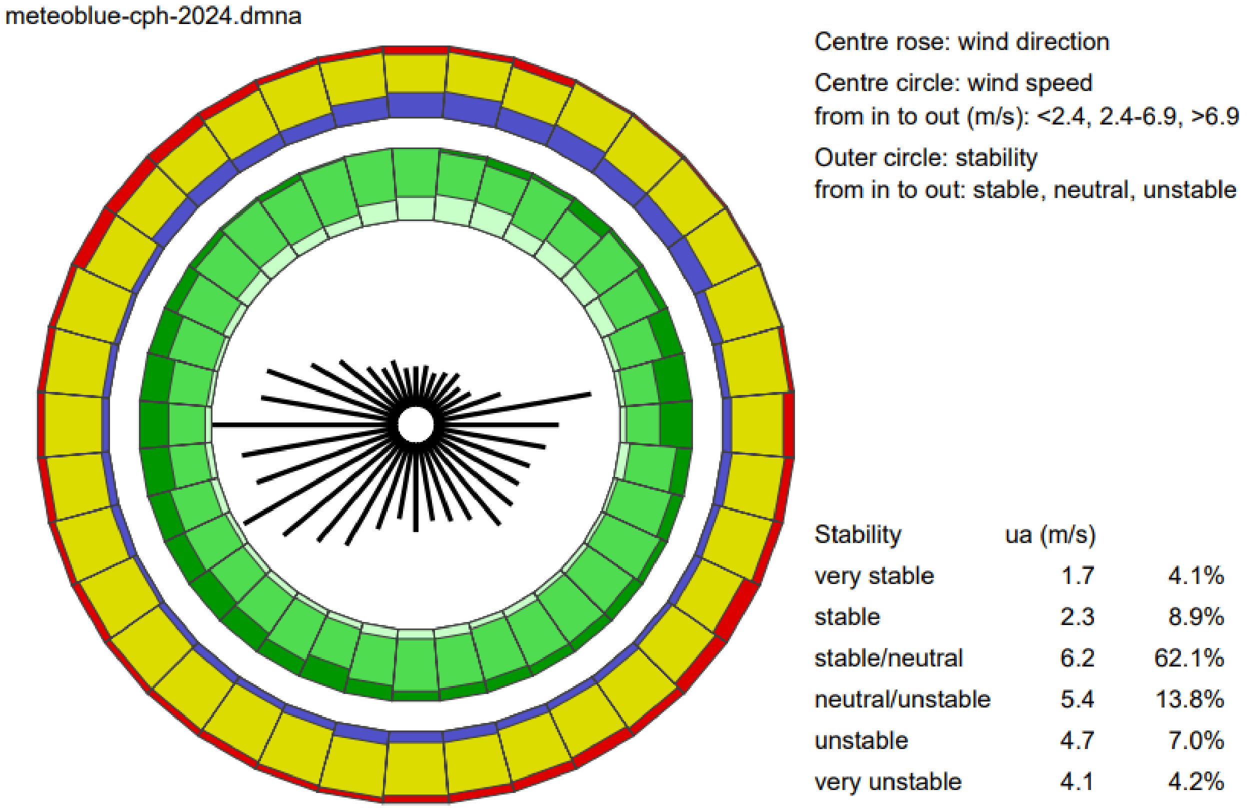
A meteorological time series with hourly values of wind speed, wind direction, temperature, and cloud cover for Copenhagen and the calendar year 2024 was ordered from the data provider Meteoblue. The data refer to a height of 10 m above ground level.

The surface roughness length to which the data apply was assumed as 0.1 m. The average surface roughness length of the calculation area was estimated as 0.3 m. Wind data was transferred to this increased roughness length by applying a modified anemometer height of 15.4 m according to the standard VDI 3783-8 (13).

Stability classes (from very stable to very unstable) were then calculated according to the standard VDI 3782-6 (14) and converted into Obukhov lengths (continuous stability parameter) according to the standard VDI 3783-8.

Wind speed, wind direction, and Obukhov length were then applied hour by hour as input parameters in LASPORT to initialize the boundary layer model according to the standard VDI 3783-8.

Figure 36 shows a statistical evaluation of the meteorological time series. Table 2 shows the statistical distribution of stability classes over the hours of the day (GMT+1).



Stability	ua (m/s)	
very stable	1.7	4.1%
stable	2.3	8.9%
stable/neutral	6.2	62.1%
neutral/unstable	5.4	13.8%
unstable	4.7	7.0%
very unstable	4.1	4.2%

Figure 36: Statistical evaluation of the meteorological time series.

In the dispersion calculation, meteorological data (and movement data) were applied as hourly values and the non-stationary concentrations were calculated as subsequent hourly means for the complete calendar year and then averaged to obtain the annual mean concentration.

Class	[00,03]	[03,06]	[06,09]	[09,12]	[12,15]	[15,18]	[18,21]	[21,24]
Very stable	10	8	2	0	0	0	3	10
Stable	14	13	10	1	0	4	14	14
Stable/neutral	76	79	74	52	33	43	63	76
Neutral/unstable	0	0	9	23	32	29	17	0
Unstable	0	0	5	16	16	15	3	0
Very unstable	0	0	0	6	19	9	0	0

Table 2: Statistical distribution of stability classes over the hours of the day (GMT+1), in percent.

5.3 Base case

The base case is the one with no SAJF corrections. The emission inventory is shown in Figure 37 (upper part). Emissions from main engines (AC) were summed up to a height of 3000 ft (914.4 m) above ground level which is a commonly applied upper height for aircraft emission inventories. Emissions from aircraft main engines dominate, with APU contributing less than 5% except for non-volatile PM mass, where the contribution is a bit more than 20%.

