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D5.2 – Use Cases Definition

Document Author(s)	U. Gupta (CU), J. Pons-Prats (UPC), I. Mayeres (TML)
Document Contributor(s)	A. Riaz (CU), J. Huete (CU), S. Van der Loo (TML), X. Prats (UPC), F. Brenner (USTUTT), R. Grosmann (NLR), A. Junior (DLR), B. Danet (ONERA)

Abstract

This deliverable describes the scope of the three demonstration use cases of the Impact Monitor project, as well as the plan for their implementation in the Impact Monitor collaborative assessment framework and their connection to the Impact Monitor dashboard application.

The aim of the use cases is to demonstrate the capability of the Impact Monitor framework and its dashboard application, and not to carry out the studies (with their quantified KPIs) used for this demonstration.

Keywords

Demonstration, Use Cases, Implementation, Framework, Dashboard Application

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Authoring & Approval

Prepared by		
Name and Organisation	**Position and title**	**Date**
Atif Riaz (CU)	WP5 Task Lead, Dr	15/10/2023
Utkarsh Gupta (CU)	WP5 Task Lead, Mr	15/10/2023
Jon Huete (CU)	WP5 Task Lead, Dr	15/10/2023
Inge Mayeres (TML)	WP5 Task Lead, Dr	15/10/2023
Saskia Van der Loo (TML)	WP5 Participant, Dr	15/10/2023
Jordi Pons-Prats (UPC)	WP5 Task Lead, Dr	15/10/2023
Xavier Prats (UPC)	WP5 Participant, Dr	15/10/2023
Felix Brenner (USTUTT)	WP5 Participant, Mr	15/10/2023
Ronald Grosmann (NLR)	WP5 Participant, Mr	15/10/2023
Alf Junior (DLR)	WP5 Participant, Mr	15/10/2023
Brieuc Danet (ONERA)	WP5 Participant, Mr	15/10/2023

Reviewed by		
Name and Organization	**Position and title**	**Date**
Giota Sakellariou (EASN-TIS)	WP6 Lead, Mrs	06/11/2023
Michel Van Eenige (NLR)	WP1 Lead and WP5 Participant, Dr	17/11/2023
Thierry Lefebvre (ONERA)	WP5 Lead, Mr	29/11/2023
Patrick Ratei (DLR)	Project Coordination Team, Mr	29/11/2023

Approved for submission by		
Name and Organization	**Position and title**	**Date**
Prajwal Shiva Prakasha (DLR)	Project Coordination Team, Mr	30/11/2023

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Table of Acronyms and Abbreviations

Acronym/Abbreviation	Description / Meaning
ACN	Aircraft Classification Number
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
ATS	Air Transport System
BPR	Bypass Ratio
CDO	Continuous Descent Operations
CINEA	European Climate, Infrastructure and Environment Executive Agency
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPACS	Common Parametric Aircraft Configuration Schema
CU	Cranfield University
DA	Dashboard Application
EEA	European Economic Area
EIS	Entry Into Service
ETS	Emission Trading System
FPR	Fan Pressure Ratio
GA	Grant Agreement
GDP	Gross Domestic Product
GVA	Gross Value Added
ICA	Initial Climb Altitude
ILUC	Induced Land Use Change
ISA	International Standard Atmosphere
KER	Kerosene
KPI	Key Performance Indicator
MDAX	MDAO Workflow Design Accelerator
MLW	Maximum landing weight
MRO	Maintenance, Repair and Operations
MTO, MCL and MCR	Maximum Take-off, Maximum Climb and Maximum Cruise Thrust
MTOW	Maximum take-off weight

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NPV	Net Present Value
OAG	Official Airline Guide
OD (pair)	Origin - Destination (pair)
OEI	One Engine Inoperative
OPR	Overall Pressure Ratio
RCE	Remote Component Environment
R&I	Research & Innovation
SAF	Sustainable Aviation Fuels
SPP	Standard Payload Passenger
TET	Turbine Entry Temperature
TLAR	Top Level Aircraft Requirement
TMA	Terminal Control Area
TTC	Time-To-Climb
TTW	Tank to Wheel
UC	Use Case
ULR	Ultra-Long Range
UHBR	Ultra-High Bypass Ratio
VHBR	Very High Bypass Ratio
WP	Work Package
XML	Extensible Markup Language
XWB	eXtra Wide Body
WTW	Well to Wheel

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1. INTRODUCTION

The main objective of the Impact Monitor project is to deliver a coherent and holistic framework and toolbox that aim to become the reference choice for technology and policy assessment of the environmental, economic and societal impact of European aviation R&I. The comprehensive Impact Monitor framework is composed of two tightly connected elements:

- A scalable, open source, distributed and multidisciplinary MBSE framework dedicated to collaborative assessment;
- A web-based environment employed at the post-processing stage for design space exploration and studies analysis;

Within this project Work Package (WP) 5 develops three example Use Cases (UCs) that aim to demonstrate the capability of the Impact Monitor framework.

Figure 1 provides an overview of the work-breakdown structure of the Impact Monitor project with a focus on the interaction between the WPs 3 to 5, which focus on the technical development and implementation.

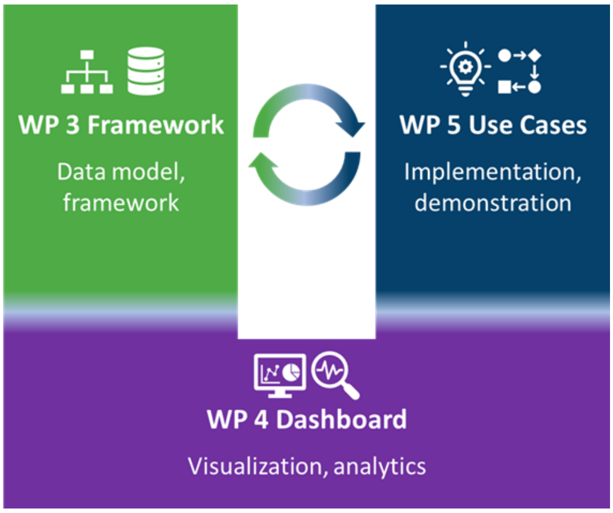

Figure 1: Impact Monitor Work-breakdown Structure for Technical Development and Implementation.

More specifically, every UC targets:

- An environmental-, economic- and/or societal-impact assessment of an exemplary (although hypothetical) R&I innovation in aviation;
- One or more assessment levels (i.e., aircraft, airport and/or air-transport system level);
- A dedicated subset of the requirements of the Impact Monitor framework, as specified in WP3 and reported in the Impact Monitor document D3.1 [1];
- A dedicated subset of the requirements of the Impact Monitor Dashboard Application, as specified in WP4 and reported in the Impact Monitor document D4.1 [2].

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The implementation of the three demonstration UCs follows four steps from the definition of the scenario definition to the selection of the models, which are then integrated into collaborative workflows in order to compute and provide the desired metrics for the quantitative assessment of the defined scenario. Figure 2 illustrates the sequence of these implementation steps, which are carried out by all three demonstration UCs.

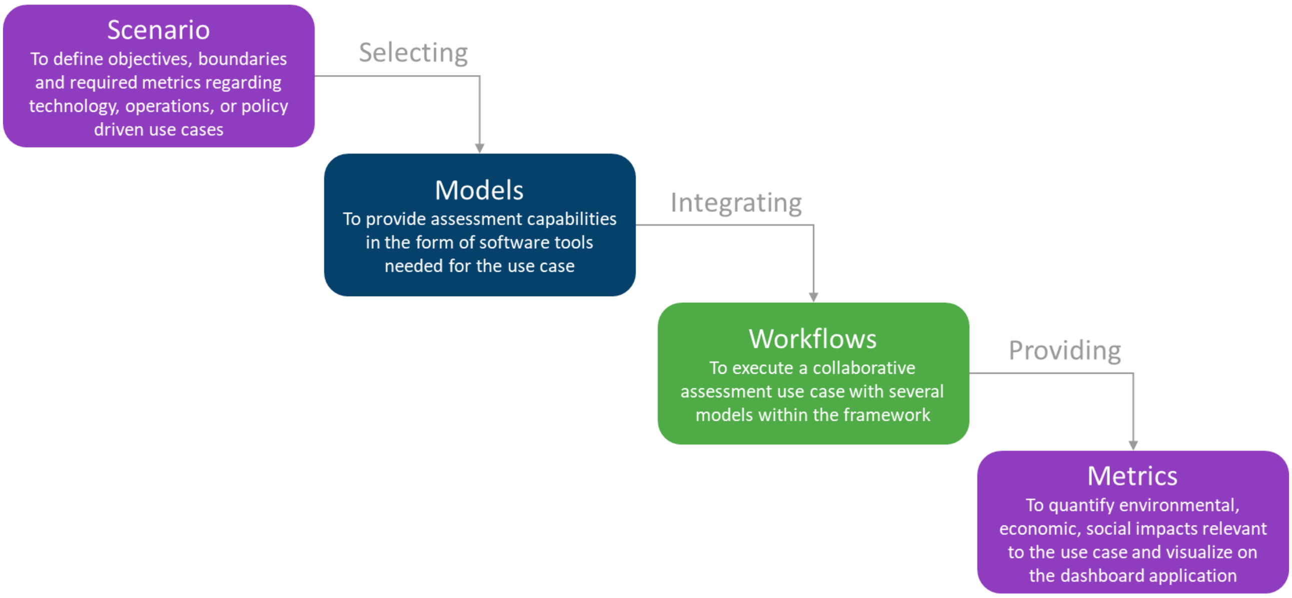

Figure 2: Implementation Steps for the Demonstration Use Cases

Jointly, the three UCs address all three assessment levels. Furthermore, these UCs intend to consider expected needs coming from selected stakeholders identified in WP2 and to produce key performance indicators (KPIs) identified in WP1.

The three UCs together with their respective assessment levels are shown in Figure 3 and are titled as follows:

- UC1: Advanced Propulsion System;
- UC2: Continuous Descent Operations;
- UC3: Sustainable Aviation Fuel.

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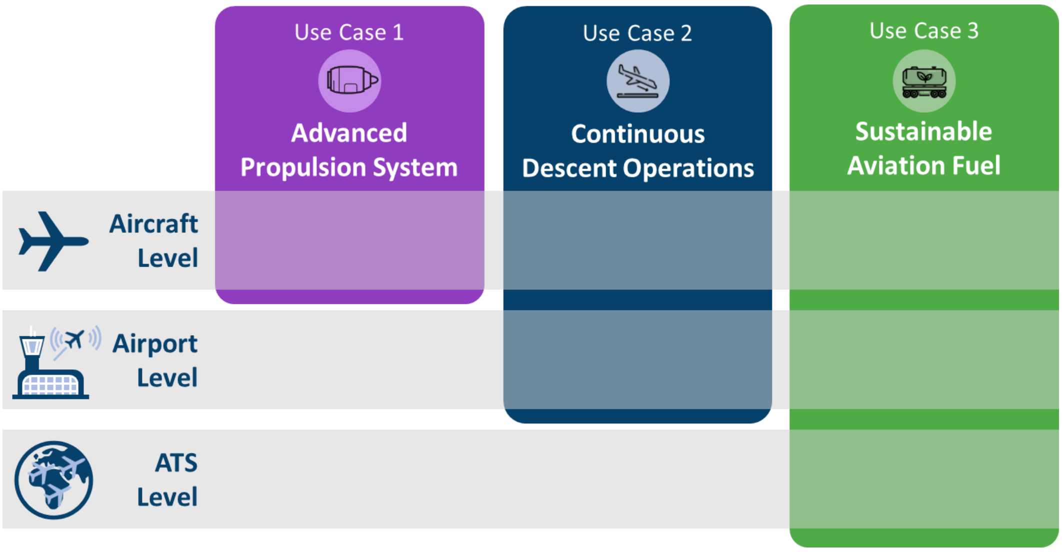

Figure 3: Schematic Representation of the Demonstration Use Cases and Assessment Levels

The present deliverable (D5.2) provides a specification of the three UCs, including their implementation and demonstration plans. It is organised as follows:

- Section 2 provides a specification and an implementation plan of UC1 (Advanced Propulsion System);
- Section 3 provides a specification and an implementation plan of UC2 (Continuous Descent Operations);
- Section 4 provides a specification and an implementation plan of UC3 (Sustainable aviation fuel);
- Section 5 presents the demonstration plan;
- Section 6 concludes the document, summarising the information provided herein.

The aim of the UCs is to demonstrate the capability of the Impact Monitor framework and its Dashboard Application, and not to carry out the studies (with their quantified KPIs) used for this demonstration.

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2. Use Case 1: Advanced Propulsion System

Use Case 1 (UC1) concerns the demonstration of an impact-assessment at aircraft level of future SAF fuelled novel aircraft concepts with advanced propulsion systems. The following subsections provide a description of UC1 (Subsection 2.1) and its implementation plan (Subsection 2.2).

2.1 Description

The idea behind the use case is to investigate the viability and competitiveness of future SAF fuelled long and medium range aircraft concepts, and to demonstrate the capabilities developed by the Impact Monitor framework and interactive Dashboard Application (DA). On a generic and high-level view, the major capabilities targeted for demonstration through UC1 can be described as:

- Targeted Impact Monitor Framework capabilities:
  - Execution of workflow;
  - Connectivity and communication of various tools provided by different partners;
  - Uninterrupted data flow among the tools.
- Targeted Dashboard Application capabilities:
  - Loading of the input data;
  - Visualisation of the results through charts, tables and maps;
  - Exporting and downloading of results.

The capabilities and user requirements which will be fulfilled by this use case demonstration are discussed in detail in Section 5.

Primarily based on an aircraft-level analysis, the use case would be focused on investigating the viability and competitiveness of future SAF fuelled novel aircraft concepts with advanced propulsion systems for long-range application (assuming a 2040/50 EIS).

Aircraft types to be used for the analysis and study:

- Conventional Tube and Wing aircraft (Long Range based on A350 XWB – 900 ULR);
- Conventional Tube and Wing aircraft (Short Range based on A321 Neo).

Starting with a set of pre-defined TLARs (Top Level Aircraft Requirements), the novel aircraft architecture design will be based on the above-mentioned aircraft models. To demonstrate the applicability for an aircraft family, two variants of the concept will be modelled, which will be sized for different payload / seat and range capabilities. The analysis will further entail a performance comparison for typical missions with the SAF fuelled "classical technology" aircraft (adapted from UC3 on SAF) to establish an improved payload-range capability & emission reduction potential. A set of metrics of interest for the evaluation of advanced propulsion systems are retained such as aircraft level fuel burn (kg), aircraft level emissions (CO_2) & energy to revenue work ratio.

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UC1 compares the performance between two propulsion systems:

- VHBR (9-10) – Based on Trent XWB (KER + SAF);
- UHBR 15+ with Gearbox (Based on Trent Ultra fan) (KER + SAF).

As part of evaluating solutions and technologies for reducing the environmental impact of aviation, this use case focuses on an aircraft level assessment by analysing several critical performance metrics related to sustainability. The key performance indicators (KPIs) agreed for assessment are fuel burn, carbon dioxide emissions (CO_2), nitrogen oxide emissions (NO_X), overall sustainability, and contrails.

2.2 Implementation plan

This section presents the methodology of the UC1 implementation. The proposed Impact Monitor Framework (developed in WP3), and the design space exploration environment (Dashboard Application, developed in WP4), will be employed for the execution of this use case. The storyboard for the execution of this use case is presented in Figure 4. Firstly, the user will specify the top-level aircraft requirements (TLARs). Next, the aircraft mission and the configuration/architecture will be modelled. Step 3 of the storyboard involves the creation of the computational workflow using the Impact Monitor framework. All the tools will be integrated using MDAx [3], a workflow modelling application, and the communication between the tools will be performed through the CPACS standard [4], an XML based central data schema for the exchange of data dedicated to the air transportation system. The computational workflow will then be executed in step 4 as part of the design studies, including optimisation, design of experiments, and sensitivity analysis. Finally, in step 5, the results of the design studies will be analysed and compared through maps and charts using the Dashboard Application. In addition, the capabilities to modify the computational workflow and performing what-if and trade-off design studies will be demonstrated in step 6. Step 7 will then allow the user to generate and export reports.

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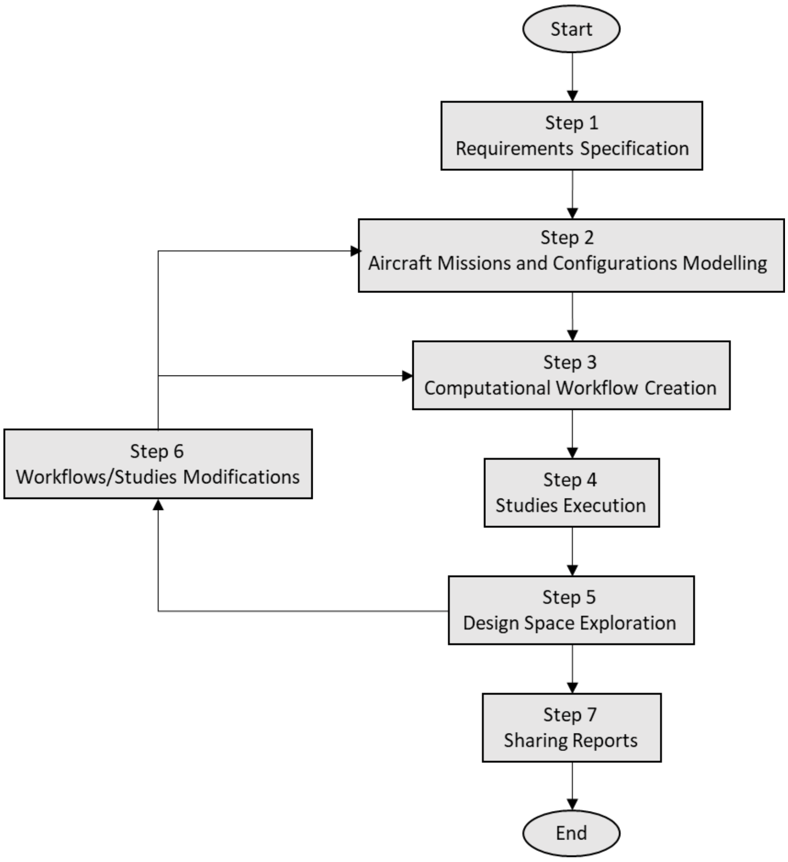

Figure 4: UC1 storyboard

The rest of this section describes the implementation details of the individual steps of the storyboard.

Step 1: Requirements Specification

The first step of the use case storyboard is to define the top-level aircraft requirements (TLARs). Apart from the performance requirements (e.g., take-off field length, landing field length, and approach velocity), environmental requirements (e.g., contrails, NO_X emissions, and sustainability) will also be considered. The chief architect/designer will specify which requirements will be stored in the CPACS file. These requirements will be visualised as tabular data in the DA, as shown in Figure 5, and may later serve as constraints for the aircraft design studies.

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	Key Aircraft Requirements
SPP (design) range	8200 nm
Cruise Mach number	0,85
Max. operating Mach number M_{MO}	0,89
Max. operating speed v_{MO}	340 kts CAS
Initial cruise altitude (ICA) capability after take-off at MTOW, ISA+10°C	SHALL be not less than 33000ft
Time-to-climb (TTC) after take-off at MTOW, ISA+10°C	From 1500ft to 33000ft SHOULD be ≤ 23 min and SHALL not exceed 25 min
One-engine-out OEI net ceiling	SHOULD be ≥ 14000ft SHALL be ≥ 13000ft
Max. cruise altitude	43000 ft
Take-off Field Length (sea level; ISA+15)	SHALL be < 10700 ft
Landing distance limit @ MLW; ISA; SL; dry	SHALL be < 6800 ft
Max. wingspan	SHALL be ≤ 80.0 m
ACN (flex B)	SHALL be < 75
Approach speed v_{App}	SHALL be Cat. D SHOULD be ≤ 145 kts

Figure 5: Notional top level aircraft requirements

Step 2: Aircraft Missions and Configurations Modelling

After specifying the TLARs, the second step of the use case storyboard will be the modelling of the aircraft mission and configuration (i.e., different platform wing geometries, empennage types, and powerplant arrangements, etc.). An example aircraft mission is shown in Figure 6, which would be stored in a CPACS file and visualised using the DA. Although the Impact Monitor framework would be able to handle any aircraft configuration/architecture, only conventional aircraft (tube and wing) configurations, as shown in Figure 7, will be considered for the current use case. As mentioned earlier, a single-aisle aircraft configuration (similar to A321) and a twin-aisle aircraft configuration (similar to A350) will be considered.

The elements for definition of the missions and their constituent segments will be stored in a CPACS file.

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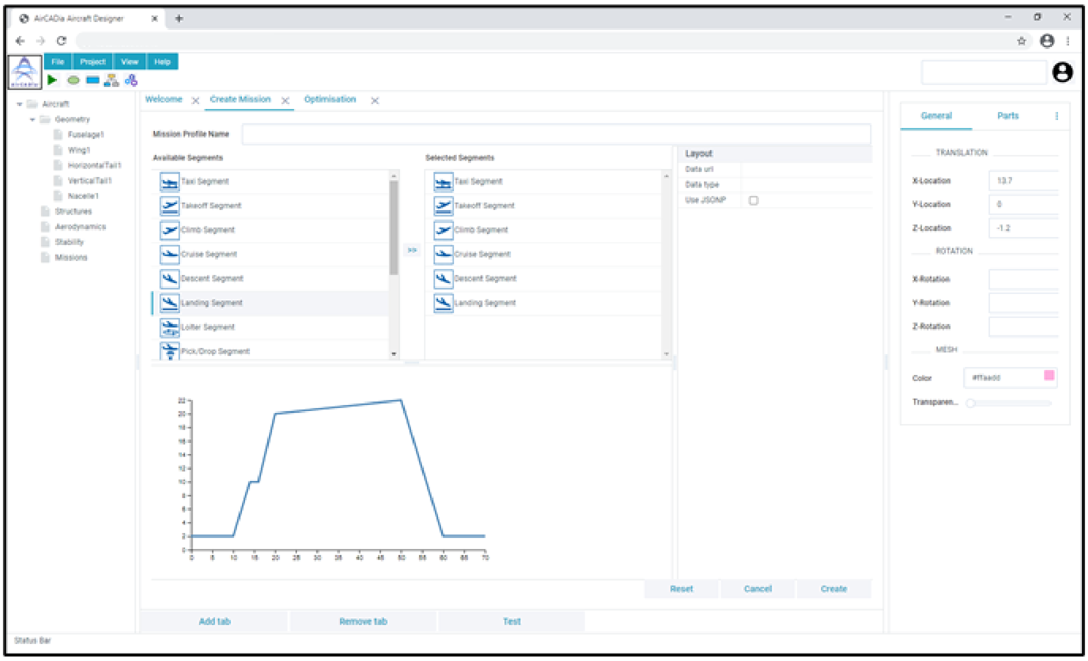

Figure 6: Definition of aircraft mission

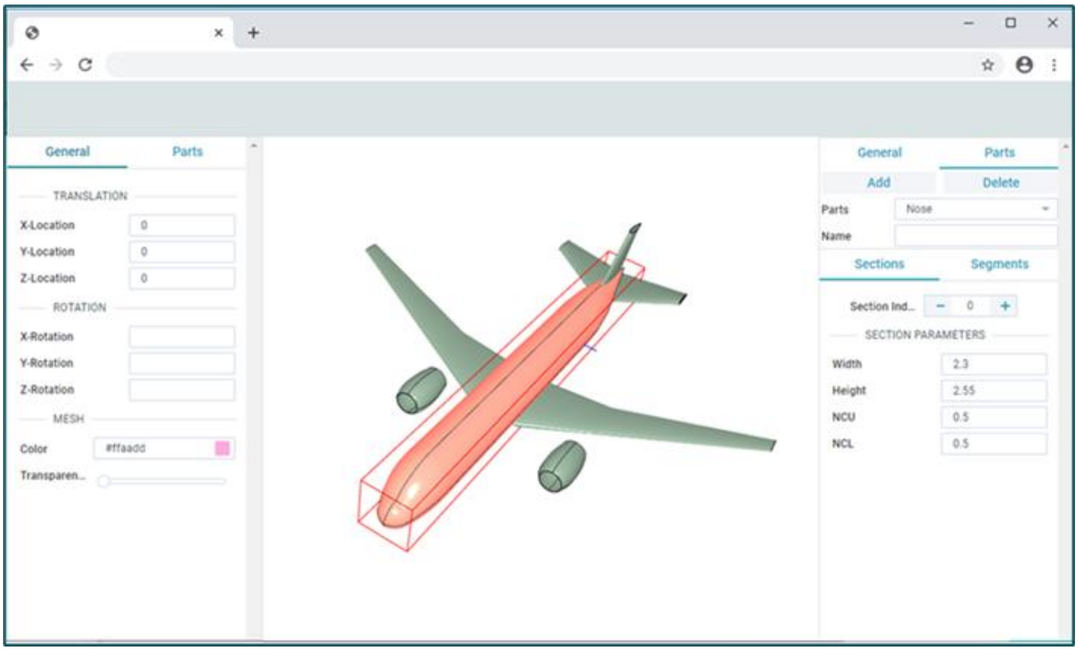

Figure 7: Conventional aircraft (tube and wing) configuration

Step 3: Computational Workflow Creation

After specifying the aircraft configurations, the next step for the current use case is to setup the workflow for conducting studies. Here, a multidisciplinary computational workflow, involving aerodynamics, structures, propulsion, mission performance, emissions, sustainability, etc. will be developed using MDAO Workflow Design Accelerator (MDAx). MDAx enables workflow integrators and disciplinary experts to model, inspect, and explore workflow components and their relationships,

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and export workflow configurations for execution on integration platforms. MDAx offers a graphical user interface for creating collaborative MDAO workflows that use a central data schema for data exchange. An example workflow for the current use case (created using MDAx) is shown in Figure 8 and will be part of Impact Monitor deliverable D3.2 [5].