Figure 37 (lower part) shows the distribution of main engine emissions over the segments of the LTO. Here, the maximum height was reduced to 1000 ft (304.8 m) above ground level to provide a more meaningful comparison across the segments: The higher the emission release above ground level, the smaller is the contribution to the near ground concentration. Emissions above some 100 m (approach, climb) contribute only very little in comparison to near-ground emissions (idle, takeoff). Taxiing makes the main contribution to the emission of SO_x, CO, and nvPN (non-volatile PM number), whereas it is the takeoff segment for NO_x.

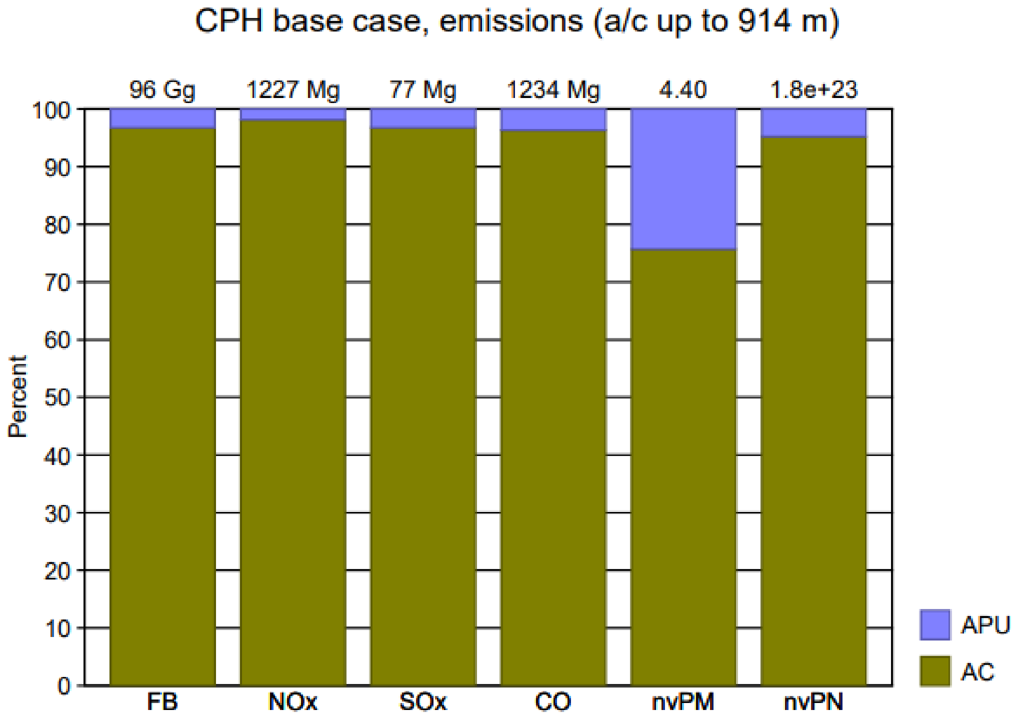
Figures 38 to 40 show the results of the dispersion calculation for SO_x, CO, nvPM (mass), nvPN (number), and NO_x.

Also shown in the graph are 2 monitor locations M1 (about 1 km North-east of the airport) and M4 (about 2 km West from the airport). In the next section, concentrations at these stations are explicitly addressed.

5.4 SAJF usage

Copenhagen Airport provided SAJF blend fractions for future years in accordance with current expected ReFuelEU Aviation blend-in requirements. ACRP 41 provides overall emission correction factors for a given blend fraction up to 50% blend-in. As the correction factors apply equally to all emissions that are studied in this task (main engines and APU), the correction factors apply also to the concentrations of the base case (concentration is proportional to emission). Hence it is not required to make a new calculation for every SAJF scenario. Instead, the emissions and concentrations can be obtained simply by multiplication of the base case results with the according correction factors.

The ACRP 41 correction factors apply to jet engines, not to pistons. Therefore, piston and jet aircraft must be handled separately. Given the extremely small amount of piston aircraft at Copenhagen Airport (see Figure 35) this can be omitted and the correction factors were applied to all movements.



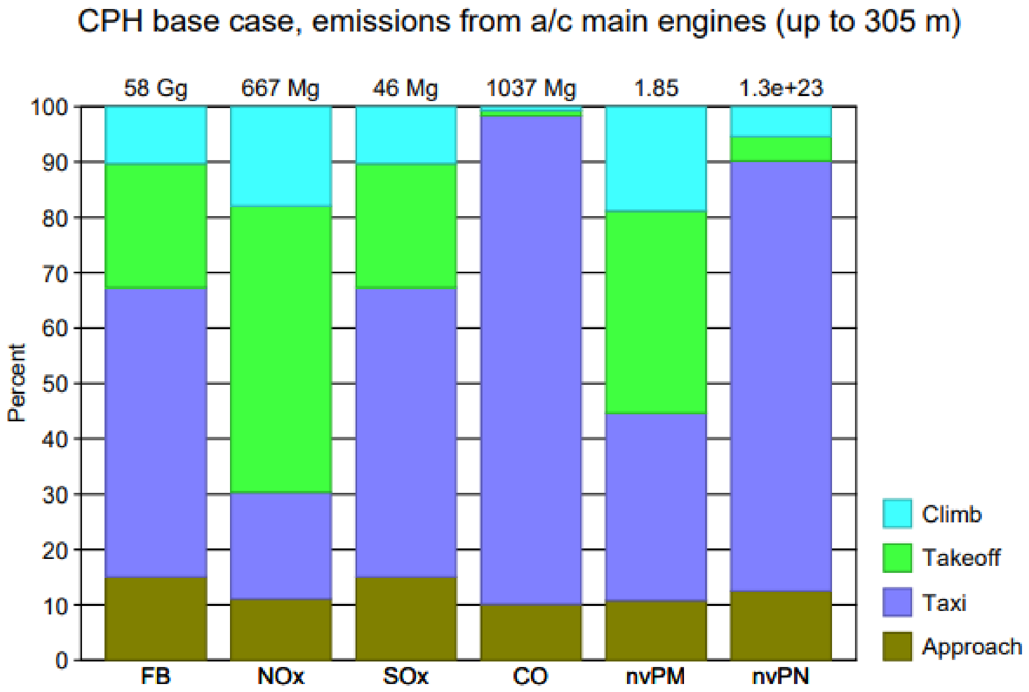


Figure 37: Upper part: Annual emission inventory (aircraft main engines, AC, and APU) with aircraft emissions up to 3000 ft (914.5 m). Lower part: Distribution of annual emissions from aircraft main engines up to 1000 ft (304.8 m) over the segments of the LTO.