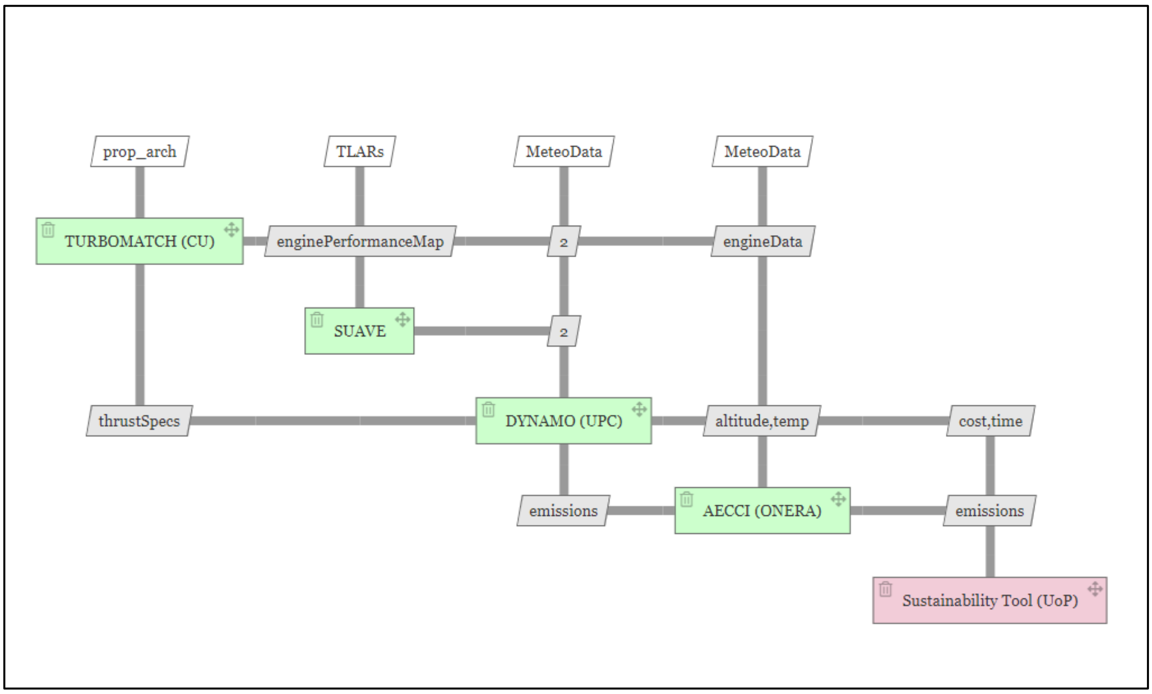

Figure 8: A generic representation of UC1 with all the tools connected

Here, SUAVE and Turbomatch will be executed first for aircraft sizing by incorporating the TLARs. Current industrial design process for airframe-engine matching involves iterative and sequential (throw it over the wall) approach. Here, airframe manufacturers use baseline engine models and past experience or knowledge to predict the thrust requirements (i.e., end-of-runway, top-of-the-climb, and mid-cruise), which are then passed to engine manufacturers who generate performance deck and dimensions of the designed engine. The airframe manufacturer then employs the newly generated engine performance deck to determine the new set of thrust requirements. This whole process, illustrated in Figure 9, is iteratively executed multiple times until convergence is achieved and all the TLARs (e.g., take-off field length, landing field length, and approach velocity) are met.

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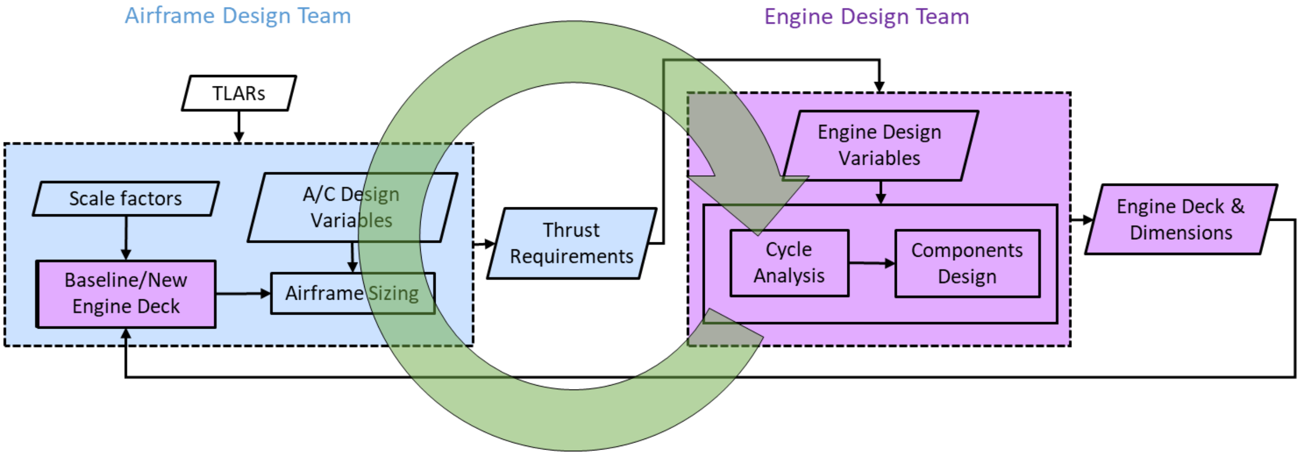

Figure 9: Current design process for airframe-engine matching

The current process for airframe-engine matching and design is very slow due to manual operations and transfer of data between airframe and engine manufacturers. The main goal of this use case is to demonstrate the benefits of the collaborative multidisciplinary design framework (i.e. Impact Monitor framework) for airframe-engine matching and design. This framework will enable the airframe and engine manufacturers to work collaboratively by allowing their tools to automatically execute and transfer data between them, without requiring the tools to be present or executed on a common single computing machine. As mentioned earlier, for the current use case, SUAVE and Turbomatch will be employed for airframe sizing and engine cycle analysis and design, respectively. The description of these two tools is presented in Table 1 and Table 2.

Furthermore, both tools will be inter-connected as part of a computational workflow through MDAx, and the communication between the tools will be performed using the CPACS standard.

Table 1: Turbomatch description

Name	Turbomatch (Cranfield University) – Engine Performance and Modelling Tool
Purpose	To model aircraft engine and perform/simulate design points, off design points and transient analysis
Inputs	Off design cases, i.e., altitude, Mach number, ISA deviation combinations, and preconfigured parameters: components sequence/connections, components efficiencies, bleeds, pressure ratios, power extraction, mass flow
Outputs	Engine performance data at design point and off design points, i.e., thrust, mass flows, fuel flow, and key engine station (component) related data, temperatures (total and static), pressures (total and static)

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Table 2: SUAVE description

Name	SUAVE (University of Stuttgart) – Aircraft Modelling Tool
Purpose	To perform aircraft conceptual design and analysis, and evaluate impact at aircraft level
Inputs	Aircraft configurations, calibration factors, design points, envelope properties, wing geometry, engine networks, mission phase definitions
Outputs	Fuel consumption, aerodynamic performance

Similar to SUAVE and Turbomatch, the information about the other tools of UC1 is presented below.

Table 3: AECCI description

Name	AECCI (ONERA) – Aircraft Emission and Contrails for Climate Impact Tool
Purpose	Evaluate CO_2 and non-CO_2 emissions of aircraft, and the temporary and persistent contrails through trajectory
Inputs	Number of engines, Engine Identification number, Altitude, Mach number, Fuel consumption, Thrust force, Thrust rate, Temperature (optional), Pressure (optional), Relative Humidity (optional)
Outputs	CO_2 emissions, H_2O emissions, SO_X emissions, NO_X emissions, CO emissions, HC emissions, particle emissions, contrail formation

Table 4: DYNAMO description

Name	DYNAMO (Technical University of Catalonia UPC) – Trajectory amendment for Contrail Avoidance
Purpose	Research software suite capable to compute high-fidelity aircraft 4D trajectories for aircraft operations and Air traffic Management (ATM) purposes
Inputs	Aircraft performance models/data (BADAv4, BADAv3, in-house models), Weather data, Basic dispatch (or in-flight) inputs: aircraft weights, optimisation policy, etc., ATM constraints: airways, SIDs/STARs, avoidance sectors/areas, altitude/speed limitations, etc., En-route charges, automatically process a list of flights: EurocontrolDDR2 ALLFT+, so6, etc [batch mode]
Outputs	"Flight data recorder" variables (weather, performance, navigation data), 3D trajectory with contextual data, lateral route and vertical profile with aircraft intent, different kinds of plots for debugging/visualisation

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Step 4: Studies Execution

Once the computational workflow is created using MDAx, the next step is concerned with the execution of the workflow as part of design studies, such as optimisation and design of experiments, sensitivity analysis, and uncertainty quantification. Here, RCE [6] will be employed to automatically execute the design studies. RCE is a distributed, workflow-driven integration environment. RCE takes care of the heterogeneous infrastructure: every tool involved is integrated in an RCE instance running on the tool's host machine. The distributed RCE instances are connected to each other and build a peer-to-peer network.

Step 5: Design Space Exploration

For UC1, Turbomatch is employed to model the aircraft engine configuration and perform/simulate design point, off design and transient analysis. The inputs required for Turbomatch are engine design parameters, such as fan pressure ratio (FPR), overall pressure ratio (OPR), bypass ratio (BPR), turbine entry temperature (TET), component efficiencies, and altitude/Mach combinations for off-design performance, whereas the outputs of Turbomatch include engine deck performance maps (including thrust, fuel flow, specific fuel consumption). Both input and output parameters of Turbomatch will be stored in a CPACS data file. The designers will be able to visualise the engine deck performance maps in the DA, as shown in Figure 10 and Figure 11**Fehler! Verweisquelle konnte nicht gefunden werden.**.

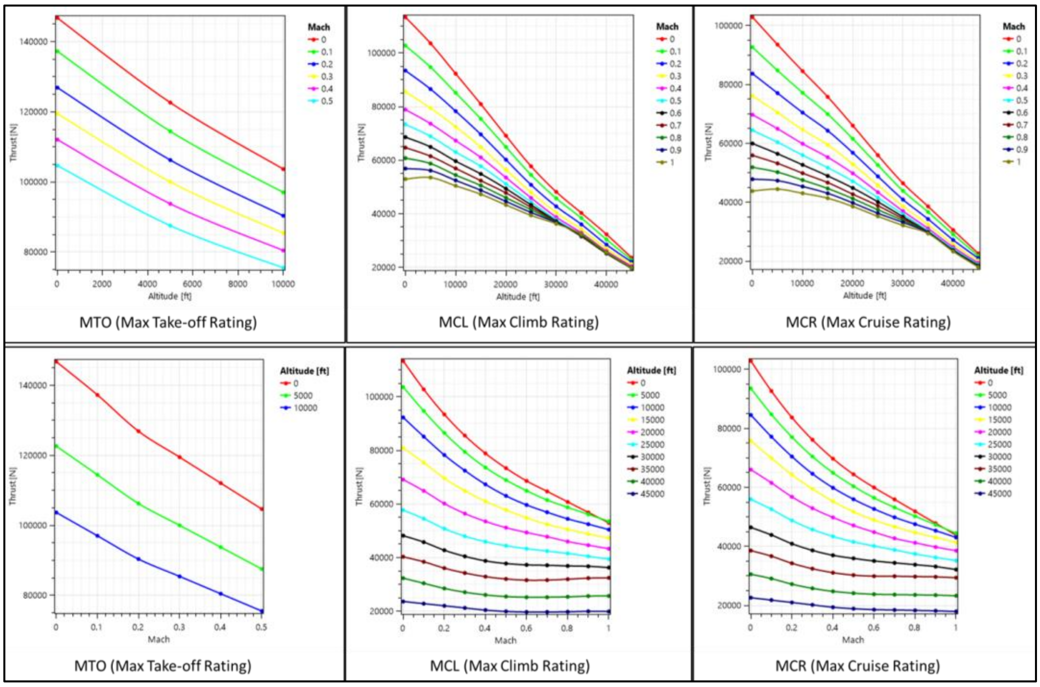

Figure 10: Engine performance deck (thrust variations for MTO, MCL, and MCR ratings)

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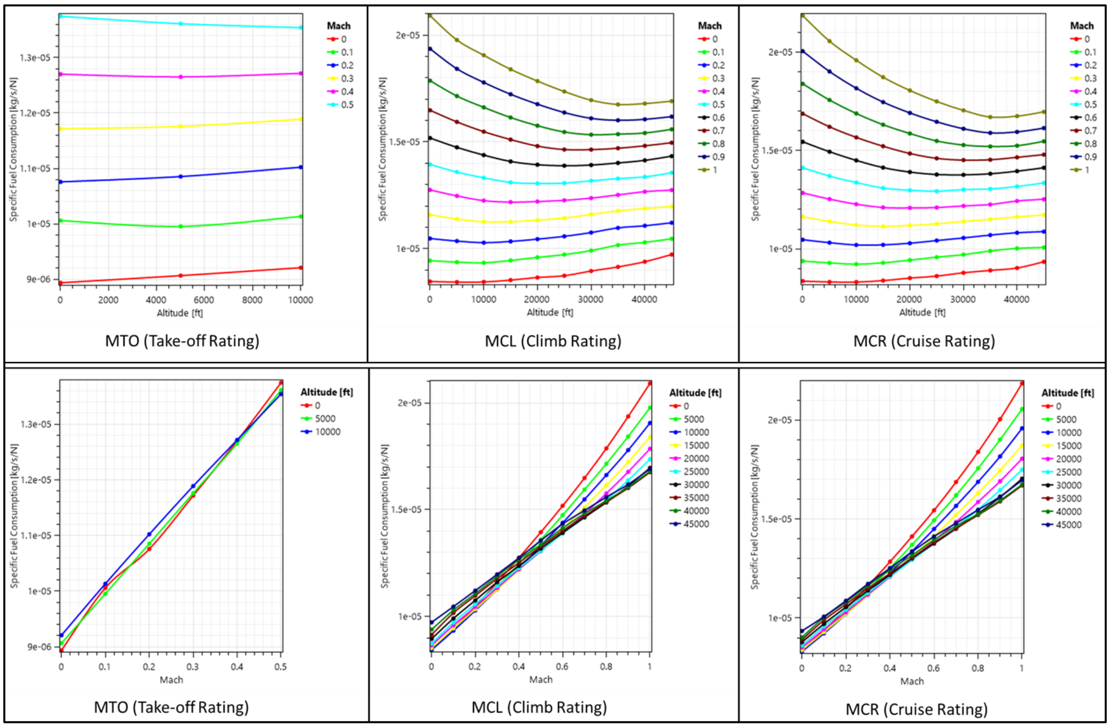

Figure 11: Engine performance deck (specific fuel consumption variations for MTO, MCL, and MCR ratings)

For UC1, SUAVE is employed to model and analyse aircraft configurations and to evaluate the impact of SAF at aircraft level. The inputs to SUAVE are the geometry parameters (wing reference area, wing aspect ratio, wing sweep, fuselage diameter, fuselage length), engine deck performance maps, and design mission. The outputs produced by SUAVE include mission performance (block fuel, time, range) and the instantaneous discrete points of the different mission segments. The users will be able to visualise the aircraft performance in the DA, as shown in Figure 12**Fehler! Verweisquelle konnte nicht gefunden werden.**.

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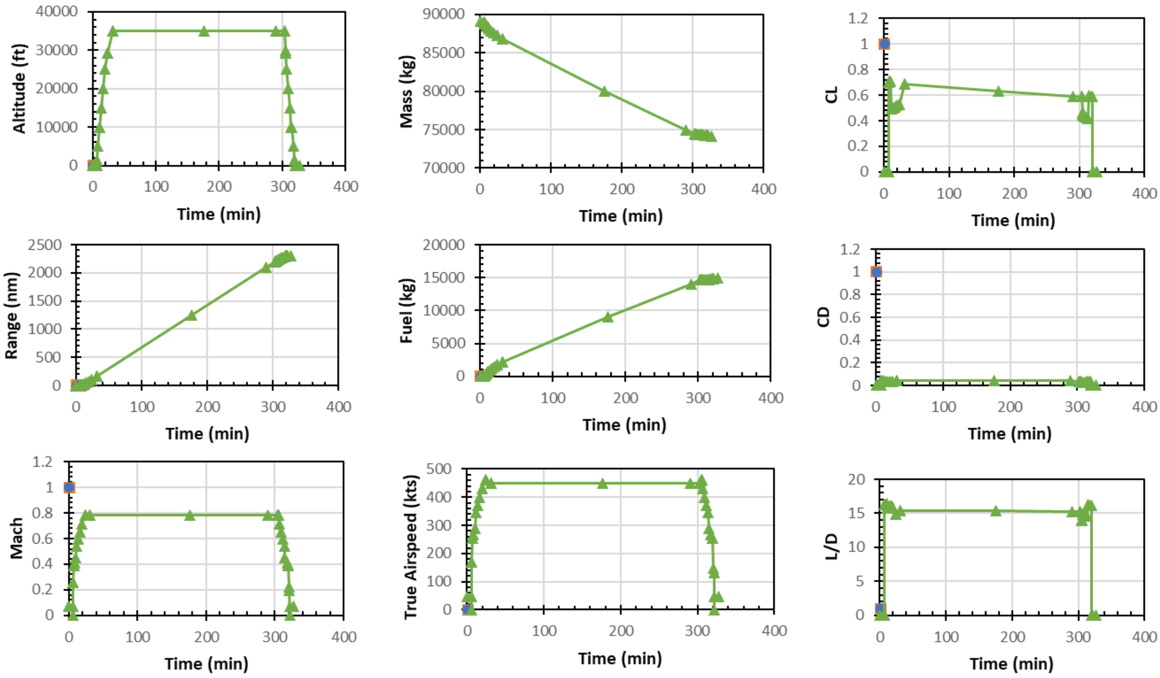

Figure 12: Mission performance

In order to estimate these mission performance parameters, SUAVE will first calculate the data for individual disciplines, such as aerodynamic (drag polars) and structures (weight and balance). The users will also be able to visualise the data for these individual disciplines as all the intermediate data will be stored in the CPACS files. Figure 13 shows an example of high-speed and low-speed drag polars. Furthermore, other performance data will be estimated to be utilised for creating plots for the DA. For instance, data will be generated for pay-load range, flight envelop diagrams, as shown in Figure 14.

Step 6: Workflows/Studies Modifications

One of the core requirements of UC1 is to demonstrate the capabilities of the Impact Monitor framework and Dashboard Application to perform what-if and trade-off design studies. Therefore, step 6 involves the modification of computational workflows and design studies, e.g., design variables ranges, objectives, and constraint values.

Step 7: Sharing Reports

In the final step of the use case development, the user will generate and export reports using the Dashboard Application. As the proposed DA will be a web-based software for design space exploration of complex systems (such as transport aircraft) involving multiple teams, this step is concerned with enabling collaboration between different users or teams. The reports will be displayed and downloaded in various formats, such as Excel, PDF, HTML, etc. for further analysis.

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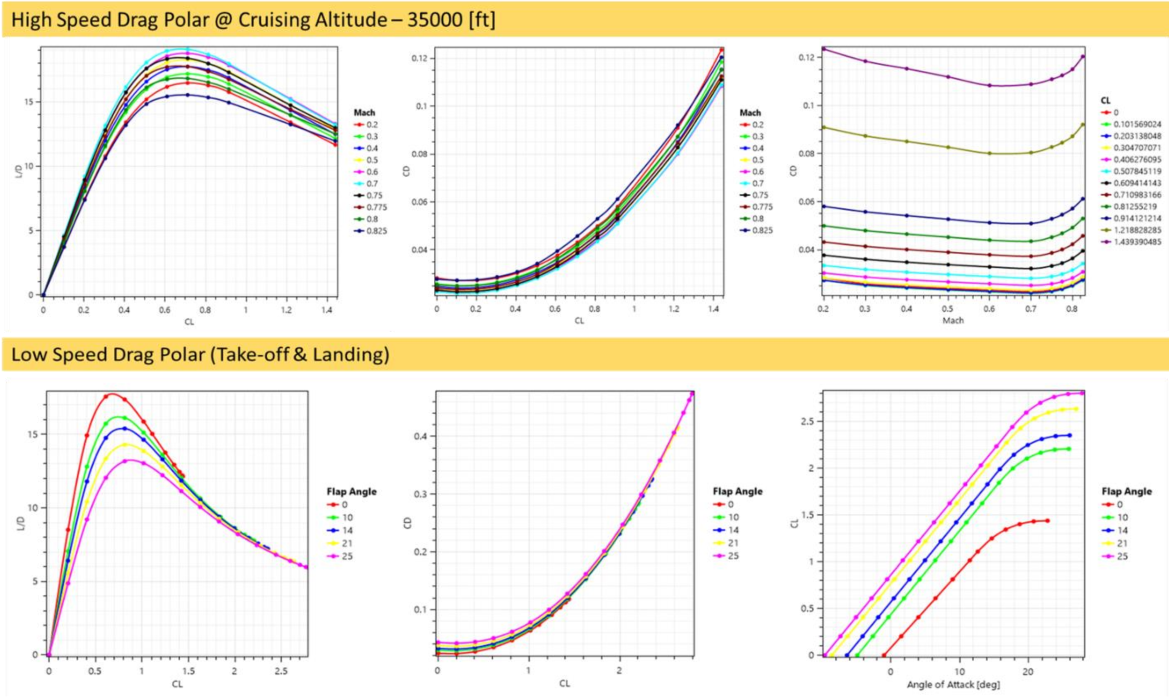

Figure 13: Aerodynamic drag polars

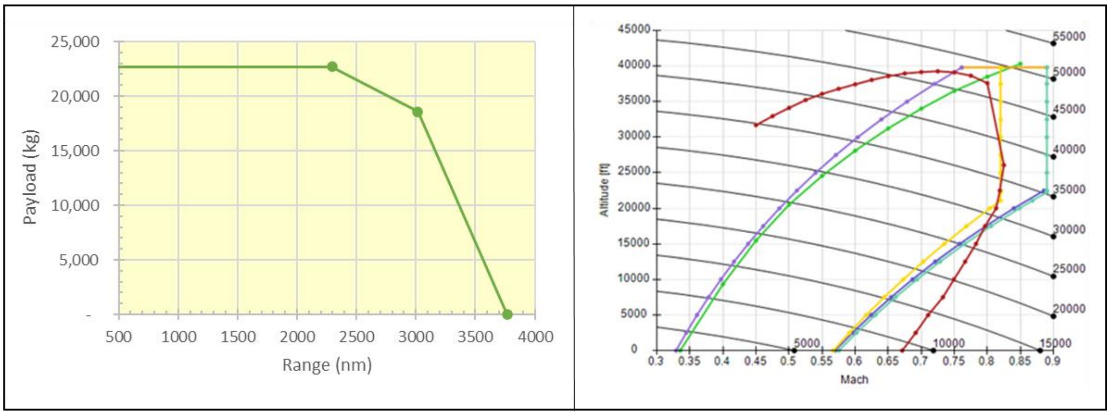

Figure 14: Aircraft performance plots

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3. Use Case 2: Continuous Descent Operations

Use Case 2 (UC2) concerns the demonstration of an impact-assessment at aircraft and airport level of an implementation of Continuous Descent Operations. The following subsections provide a description of UC2 (Subsection 3.1) and its implementation plan (Subsection 3.2).

3.1 Description

UC2 is aimed at demonstrating the capabilities of the Impact Monitor framework through the analysis of the implementation of Continuous Descent Operations (CDOs).

CDOs allow aircraft to follow an optimum flight path that delivers major environmental and economic benefits, giving as a result engine-idle continuous descents that reduce fuel consumption, pollutant emissions and noise nuisance (cf. e.g. [7], [8], [9] and [10]). Figure 15 illustrates this concept and the reduction on the noise footprint when following a CDO strategy.

CDOs are on the research desk for a while, but they have not been fully deployed. The use case on CDOs will explore the impacts of this ATM strategy on the sustainability of these operations. To demonstrate the Impact Monitor framework capabilities with regards to CDOs, two levels of assessment will be considered thanks to the integration of several of models enabling the analysis of CDOs impact: aircraft and airport level. Aspects of investigation include the following: a) at aircraft level, the impact of CDOs on emissions and operations will be analysed using deterministic aircraft trajectory prediction; b) at airport level, starting from a one-day flight schedule, the environmental-impact assessment of CDOs will be performed, comparing for the selected airport and flight schedule the environmental performance of the case without CDOs and the case with CDOs. Here, noise impact (e.g. L_{den} and L_{night} contours and population exposed/annoyed/sleep-disturbed) and emissions impact (e.g. total amount of emissions) will be quantified. In addition, impact on airport capacity of the introduction of CDOs at the airport will also be addressed. In conclusion, a social cost-benefit analysis approach will be applied to evaluate the costs and benefits of CDOs.

For the analysis of CDO, the Impact Monitor project will take the generic airport named CAEPport. It provides the required flexibility, but also neutrality on the definition to be used in this kind of projects.

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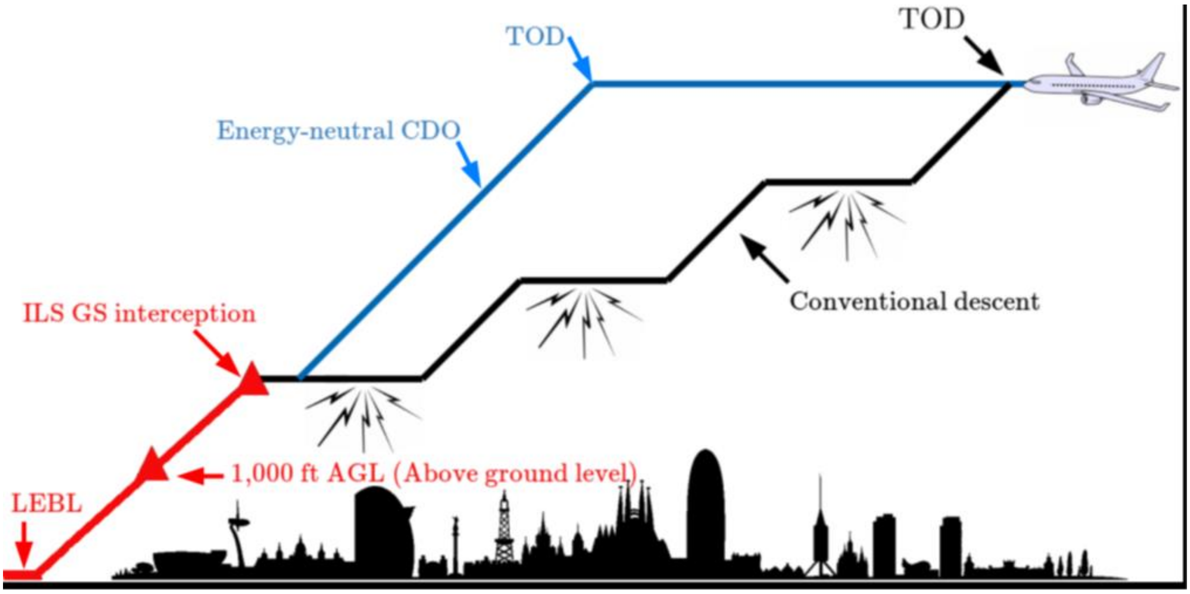

Figure 15. Illustrative comparison of a CDO and a conventional descent operation (Source: [10])

Considering the given definition and the global aim of the project, the objectives of UC2 are described below. The reader will see that the objective overlaps with the other use cases. The objectives can be split into two groups:

- Targeted Impact Monitor Framework capabilities:
  - Execution of workflow;
  - Connectivity and communication of various tool provided by different partners;
  - Uninterrupted data flow among the tools.
- Targeted Use case Application:
  - Enable the simulation of CDO using the defined tools;
  - Assess the benefits and drawbacks of the CDO implementation.