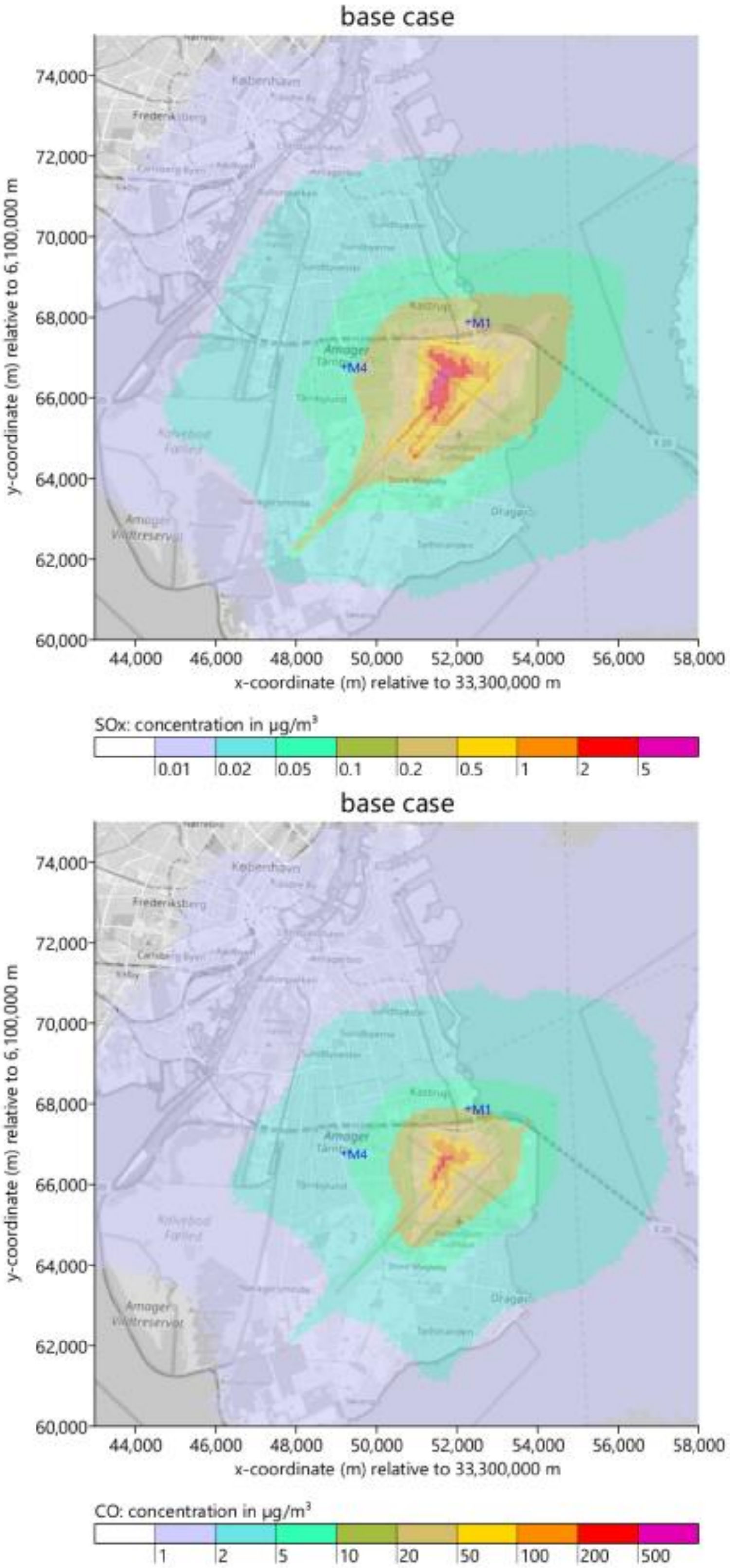


Figure 38: Annual mean concentrations near ground of SO_x and CO due to aircraft main engines and APU (base case without SAJF). (background: OpenStreetMap and Contributors)

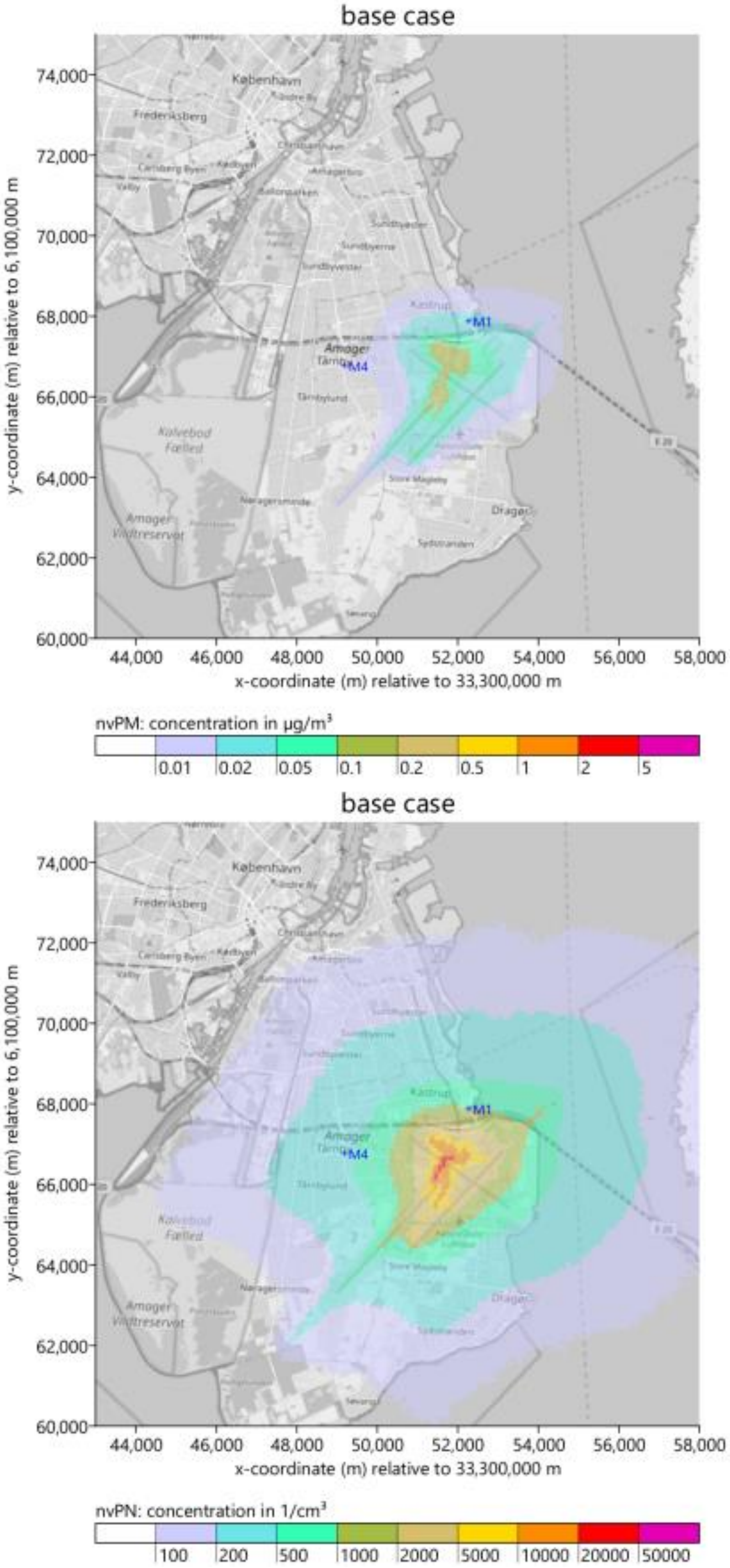


Figure 39: Annual mean concentrations near ground of nvPM and nvPN due to aircraft main engines and APU (base case without SAJF). (background: OpenStreetMap and Contributors)

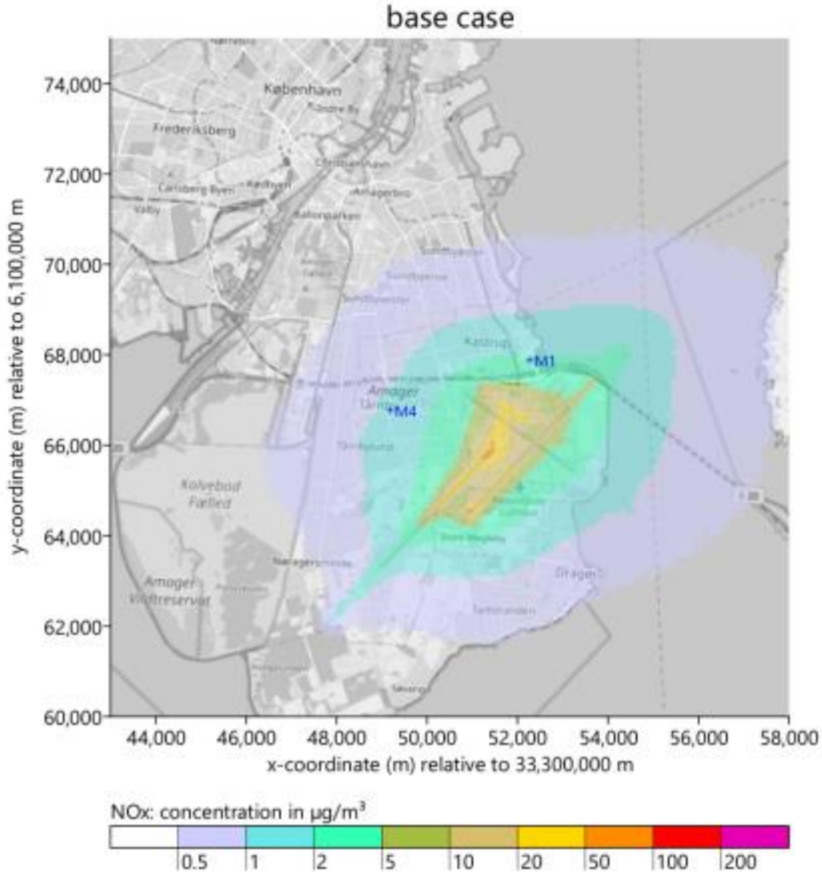


Figure 40: Annual mean concentrations near ground of NOₓ due to aircraft main engines and APU (base case without SAJF). (background: OpenStreetMap and Contributors)

5.4.1 ACRP 41 correction factors

ACRP provides an interactive tool for the calculation of reductions r as a function of SAJF blend fraction and pollutant. However, some underlying assumptions are hidden and the tool does not allow to handle nvPN (non-volatile particle number).