UC2 will be integrated into the project interactive DA in order to visualise and analyse the results.

3.2 Implementation plan

The steps followed in the implementation of UC2 are:

- ✓ Step 1: Specification of the use case;
- ✓ Step 2: Selection of the tools to be integrated;
- ✓ Step 3: Specification of the tools workflow;
- ✓ Step 4: Implementation of the workflow in MDAx.
- ✓ Step 5: Workflow execution using RCE for (partly) automation;

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✓ Step 6: Studies exploration;

✓ Step7: Sharing results through the Dashboard Application.

According to the definition of the Use Case and its objectives, the main ideas to be implemented in the workflow are:

- Define a flight schedule for CAEPport, enabling CDOs;
- Simulate the approach trajectories to assess the level of implementation of CDO;
- Calculate the effects of the proposed trajectories, assessing emissions, noise and third-party risk;
- Assess the overall impact of these effects to several stakeholders.

For this purpose, the tools Scheduler (Table 5), AirTOp (Table 6), Tuna (Table 7), LEAS-iT (Table 8), TRIPAC (Table 9) and SCBA (Table 10) are considered. The referred tables briefly describe them, highlighting inputs and outputs of interest for the study.

Table 5: Scheduler description

Name	Scheduler (DLR) – Airport Flight Scheduling modelling tool
Purpose	To define the flight schedule of a given airport according to the fleet and OD pairs
Inputs	Airport and fleet characteristics
Outputs	Flight schedule

Table 6: AirTOp description

Name	AirTOp (NLR's COTS software from Transoft Solutions) – Airport and airspace simulation platform
Purpose	To realistically simulate aircraft movements at and around an airport
Inputs	Flight schedule
Outputs	4D trajectories

Table 7: TUNA description

Name	Tuna (NLR) – ECAC Doc.29 compliant noise model
Purpose	To calculate noise around an airport
Inputs	4D trajectories and airport vicinity description/population
Outputs	Noise level, noise footprint

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Table 8: LEAS-it description

Name	LEAS-iT (NLR) –Boeing Fuel-Flow Method 2 compliant emissions model
Purpose	To calculate emissions around an airport
Inputs	4D trajectories
Outputs	Emissions level, emissions footprint

Table 9: TRIPAC description

Name	TRIPAC (NLR) – Risk modelling tool
Purpose	To model accident/incident risk around an airport
Inputs	4D trajectories and airport vicinity description/population
Outputs	Risk level, risk footprint

Table 10: SCBA description

Name	SCBA (TML) – Impact Assessment tool
Purpose	To assess individual and societal impact
Inputs	Noise, Emissions and Risk footprints
Outputs	Impact on stakeholders

The rationale behind the list of tools can be briefly described as follows:

- Scheduler: provides a flight schedule associated to aircraft type, Origin-Destination (OD) pair, leg distance, arrival time and departure time.
- AirTOp: based on the flight schedule (and airport and airspace data and aircraft-performance characteristics) realistically simulates the aircraft movements at and around the airport.
- DYNAMO: computes refined 4-D trajectories including CO_2, fuel flow, and thrust along the whole trajectory or limited to a specific stage.
- Tuna: the noise model processes the 4-D trajectories from AirTOp to generate L_{den}/L_{night} and (when combined with a population density database) population impacted (and highly annoyed and highly sleep disturbed).
- LEAS-iT: the emissions model processes the 4-D trajectories from AirTOp to generate total emissions (e.g. CO_2, NO_X) below 3,000 ft.
- AECCI: using 4-D trajectories from DYNAMO, generates accurate emissions prediction.

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- TRIPAC: the third-party risk model processes the 4-D trajectories from AirTOp to generate individual and societal risk.
- SCBA: computes the overall societal impact assessment.

With the listed tools, the proposed workflow is shown in Figure 16. This workflow defines the relationship among tools, which can be briefly summarised with the list of input and output for each tool, and which tool they are feeding. Like the other UCs, all the communication between the tools will be performed using the CPACS standard.

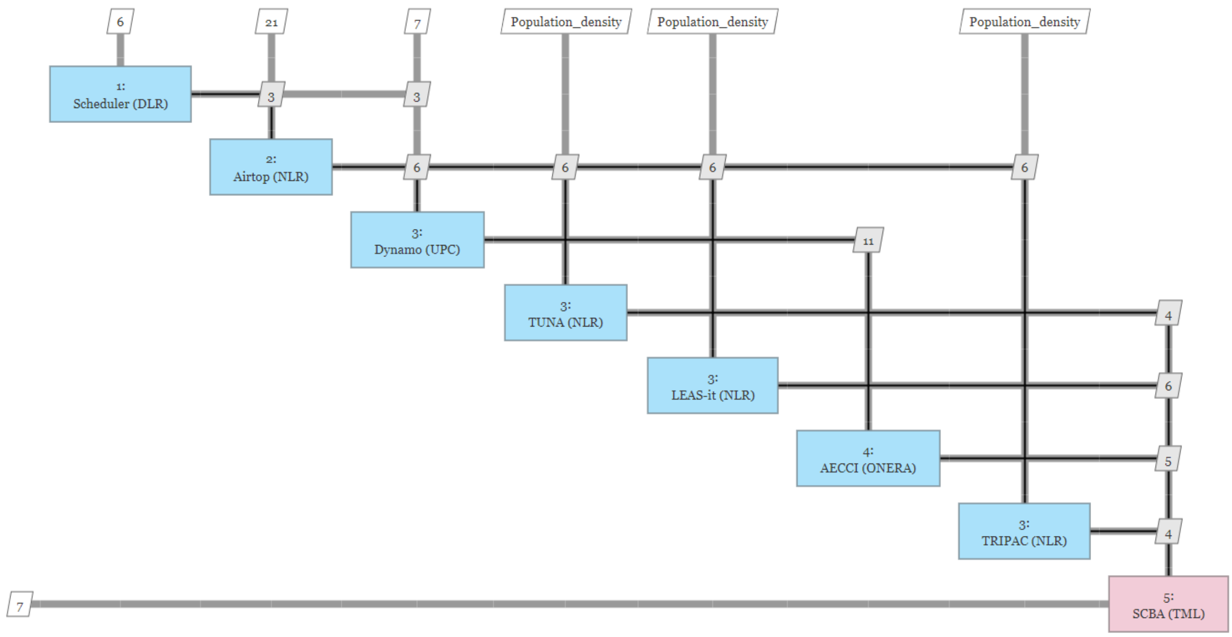

Figure 16. UC2 proposed Workflow

In addition to the tools, UC2 requires the definition of an airport where to apply the CDO concept. For this purpose, the generic airport CAEPport will be used.

The Dashboard Application will allow access to several results, including the output from all the tools involved in the workflow. For instance, AirTOp can display the aircraft ground movements and aircraft movements in local airspace. An example can be found in Figure 17. DYNAMO is also able to provide a graphical representation of a single or multiple trajectory, as seen in Figure 18, while complementing this information with several plots which analyse the performance of a given trajectory, as it is shown in Figure 19. The Dashboard Application user will also be able to access to the results of AECCI that can provide a comprehensive set of plots to analyse the emissions along the trajectory as shown in Figure 20 and Figure 21, which shows the TMA trajectories on Tokyo airport.. As a final output, the SCBA tool is able to provide both a tabular or graphical information about the cost and benefit analysis, as shown in Figure 22 and Figure 23.

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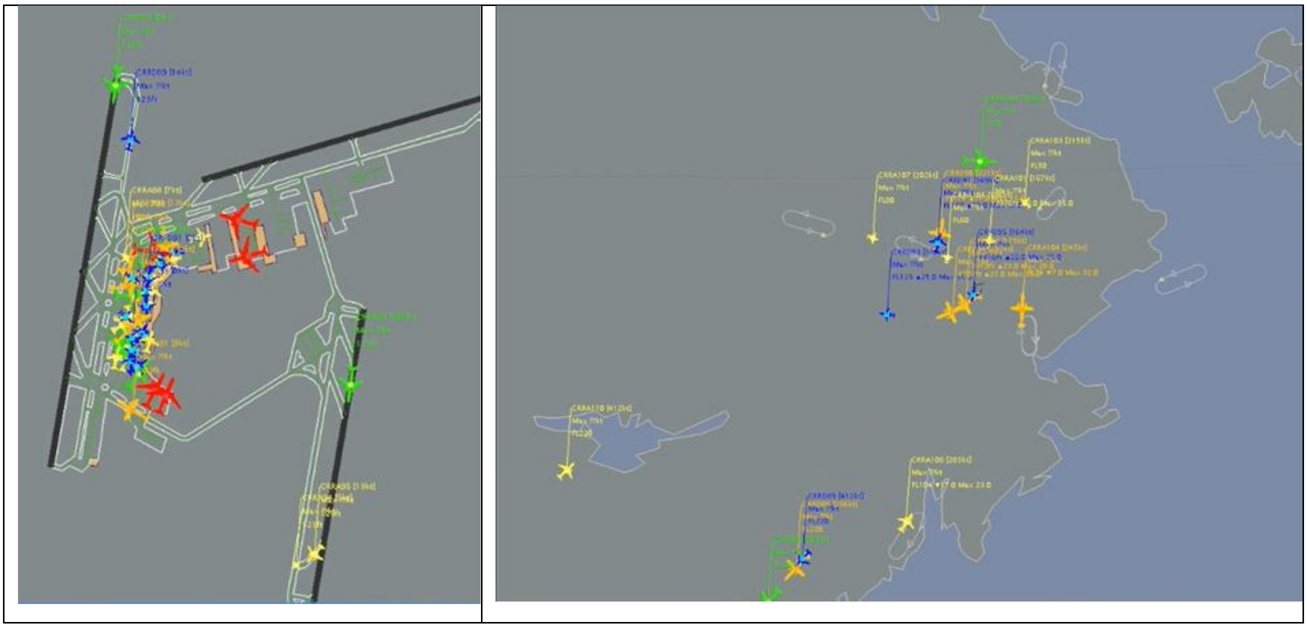

Figure 17. Example of simulation with AirTOp: Aircraft ground movements (left) and aircraft movements in local airspace (right) [Source: Royal NLR]