Therefore, the original formulas of ACRP 41 for SO_x, CO, nvPM, nvPN, UHC (unburned hydrocarbons), NO_x, and HAP (hazardous air pollutants) were implemented in a small computer program to calculate the correction factors. The formulas are listed in the following, where B refers to the blend fraction in percent (value between 0 and 100).

$$r_{SOx} = \frac{B}{100}\left(\frac{S_s}{S_c} - 1\right) \tag{1}$$

$$r_{CO} = -2.16 * 10^{-3} B \tag{2}$$

$$r_{nvPM} = -1.90 * 10^{-2} B + 1.20 * 10^{-4} B^2 \tag{3}$$

$$r_{nmPN} = -1.25 * 10^{-2} B + 5.91 * 10^{-5} B^2 \tag{4}$$

$$r_{UHC} = -0.3482 \tanh{(0.322B)} \tag{5}$$

$$r_{NO_x} = 0 \tag{6}$$

$$r_{HAP} = 0 \tag{7}$$

S_s is the fuel sulfur content of the SAJF and S_c is the fuel sulfur content of the conventional jet fuel. From the results of the ACRP tool it can be deduced that it assumes $S_\mathrm{s}/S_\mathrm{c}$ = 1/4. This ratio was applied also for the following calculations. Note that the formula for r_{SOx} is misspelled in Table 1 of ACRP 41. The correct formula is given at the end of Section 4.1 in ACRP 41.

The correction factor f, by which emissions and concentrations are multiplied to obtain the results with SAJF blend, is

$$f = 1 + r \tag{8}$$

for each pollutant.

For the blend percentages provided by Copenhagen Airport for different future years, the resulting correction factors are listed in Table 3.

Year	Blend(%)	SO_x	CO	nvPM	nvPN	UHC	NO_x	HAP
2025	2	0.9850	0.9957	0.9625	0.9752	0.8024	1.000	1.000
2030	6	0.9550	0.9870	0.8903	0.9271	0.6661	1.000	1.000
2035	20	0.8500	0.9568	0.6680	0.7736	0.6518	1.000	1.000
2040	34	0.7450	0.9266	0.4927	0.6433	0.6518	1.000	1.000
2045	42	0.6850	0.9093	0.4137	0.5793	0.6518	1.000	1.000
2050	50	0.6250	0.8920	0.3500	0.3500	0.6518	1.000	1.000

Table 3: Reference years, assumed SAJF blend fractions and correction factors $f = 1 + r$ resulting from the ACRP 41 reductions r.

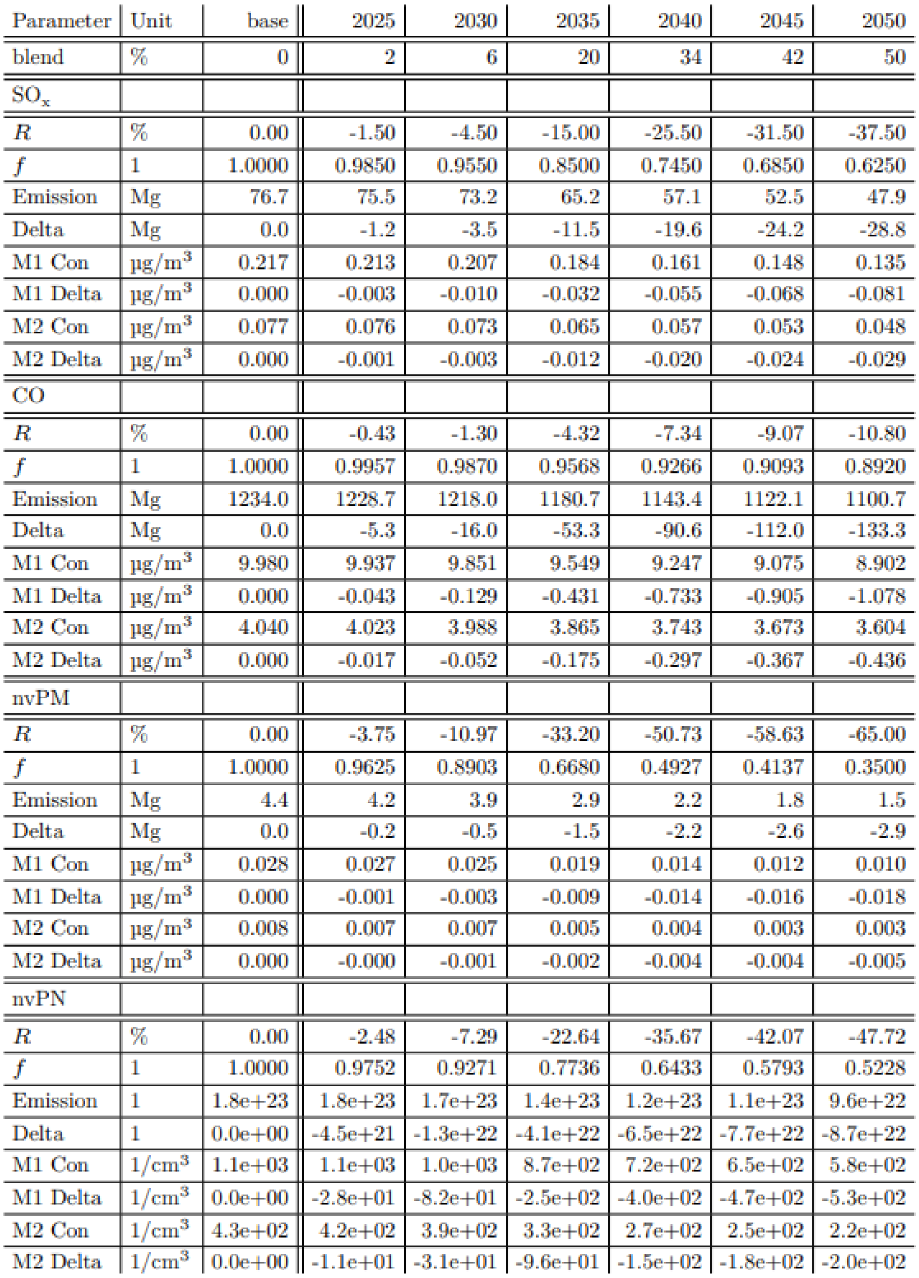
Reductions for NO_x and HAP were 0 and thus not studied further. A reduction of UHC was not considered in the following because the emission data bases did not distinguish between fully, partly and unburned hydrocarbons.

5.5 Results and discussion

5.5.1 Results LASPORT

Figure 41 lists in a compact format the reference years with the associated SAJF blend percentages and for each reference year and substance

- the reduction in percent ($R = 100r$) and the associated correction factor $f = 1{+}r$,
- the annual emission up to 3000 ft (emission in the base case times the correction factor) and the absolute difference (Delta) to the base case,
- the concentration at the monitor locations M1 and M2 (concentration in the base case times the correction factor) and the absolute difference (Delta) to the base case.



Parameter	Unit	base	2025	2030	2035	2040	2045	2050
blend	%	0	2	6	20	34	42	50
SO_x								
R	%	0.00	-1.50	-4.50	-15.00	-25.50	-31.50	-37.50
f	1	1.0000	0.9850	0.9550	0.8500	0.7450	0.6850	0.6250
Emission	Mg	76.7	75.5	73.2	65.2	57.1	52.5	47.9
Delta	Mg	0.0	-1.2	-3.5	-11.5	-19.6	-24.2	-28.8
M1 Con	$\mu g/m^3$	0.217	0.213	0.207	0.184	0.161	0.148	0.135
M1 Delta	$\mu g/m^3$	0.000	-0.003	-0.010	-0.032	-0.055	-0.068	-0.081
M2 Con	$\mu g/m^3$	0.077	0.076	0.073	0.065	0.057	0.053	0.048
M2 Delta	$\mu g/m^3$	0.000	-0.001	-0.003	-0.012	-0.020	-0.024	-0.029
CO								
R	%	0.00	-0.43	-1.30	-4.32	-7.34	-9.07	-10.80
f	1	1.0000	0.9957	0.9870	0.9568	0.9266	0.9093	0.8920
Emission	Mg	1234.0	1228.7	1218.0	1180.7	1143.4	1122.1	1100.7
Delta	Mg	0.0	-5.3	-16.0	-53.3	-90.6	-112.0	-133.3
M1 Con	$\mu g/m^3$	9.980	9.937	9.851	9.549	9.247	9.075	8.902
M1 Delta	$\mu g/m^3$	0.000	-0.043	-0.129	-0.431	-0.733	-0.905	-1.078
M2 Con	$\mu g/m^3$	4.040	4.023	3.988	3.865	3.743	3.673	3.604
M2 Delta	$\mu g/m^3$	0.000	-0.017	-0.052	-0.175	-0.297	-0.367	-0.436
nvPM								
R	%	0.00	-3.75	-10.97	-33.20	-50.73	-58.63	-65.00
f	1	1.0000	0.9625	0.8903	0.6680	0.4927	0.4137	0.3500
Emission	Mg	4.4	4.2	3.9	2.9	2.2	1.8	1.5
Delta	Mg	0.0	-0.2	-0.5	-1.5	-2.2	-2.6	-2.9
M1 Con	$\mu g/m^3$	0.028	0.027	0.025	0.019	0.014	0.012	0.010
M1 Delta	$\mu g/m^3$	0.000	-0.001	-0.003	-0.009	-0.014	-0.016	-0.018
M2 Con	$\mu g/m^3$	0.008	0.007	0.007	0.005	0.004	0.003	0.003
M2 Delta	$\mu g/m^3$	0.000	-0.000	-0.001	-0.002	-0.004	-0.004	-0.005
nvPN								
R	%	0.00	-2.48	-7.29	-22.64	-35.67	-42.07	-47.72
f	1	1.0000	0.9752	0.9271	0.7736	0.6433	0.5793	0.5228
Emission	1	1.8e+23	1.8e+23	1.7e+23	1.4e+23	1.2e+23	1.1e+23	9.6e+22
Delta	1	0.0e+00	-4.5e+21	-1.3e+22	-4.1e+22	-6.5e+22	-7.7e+22	-8.7e+22
M1 Con	$1/cm^3$	1.1e+03	1.1e+03	1.0e+03	8.7e+02	7.2e+02	6.5e+02	5.8e+02
M1 Delta	$1/cm^3$	0.0e+00	-2.8e+01	-8.2e+01	-2.5e+02	-4.0e+02	-4.7e+02	-5.3e+02
M2 Con	$1/cm^3$	4.3e+02	4.2e+02	3.9e+02	3.3e+02	2.7e+02	2.5e+02	2.2e+02
M2 Delta	$1/cm^3$	0.0e+00	-1.1e+01	-3.1e+01	-9.6e+01	-1.5e+02	-1.8e+02	-2.0e+02

Figure 41: Reduction in percent (R), according correction factor f), and the resulting annual emissions and concentrations at monitor locations M1 and M2 for the different years (SAJF blend percentages) and substances.

5.5.2 Discussion LASPORT

The overall emission reduction of SO_x , CO and nvPM (mass and number) due to SAJF blend can be put into context with the full airport emission inventory and related issues, which was not subject of this task. However, a reduction of almost 40% for SO_x and almost 50% for non-volatile PM number for an assumed 50% SAJF blend in the year 2050 appears substantial, given that an airport is usually a dominant source of SO_x and ultrafine particles.

On the concentration side, the absolute reduction of SO_x which is of the order of 0.1 $\mu g/m^3$ or less in the airports vicinity appears of minor relevance, given an annual limit value of 20 $\mu g/m^3$ anticipated by the EU for the year 2030 (15). Similar applies to CO and non-volatile PM mass.