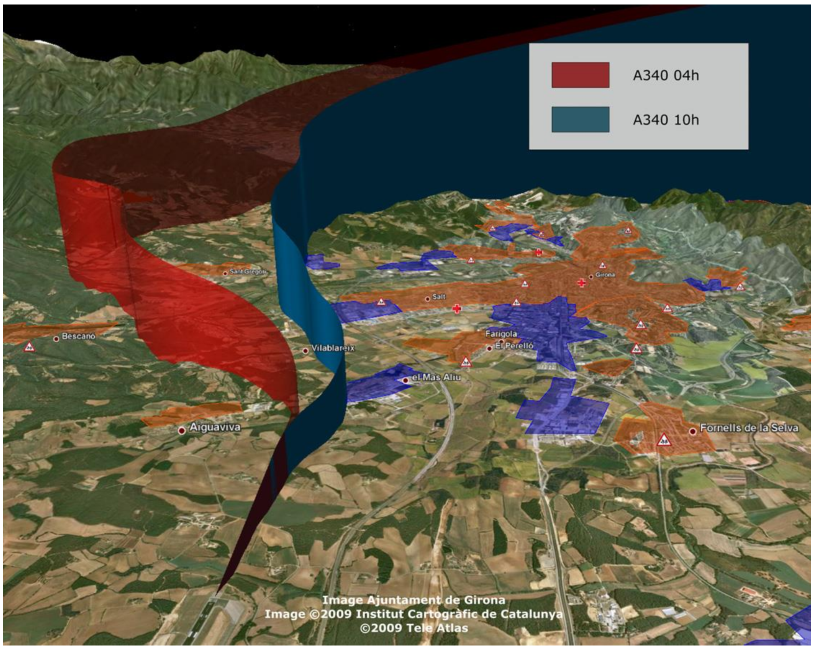

Figure 18. DYNAMO output: graphical representation of a descent trajectory

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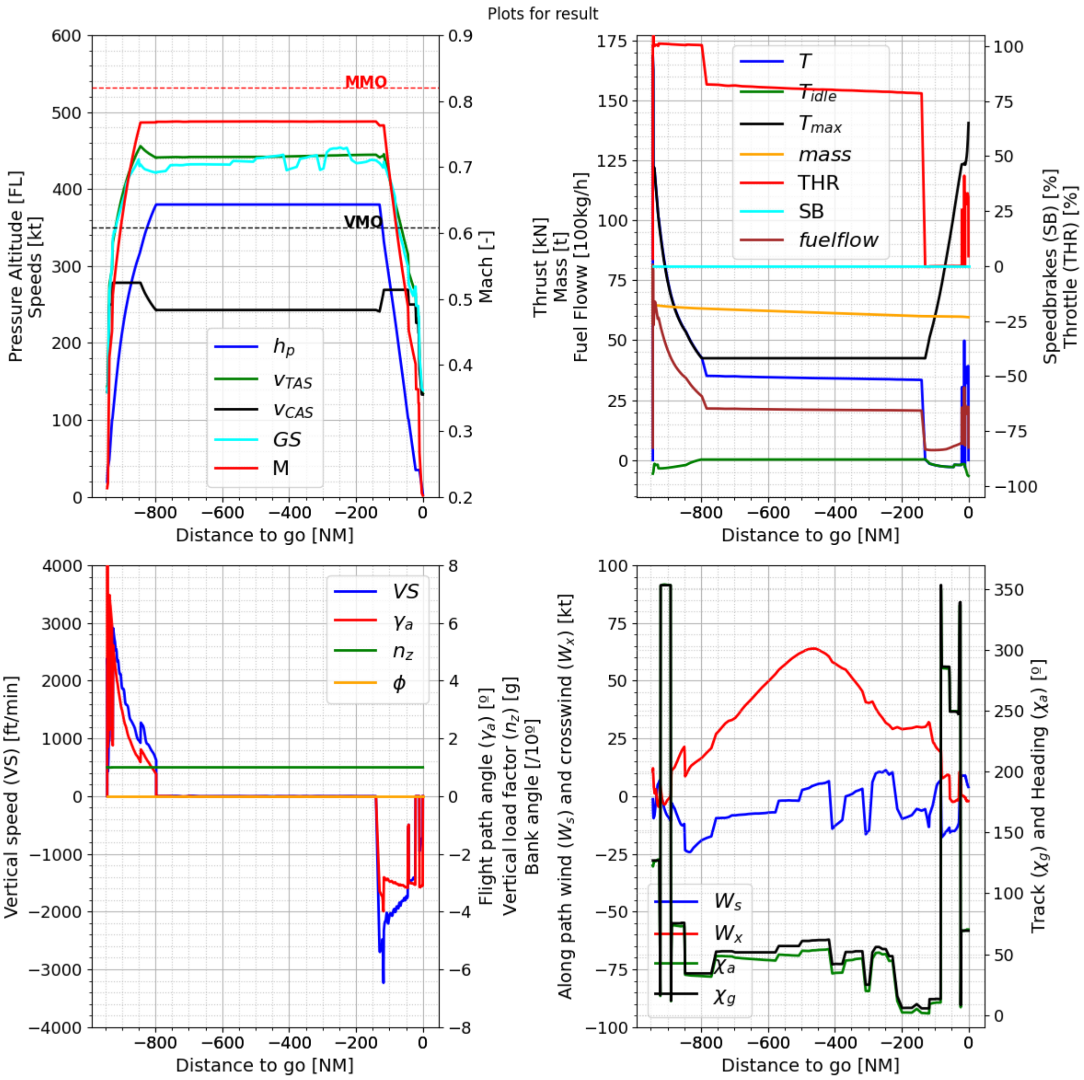

Figure 19. DYNAMO output: analysis of a given trajectory

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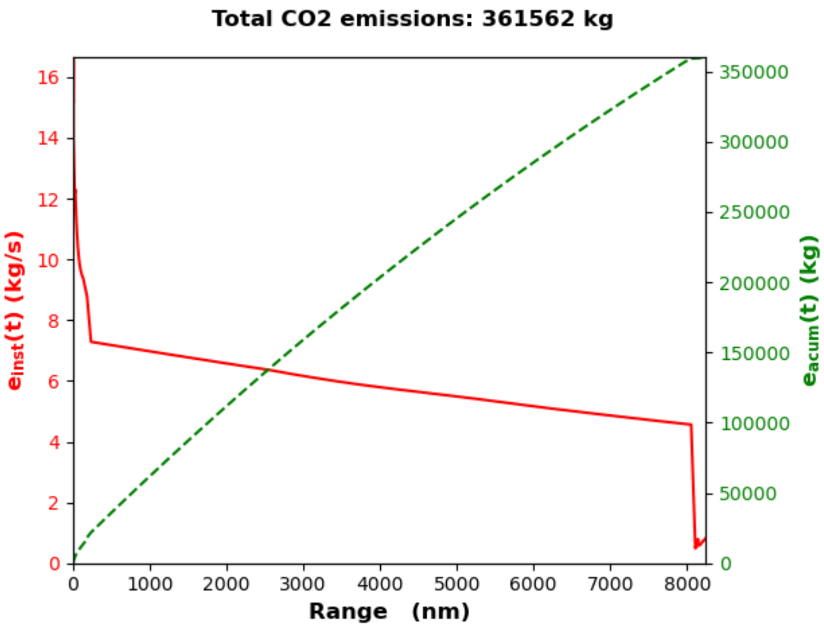

Figure 20. AECCI: CO_2 emission analysis of a given trajectory

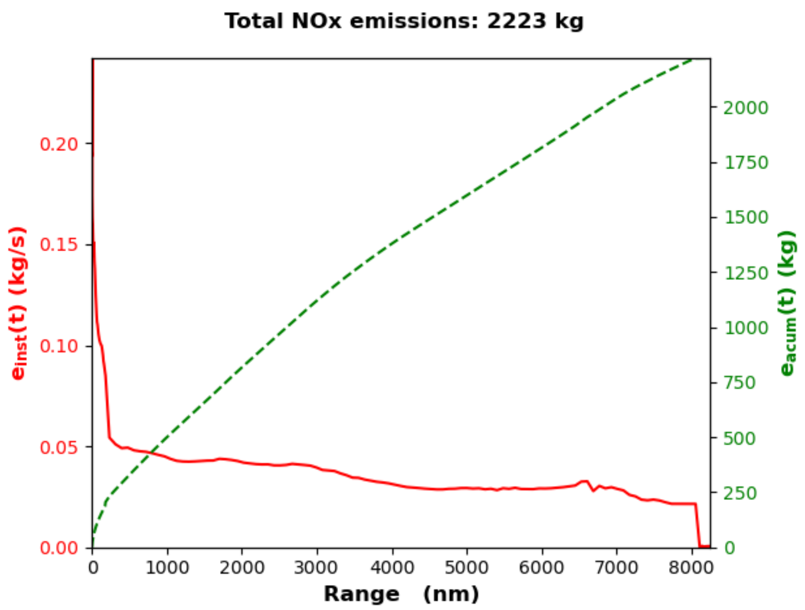

Figure 21. AECCI: NO_X emissions along the trajectory

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Net present value in 2022 of all costs and benefits, in million euro$_{2020}$

Direct effects on passengers	time costs	50	
	delay costs	50	
	Total		100
Direct effects on airlines	time costs	20	
	delay costs	20	
	fuel burn	20	
	operating costs	20	
	Total		80
External effects	Co2 emissions	30	
	Other emissions	30	
	noise	30	
	accidents	30	
	Total		120
Total Benefits			**300**
Total Costs	investment, maintenance		**100**
	NPV		**200**
	benefit-cost ratio		**3**

Figure 22. SCBA: Cost and benefit analysis table (example of SCBA output)

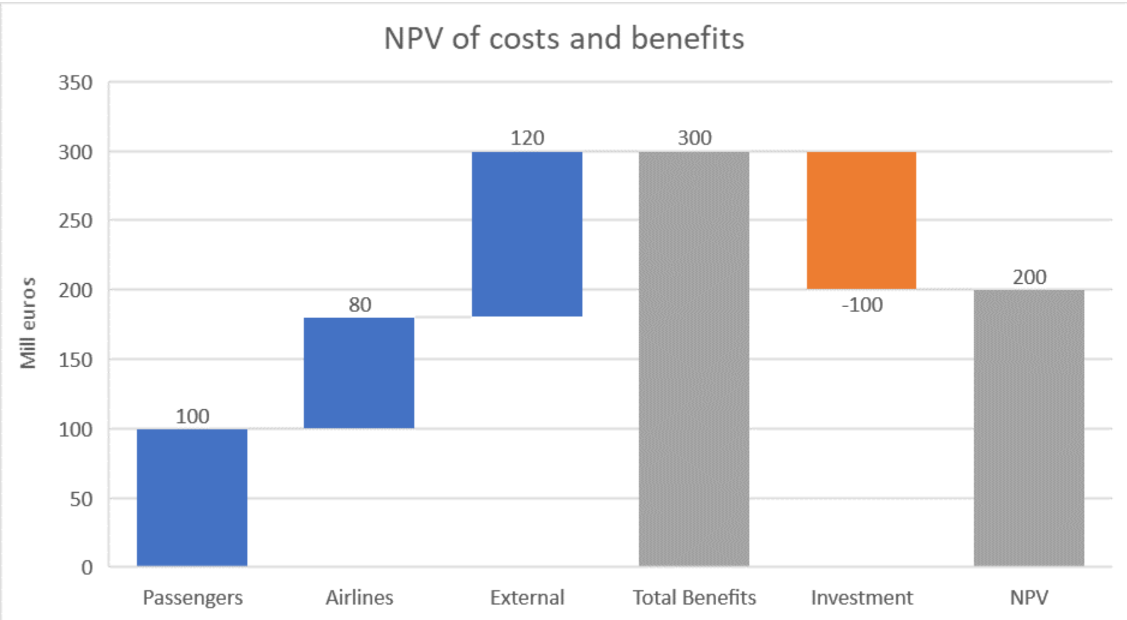

Figure 23. SCBA: Cost and benefit analysis plot (example of SCBA output)

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4. Use Case 3: Sustainable Aviation Fuel

Use Case 3 (UC3) concerns the demonstration of an impact-assessment at air-transport system level of different policies for the update of sustainable aviation fuels. The following subsections provide a description of UC3 (Subsection 4.1) and its implementation plan (Subsection 4.2).

4.1 Description

In Use Case 3 different policies for the uptake of sustainable aviation fuels (SAF) are evaluated at the air-transport system level (ATS level). In addition to this there will be a link between the analysis at aircraft level from UC1. The aim of UC3 is thereby to demonstrate the capabilities developed by the Impact Monitor framework and the interactive DA. Note that while the uptake of SAF may also have implications at airport level, this level is not in the scope of UC3. The airport level is covered in UC2.

On a generic and high-level point of view, the major capabilities that are being targeted for the demonstration of the framework and DA, through the ATS level assessment in UC3 can be considered as below:

- Targeted Impact Monitor Framework capabilities:
  - Execution of workflow;
  - Connectivity and communication of various tools provided by different partners;
  - Uninterrupted data flow among the tools.
- Targeted Dashboard Application capabilities:
  - Loading the input data;
  - Visualising the results through charts, tables, and maps;
  - Exporting and downloading of results.

The capabilities and user requirements which will be fulfilled by this use case demonstration are discussed in detail in Section 5.

UC3 compares the impacts of at least two policy scenarios for promoting the uptake of SAF in aviation. Examples of policies include among others a blending mandate (as in REFuelEU aviation), a tax on fossil jet fuel, subsidies for SAF or a carbon tax on aviation fuels.

The policy scenarios will be compared with a reference scenario without specific SAF policies. The reference scenario considers outlooks for the economic and demographic developments, as well as existing policies (with the exclusion of SAF policies).

The time horizon of UC3 will be 2050. The analysis will be done in steps of five years. The geographical scope consists of three broad categories of flights: (1) flights covered by the EU Emission Trading System (EU ETS) (i.e. flights within the European Economic Area or EEA), (2) other flights to/from the EEA member states, and (3) other flights.

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As part of evaluating solutions and technologies for reducing the environmental impact of aviation, UC3 will be analysing several critical performance metrics:

- Metrics related to the emissions of air pollutants: total emissions, emissions per passenger, emissions per km or nm;
- Metrics related to the emissions of greenhouse gases: total emissions, emissions per passenger, emissions per km or nautical mile, aviation fuel mix, well-to-tank emissions and ILUC emissions associated with SAF production and distribution, CO_2 offsets (e.g. EU ETS, CORSIA);
- Economic metrics:
  - Costs/revenues per stakeholder, consumer and producer surplus, external costs, taxes;
  - GDP and GVA, jobs, labour income, gross output, aviation fuel demand and consumption;
  - Movements, flights, air passenger volumes, available seat kilometres, revenue passenger kilometres, prices.
- Social metrics and metrics for quality of life: social welfare, external costs;
- Efficiency metrics: social costs and benefits;
- Effectiveness: contribution to goals/targets regarding SAF.

Various aspects of the Impact Monitor framework and interactive DA used by UC3, and the procedure/steps to interact the DA by end user will be discussed in a detailed fashion in the next paragraph and Section 5. On a high level, these capabilities could be considered as below:

- Connection and integration of different tools/models provided by different partners, working together as a workflow.
- Plotting and visualising various plots.
- Execution of use case defined workflow.
- Reading and writing data from CPACS files.