For non-volatile PM number concentration, an absolute reduction of up to 500 $1/cm^3$ until the year 2050 seems more noticeable:

There is no ambient limit value for PM number, but the WHO regards ambient daily mean concentrations of PM (above 10 nm) below 1000 $1/cm^3$ as low and above 10000 $1/cm^3$ as high (16). Total PM consists of non-volatile and volatile PM, the number fraction of non-volatile PM in total PM from aircraft engines is of the order of 10% to 30%, and the number of volatile PM is mainly driven by the sulfur content of the fuel (17) (18) (19).

Therefore, it seems plausible to assume that a reduction of non-volatile PM number concentration of 500 $1/cm^3$ due to a 50% SAJF blend that also reduces SO_x by about 40% goes along with a reduction of total PM number concentration of several 1000 $1/cm^3$. This appears substantial when compared to the WHO definitions of low and high PM number concentration.

The ACRP 41 report does not suggest a major influence of SAJF on the aircraft NO_x emission. This is expected and noteworthy, considering that the annual limit value of NO_2 is reduced in the EU from presently 40 $\mu g/m^3$ to 20 $\mu g/m^3$ in the year 2030 (15), and given that NO_x contributions from vehicle traffic, the other major NO_x source at and around an airport, will continuously decrease over the next years due to electrification of the vehicle fleet.

6 Conclusions and recommendations

Following the three overarching questions regarding aviation fuels and the use of SAF at airports in relation to aircraft emissions, as defined in Section 2.2, the following conclusions and recommendations can be drawn from the demonstration activities presented in this report:

- **What is the current status?**
  Current jet fuel uplift continues to be dominated by conventional fossil-based Jet A-1, accounting for at least 98% of total volume. Although produced from a single primary feedstock—crude oil—significant variation in fuel properties can still be observed between different batches, even when remaining within ASTM D1655 specification limits. Additional variability arises within the airport fueling infrastructure and in the fuel tanks of arriving aircraft, both of which typically contain mixtures of multiple batches that cannot be individually traced.
  These variations in fuel composition have been shown to result in measurable differences in aircraft emissions. During the FuelTrack campaign, the fuel distributed through the Copenhagen Airport hydrant system exhibited slightly more favorable properties—particularly in terms of lower aromatic content and higher hydrogen content—compared to the average of the sampled incoming aircraft fuel.
- **What could be done in the near future?**
  Introducing stricter requirements for the fuel uplifted at an airport—such as setting a maximum allowable aromatic content—could serve as a potential mechanism for airports to actively promote improvements in the quality of conventional jet fuel. However, it remains an open question to what extent this cleaner fuel is actually burned during taxi-out, or whether emissions during this phase are still predominantly influenced by residual fuel from the inbound flight.
  To gain meaningful insight into the characteristics of the fuel actually uplifted at an airport, it is essential to conduct regular sampling at a strategic point in the hydrant system—specifically, at the export point from the fuel farm into the distribution network. Such data would not only improve transparency of fuel quality but also support the recently established EU monitoring, reporting, and verification (MRV) system for non-CO_2 effects in aviation.
  Moreover, as demonstrated during the FuelTrack campaign, a clear link exists between fuel properties and aircraft emissions. This relationship should be taken into account when designing emissions and air quality monitoring strategies at airports.
  While the trajectory for future SAF utilization is well defined by the ReFuelEU mandate, the SAF measurement campaign showed that only high SAF blend ratios result in measurable reductions in emissions. Due to the commingled nature of airport fuel storage and distribution systems, individual SAF batches are currently mixed and diluted, resulting in very low effective SAF blends at the aircraft wing.
  Efforts should therefore be made to incentivize SAF uplift beyond the minimum ReFuelEU requirements. One potential strategy could involve deploying available SAF volumes in high blends during periods of elevated air quality concern. However, such an

approach would require a segregated fuel storage and distribution system, which presents significant logistical challenges and additional costs.

While this report highlights SAF's potential to improve local air quality, economic and operational feasibility remain key considerations:

- Higher SAF blends demonstrate stronger emissions benefits; however, the current mixed and diluted SAF system diminishes their impact. Although physical segregation could preserve the benefits locally, it is also the most expensive chain-of-custody model.
- Furthermore, while the suggestion that blending mandates might improve emissions quality implies a higher SAF presence at specific airports, this assumption depends heavily on how such mandates are implemented.
- Additionally, introducing stricter aromatic content thresholds for jet fuel could further reduce particulate emissions, but such measures might have operational repercussions that must be weighed carefully.

- **What can be expected in the long term?**
  Over the coming decades, the volume of Sustainable Aviation Fuel (SAF) used at European airports is expected to increase substantially, in line with the ReFuelEU Aviation regulation, which mandates a progressive blending trajectory reaching up to 70% SAF by 2050. Modeling conducted under the ALIGHT project confirms that such high blend ratios can lead to significant reductions in emissions of ultrafine particles and sulfur oxides (SO_x).
  However, the transition will be gradual, and meaningful improvements in local air quality (particularly around airports) will take time to materialize. In the interim, cleaner conventional jet fuels with low aromatic content could play an important role in bridging the gap. As demonstrated in the FuelTrack campaign, even within the ASTM D1655 specification, fuel quality varies considerably, and lower aromatic content is consistently associated with reduced particle emissions. Setting aromatic content thresholds for uplifted fuel may therefore offer a practical and immediate pathway to mitigate local air pollution in the near as well as long term.
  It is also important to note that a significant share of the fuel actually burned at European airports originates from aircraft arriving from non-EU regions, where SAF mandates may not apply or may evolve differently over the coming decades. This introduces uncertainty regarding the global uptake of SAF and its cumulative impact on airport air quality.
  Continued monitoring and international collaboration will be essential to ensure that SAF deployment delivers consistent environmental benefits across the aviation network.