4.2 Implementation plan

This section presents the way in which UC3 "Sustainable Aviation Fuels" will be implemented. The proposed Impact Monitor framework and the design exploration environment (DA) will be employed for the execution of the Use Case. The following figure (Figure 24) gives an overview of the different steps in the implementation plan.

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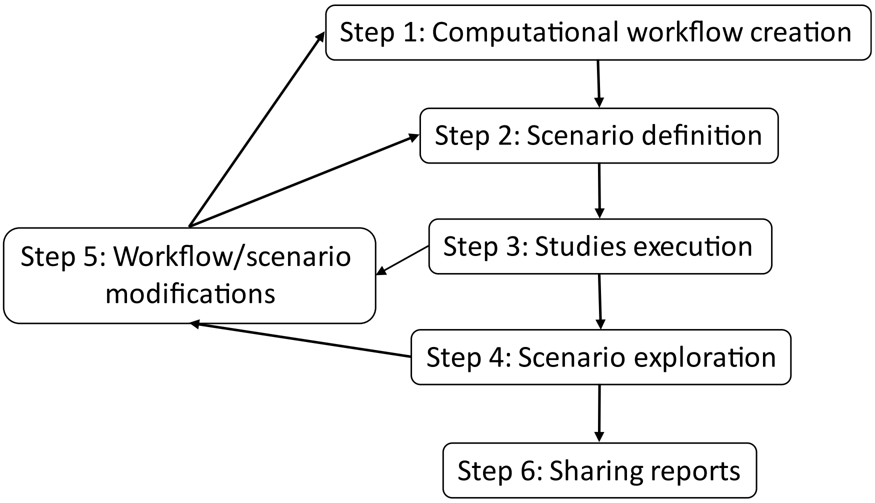

Figure 24. Implementation plan for UC3

Step 1: Computational workflow creation

In this step, the computational workflow for conducting the studies is set up. As in the other two use cases the workflow is developed using the MDAO Workflow Design Accelerator (MDAx). The Figure 25 presents the general MDAx schemes for UC3, which incorporates two stages: a calibration stage and a simulation stage. Both are discussed below.

In the calibration stage the reference scenario will be constructed and the TRAFUMA model will be calibrated. Based on the scenario for the future economic and demographic developments and the evolution of aviation fuel prices in the reference scenario – which will be defined in Step 2 – Scheduler and TCM will be used to project air travel and aviation fuel consumption and emissions in the reference scenario. This will be repeated for an alternative set of aviation fuel prices. This allows to derive the fuel demand elasticities. Based on this information the TRAFUMA model will be calibrated such that its reference scenario and demand parameters are in line with those of the other two models. By including this calibration stage, it is aimed to minimise the need for an iterative loop in the simulation stage.

In the simulation stage the effects of at least two SAF policy scenarios will be simulated. The effects of these scenarios will be determined compared to the reference scenario that was constructed in the calibration stage. Based on the definition of the policy scenarios, TRAFUMA will first compute the impact of these scenarios on the user price of aviation fuel. The outcome will then be used by Scheduler to compute the impact of the change in the fuel costs on air travel. Next, TCM will calculate the effects on aviation fuel consumption and emissions. Finally, ECOIO will compute the broader economic impacts of the SAF policies.

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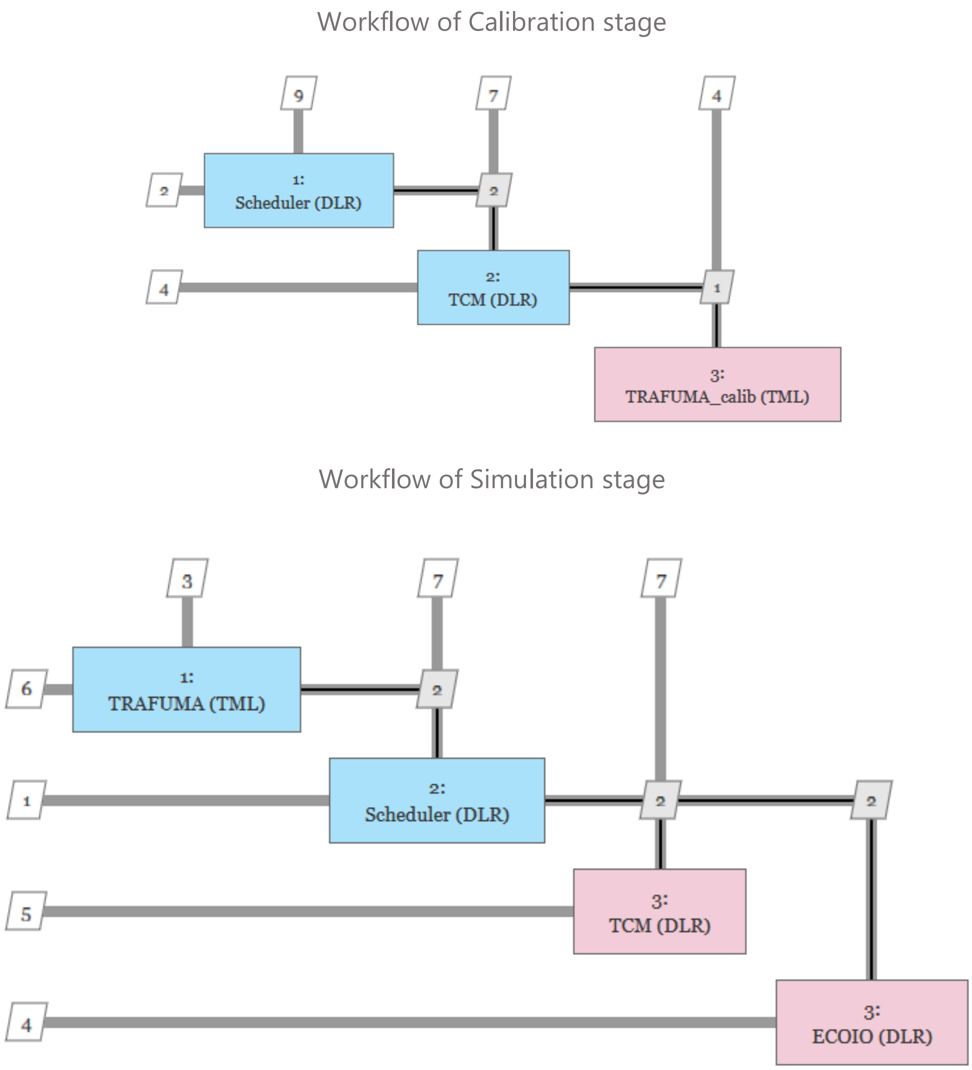

Figure 25. A generic presentation of the computational workflow in UC3 – calibration stage (top) and simulation stage (bottom)

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The different tools and their inputs and outputs are described in the following tables.

Table 11: ECOIO description

Name	ECOIO (DLR) – Economic Input/Output model
Purpose	Economic input-output model that estimates the gross value added and employment in the aviation industry for different growth paths of air transport
Inputs	Air traffic volumes measured in number of departing flights by country and year (reference year 2019 plus forecast years) Other inputs: World input-output table covering 43 countries (plus the rest of the world) and 56 industry sectors in each country (World Input-Output Database), gross value added and employment in each country and industry sector (Eurostat, U.S. Bureau of Labor Statistics, U.S. Bureau of Economic Analysis, World Input-Output Database, International Labour Organization)
Outputs	Gross value added, employment, output and labour income differentiated by industry stakeholder (airlines, airports/ANSPs, MRO firms, manufacturers), country and year

Table 12: Scheduler description

Name	Scheduler (DLR)
Purpose	State-of-the-art tool for forecasting air traffic patterns
Inputs	For all forecast years, a compact annual flight plan, with routes and aircraft details. An OAG reference flight plan, for a base year. With details of airports, countries, regions and times
Outputs	Using advanced statistical techniques, it is able to produce realistic flight schedules that accurately reflect future air traffic trends, including precise timing, aircraft types, airlines and routes. Based on annual forecasts, this model can be used for flight planning, resource management, and strategic decision making. The generated output file is in CSV format.

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Table 13: TCM description

Name	TCM
Purpose	Trajectory calculator to provide flight performance metrics along defined flight trajectories
Inputs	Wind/Weather data: International Standard Atmosphere (ISA) or detailed meteorological information (e.g. ECMWF ERA5) Flight performance data (BADA4, CPACS, or others) Flight plan description Take-off mass or load factor Engine emission indices for emission quantity calculation
Outputs	Detailed four-dimensional trajectory description in high temporal resolution including for all OD pairs of a given flight plan

Table 14: TRAFUMA description

Name	TRAFUMA (TML)
Purpose	Economic partial equilibrium model for the transport fuel markets that calculates the impacts of policies for the uptake of sustainable fuels
Inputs	Reference scenario (historic + outlook): fuel demand by transport market and region of the world, fuel cost before taxes/subsidies per fuel market, feedstock costs, fuel taxes/policies in reference scenario Other inputs: Cost structure transport fuels, conversion efficiency of fuel production process and extent of co-production, greenhouse gas emission factors per fuel (TTW, WTW, WTW with ILUC), social costs per tonne of greenhouse gas emissions, fuel demand and supply elasticities, feedstock supply functions
Outputs	Per transport mode and geographical market: total fuel demand, share of different fuel types, greenhouse gas emissions (TTW, WTW and WTW with ILUC), pre-tax price and user price of the different fuel types, change in feedstock costs, implied tax on fossil fuels and/or implied subsidy on sustainable fuels of an exogenously imposed share or target of sustainable fuels or blending mandate, social welfare and its components (consumer surplus, producer surplus, government revenues, social cost of emissions)

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These tools will be connected as part of the computational workflow through MDAx. The communication between the tools will be performed using the CPACS standard.

Step 2: Scenario definition

The next step will consist of the common definition of the underlying assumptions in the reference scenario and policy scenarios. For the reference scenario this concerns assumptions regarding, among others, the economic and demographic evolution, the crude oil price, and the price of feedstock for sustainable fuels and the policies in the transport fuel markets. The scope is broader than only aviation, as the fuel markets for the different transport modes are interrelated.

In the policy scenarios, additional policies will be introduced for promoting the uptake of SAF in aviation. This will be the only change compared to the reference scenario, such that the impact of the SAF policies can be derived by comparing the policy scenarios with the reference scenario.

Step 3: Studies execution

Once the computational workflow is created in MDAx, the workflow will be executed. Here, RCE[1] will be used to automatically generate the policy evaluation. In the course of this process, it will be checked whether full automation of the execution is possible, or whether intermediate checks by the modellers will need to be included.

Step 4: Scenario exploration

As mentioned before, selected inputs and outputs of ECOIO, Scheduler, TCM and TRAFUMA will be stored in the CPACS data file. The modellers will be able to visualise these data in the DA. Some examples of possible plots are given below with outputs of TRAFUMA (see Figure 26 and Figure 27), Scheduler (see Figure 28 and Figure 29) and ECOIO (see Figure 30).

[1] For additional information about RCE, see Step 4 in Section 2.2.

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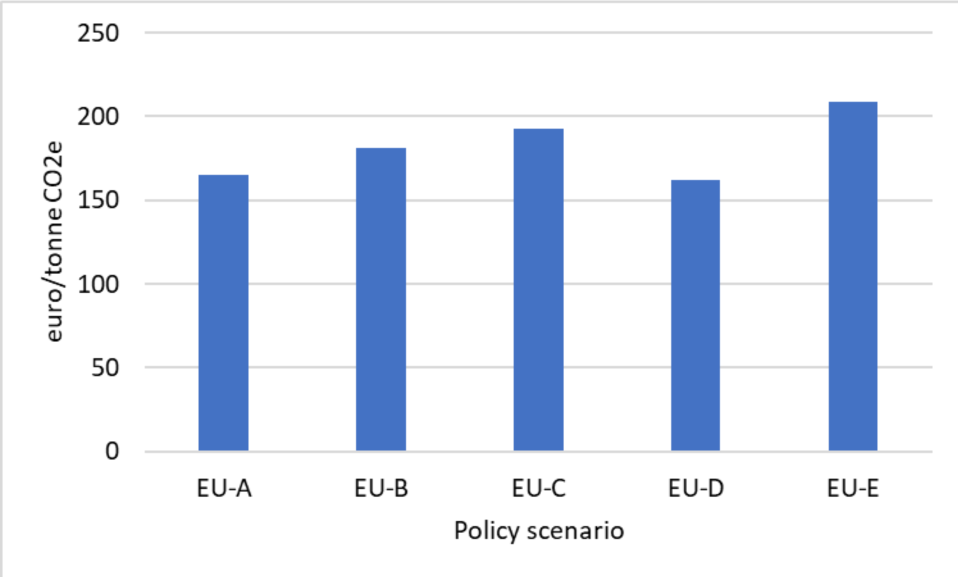

Figure 26. Social welfare cost per tonne of CO_2e avoided in 5 policy scenarios – 2030 (example of TRAFUMA output)