AIRCRAFT UTILIZATION

Aircraft movements on the ground include a range of standard operating procedures to reduce energy consumption. For instance single-engine taxiing is an effective means to lower fuel consumption during taxi. Energy management includes avoiding the use of speed brakes, follow APU policies and to only use electrical power and/or bleed air when needed. An airline should do the best possible within the circle of influence continuing to work with airports, ATC and other stakeholders. Especially the take-off phase is an energy demanding flight phase. SAS focus in particular on Technological development; Operational efficiency; and Sustainable aviation fuel. SAS is identified as one of the more fuel-efficient carriers operating at Copenhagen Airport as recognized in the measurement campaign. ALIGHT enable additional opportunities for targeted emissions reductions for all operators at the airport. From an airline perspective the field performance monitoring show the additional value of scaling up the voluntary volumes of SAF beyond the mandated volumes in terms of the environmental benefits in the vicinity of an airport. A conclusion from the airline perspective is the priority to source low aromatic fuel from the fuel providers.

7 References

1. **Durdina, L., et al.** Gaseous and Particulate Emissions from a Small Business Jet Using Conventional Jet A-1 and a 30% SAF Blend. *ACS ES&T Air.* 2 (5), 2025, Vols. pp. 967-978, DOI: 10.1021/acsestair.5c00053.

2. **Hamilton, Booz Allen and Virginia, McLean.** ACRP Report 41. Alternative Jet Fuels Emissions – Quantification Methods Creation and Validation Report. *National Academies.* [Online] 2019. https://nap.nationalacademies.org/catalog/25548/acrp-web-only-document-41-alternative-jet-fuels-emissions-quantification-methods-creation-and-validation-report.

3. **Janicke Consulting.** *LASPORT.* [Program system] 2025.

4. *LASPORT – A model system for airportrelated source systems based on a Lagrangian particle model.* **Janicke, U., Fleuti, E. and Fuller, I.** Cambridge, Great Britain. : Proceedings of the 11th International Conference on Harmonization within Atmospheric Dispersion Modeling for Regulatory Purposes, 2007.

5. *"Ultrafine particle dispersion modelling in the vicinity of the major airportFrankfurt/Main, Germany.* **H. Lorentz, U. Janicke, H. Jakobs, W. Schmidt, P. Hellebrandt, M. Ketzel, and H.** Bruges, Belgium : Proceedings of the 19th International Conference on Harmonization within Atmospheric Dispersion Modeling for Regulatory Purposes., 2019.

6. *Time resolved aircraft dispersion modelling.* **U. Janicke, E. Montreuil, W. Ghedhaïfi, and E. Terrenoire.** s.l. : 3rd ECATS Conference, 2020.

7. *Application of Effective Conversion Rates between NO and NO2 in a Standard Airport Dispersion Model System.* **Janicke, U.** 5, Überlingen, Germany : atmosphere, 2024, Vol. 15.

8. **International Civil Aviation Organisation.** *ICAO Environmental Report 2010.* s.l. : ICAO, 2010.

9. —. ICAO document 9889: Airport Air Quality Manual. s.l. : ICAO, 2023. 3rd edition, 2023.

10. **VDI.** VDI 3945 Part 3 Environmental meteorology; atmospheric dispersion models;. [Online] [Cited: 02 05, 2025.] https://www.vdi.de/en/home/vdi-standards.

11. **TA Luft 2021.** Neufassung der Ersten Allgemeinen Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft – TA Luft) [New version of the first general administrative regulation to the federal immission control act]. [Online] 09 14, 2021. [Cited: 02 25, 2024.] https://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_18082021_IGI25025005.htm. GMBl. No. 48–54, 1050-1192, 2021.

12. **UBA.** Program system AUSTAL. [Online] Federal Environment Agency, Dessau-Roßlau, 09 06, 2024. Federal Environment Agency, Dessau-Roßlau,.

13. **VDI.** VDI 3783 Part 8. *Environmental meteorology; turbulence parameters for dispersion.* [Online] 2017. [Cited: 02 05, 2025.] Environmental meteorology; turbulence parameters for dispersion. https://www.vdi.de/en/home/vdi-standards.

14. —. VDI 3782 Part 6. *Environmental meteorology; atmospheric dispersion models;.* [Online] 2023. [Cited: 02 05, 2025.] https://www.vdi.de/en/home/vdi-standards.

15. **European Union.** EUR-Lex. *Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe (recast).* [Online] October 23, 2024. [Cited: May 29, 2025.] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202402881.

16. **WHO.** WHO global air quality guidelines. *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.* [Online] September 22, 2021. [Cited: May 29, 2025.] https://www.who.int/publications/i/item/9789240034228. 9789240034228.

17. **M.T. Timko, E. Fortner, J. Franklin, Z. Yu, H.-W. Wong, T.B. Onasch, R.C. MiakeLye, and S.C. Herndon.** “Atmospheric measurements of the physical evolution of aircraft exhaust plumes". *Environ. Sci. Technol.* 2013, Vols. pp. 3513-3520, 47.

18. **B. Owen, J.G. Anet, N. Bertier, S. Christie, M. Cremaschi, St. Dellaert, J.** Review: Particulate Matter Emissions from Aircraft. *Atmosphere.* 13, 2022, Vol. 8, https://doi.org/10.3390/atmos13081230.

19. **Miake-Lye, S.H. Jones and R.** “Parameterization of H2SO4 and organic contributions to volatile PM in aircraft plumes at ground idle. *Journal of the Air & Waste Management Association.* 74, 2024, Vols. pp. 490-510, https://doi.org/https://doi.org/10.1080/10962247.2024.2354820.

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