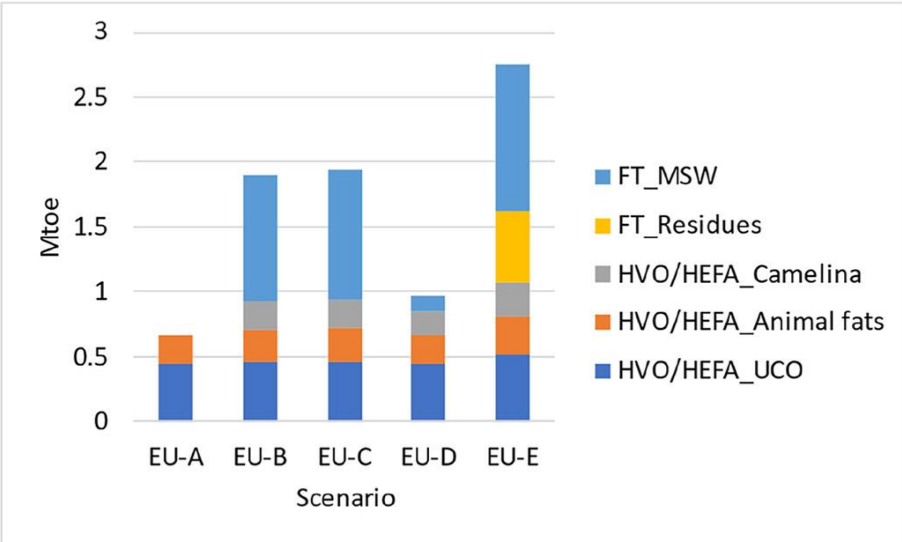

Figure 27. SAF demand EU aviation in 5 policy scenarios – 2030 (example of TRAFUMA output)

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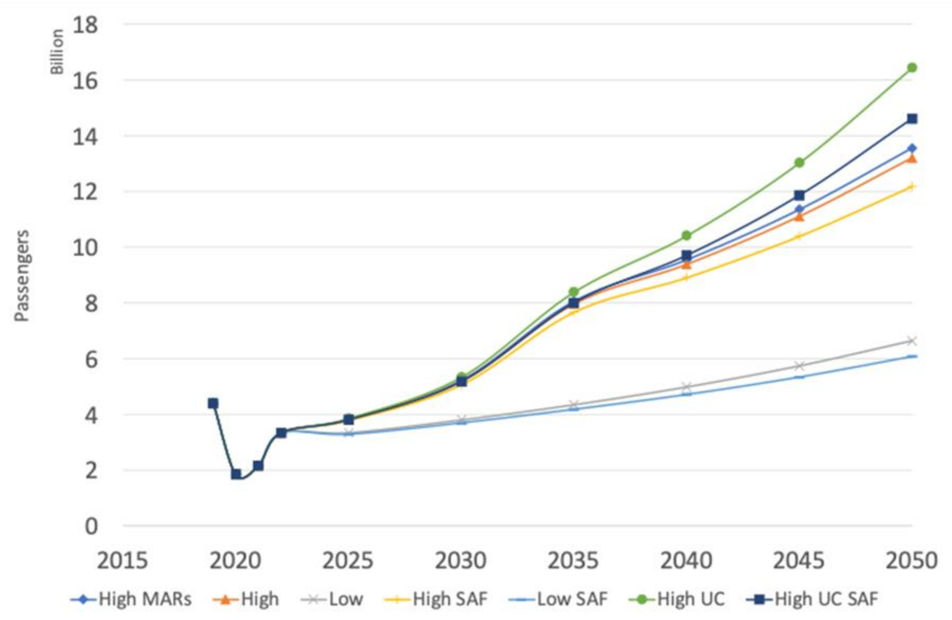

Figure 28. Pax demand (example of DLR scheduler output)

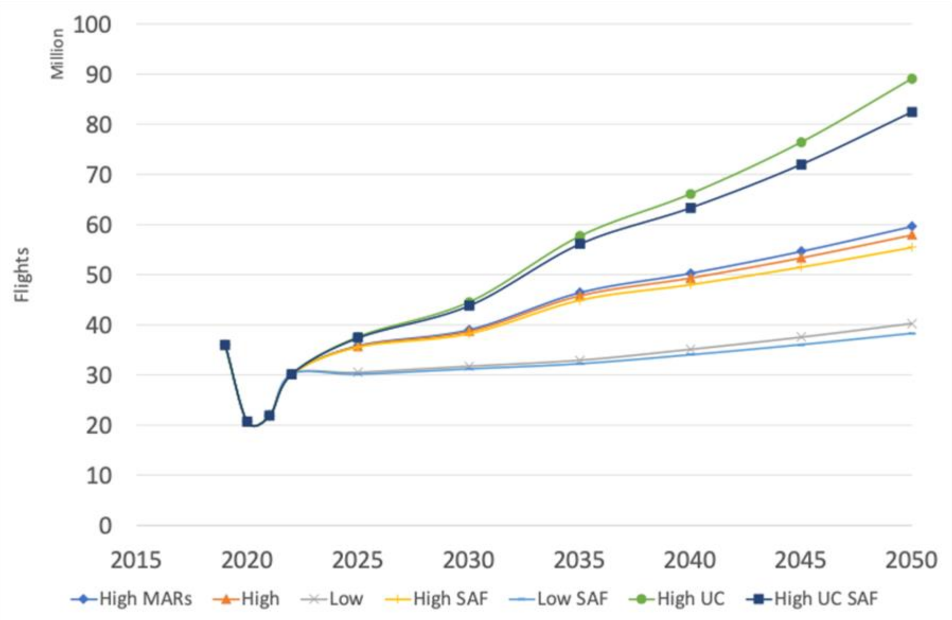

Figure 29. Flight demand (example of DLR scheduler output)

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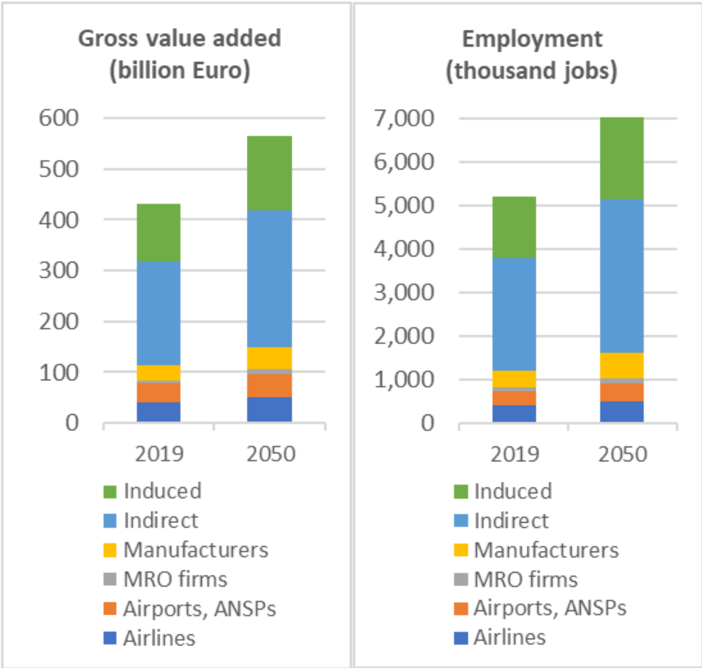

Figure 30. Gross value added and employment in EU27 and the UK (example of ECOIO output)

Step 5: Workflows/studies modifications

UC3 wishes to demonstrate the capabilities of the Impact Monitor framework and DA to perform the evaluation of policy scenarios at the ATS level. Considering the previous steps, any problems with the workflow are identified. If necessary, the workflow and the exchange of information between the tools in Step 1 are adapted. In addition, based on the exploration of the scenario impacts in Step 4, it may be decided to change the definition of the policy scenarios in Step 2. When this is done, Step 3 and Step 4 will be repeated. If necessary, the process will be repeated again.

Step 6: Sharing Reports

In the final step of UC3 implementation, the user will be able to generate and export results using the DA. It will be possible to display and download the reports in various formats, such as Excel, PDF, HTML, etc. for further analysis.

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5. DEMONSTRATION PLAN

5.1 Requirements origin

The three Uses Cases (UCs) aim at demonstrating the capability of the collaborative assessment framework to support the formulation and execution of impact assessments at multiple levels. They will also demonstrate the capability of the interactive web-based visual and data analytics environment (DA) to support the post-processing stage for design space exploration and use case data analysis.

Therefore, the requirements covered by the three UCs are directly linked to both framework and dashboard developments and can be divided in two different categories:

- Functional requirements that describe what the system should do and how it should behave in specific situations. For instance:
  - which data types the system must handle;
  - data privacy and security measures;
  - how the data should be processed and analysed;
  - which specific functions the system must provide.
- Non-functional requirements that describe the qualities or characteristics that the system must have.

5.2 Framework requirements

The requirements considered in this part deal with the collaborative assessment framework and are grouped into Data model and Framework requirements:

- Data model
  This category deals with the requirements for the data model and data handling. It addresses questions about interfaces between tools that exchange information based on this data model, as well as requirements about the provenance of the data.

  All UCs will help demonstrating several requirements belonging to the Data model category, especially in the computational workflow creation. The creation of inputs, outputs, and intermediate data of all the tools employed in each UC as well as associated metadata (such as who created it, when it was created, and versions), will be assessed. Furthermore, a library for data conversion between different formats will be created. The UCs will also demonstrate the capability of the data model to handle different levels of assessment namely aircraft (UC1), airport (UC2), and ATS (UC3).

- Framework
  This category addresses the topics of implementing a central data repository and executing workflows.

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Regarding the Framework category, several requirements will be demonstrated. For each UC, it will be demonstrated that the workflow can be easily created/generated using MDAx and can be executed using RCE, thus validating the workflow creation step capability and the workflow execution capability for the UC studies. Finally, the capabilities to perform what-if scenarios and trade-off analysis requirements inherent in the last steps of the implementation of the UCs will also be covered.

5.3 Dashboard requirements

The requirements considered in this part deal with the DA and are summarised in several categories:

- Graphical User Interface (GUI)

  This category focuses on the graphical user interface for result interpretation and decision making by policy makers and specialists.

  The UCs are not directly concerned by this category of requirements.

- Security (Authentication-Authorisation)

  This category deals with the way the application will be secured by providing user authentication and authorisation.

  The UCs are not directly concerned by this category of requirements.

- Underlying Data

  This category addresses data storage location, data types and formats and mechanisms for accessing data.

  All UCs will help demonstrating several requirements belonging to the underlying data category. For instance, the capability to import data files will be demonstrated during scenario exploration with the required dataset provided through the Dashboard Application (user uploading the CPACS file). Furthermore, intermediate data from different disciplines/tools will be plotted for comparison purposes. For UC1, those data could be selected among drag polar, engine deck, mission performance or top-level KPIs (e.g., block fuel, emissions, sustainability). For UC2, data of interest will be selected among top-level KPIs such as emissions, noise, and third-party risk. For UC3, those data could be fuel prices and top-level KPIs (e.g., air travel demand, fuel demand, SAF uptake, social welfare components).

- Visual Analytics

  This category deals with the interactive visualisation environment for rapid exploration of the potential design solutions, allowing the freedom to modify plots on the fly. Regarding the visual analytics category, several requirements will also be demonstrated. During the design space exploration / scenario exploration of each UC, various interactive plots will be generated in order to provide clear insights of the results. For instance, UC1 will explore the capability of the

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dashboard to visualise engine cycle performance, aircraft mission performance and sustainability matrices. UC2 will focus on CDO effects on various outputs and UC3 will plot various graphs for the impacts of the policy scenarios. In addition, interactive plots, such as scatter plots, line charts, and 2D/3D geometries will be displayed for all UCs in order to assess the DA capabilities.

- Filtering, Classification, and Data Manipulation

  This category focuses on design space exploration capabilities, which are useful for effective decision making. Demonstration of Filtering, Classification, and Data Manipulation capabilities will also be performed thanks to the UCs.

  Requirements regarding data manipulation will be validated during the design space / scenario exploration phase. UC1 will focus on the down-selection of promising aircraft solutions obtained from the design studies. UC2 highlights the effects of different levels of CDO applications on the airport vicinity while UC3 will demonstrate the down-selection of the impacts of specific policy scenarios obtained from the policy evaluation studies. The capability to generate tabular forms will also be checked with, for instance, impacts of policy scenarios for UC3.

- Exporting and Collaboration

  This category deals with storing, sharing, and printing visualisation plots and tabulated datasets.

  Like in previous categories, all UCs will contribute to demonstrate the capabilities of Exporting and Collaboration.

  During the last part of the UCs activities (Sharing report), results from all UCs will be downloaded and exported in various forms to share with partners assessing several capabilities of the DA.

- What-if Scenarios, Trade-off, and Comparisons

  This category addresses the capability, for users, to perform what-if and trade-off studies.

  The requirements from What-if Scenarios, Trade-off, and Comparisons categories will be covered by demonstrating what-if scenarios in order to perform trade-off studies for all the UCs. For instance, UC1 will compare different aircraft solutions, UC2 the different choice of CDO coverage and UC3 will focus on the impacts of different SAF policy scenarios compared to a reference scenario.

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6. Conclusion

The Impact Monitor deliverable D5.2 provides a specification of the three Use Cases aimed at demonstrating the Impact Monitor framework with its Dashboard Application:

- UC1: Advanced propulsion system;
- UC2: Continuous descent operations;
- UC3: Sustainable aviation fuel.

In addition, it provides a description of their targeted implementation plan, especially regarding their integration with the Impact Monitor framework and connection to the Dashboard Application. Further, the implementation plans highlight the framework and dashboard requirements to be assessed by each use case.

This deliverable will be used as a reference document by each Use Case for the implementation and demonstration of the Impact Monitor framework with its Dashboard Application.

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