IMPACT MONITOR

D5.4 – Use Cases Results

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Abstract

This deliverable provides the final results of the operating scenarios of three demonstration use cases of the Impact Monitor project, as well as the lessons learnt of their implementation and execution in the Impact Monitor collaborative assessment framework. A roadmap for future collaborative framework development is also provided.

Keywords

Demonstration, Use Cases, Results, Lessons learnt, Roadmap

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Table of Acronyms and Abbreviations

Acronym / Abbreviation	Description / Meaning
ATC	Air traffic control
ATS	Air Transport System
BADA	Base of aircraft data
CDA	Continuous Descent Arrival
CDO	Continuous Descent Operations
CINEA	European Climate, Infrastructure and Environment Executive Agency
CPACS	Common Parametric Aircraft Configuration Schema
CU	Cranfield University
DLR	Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center)
EASN	European Aeronautics Science Network
GA	Grant Agreement
KPI	Key Performance Indicator
MBSE	Model based system engineering
MD(A)O	Multidisciplinary Design Analysis and Optimization
MDAX	MDAO Workflow Design Accelerator
MDO	Multidisciplinary design optimization
NLR	Stichting Koninklijk Nederlands Lucht- Ruimtevaartcentrum (Royal Netherlands Aerospace Centre)
ONERA	Office National d'Etudes et de Recherche Aerospatiales
RCE	Remote Component Environment
R&I	Research & Innovation
SAF	Sustainable Aviation Fuel
TML	Transport & Mobility Leuven
toe	Tonne of oil equivalent
UC	Use Case
UPC	Universitat Politècnica de Catalunya (Technical University of Catalonia)
WP	Work Package
XML	Extensible Markup Language

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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 Model Based System Engineering (MBSE) framework dedicated to collaborative assessment;
- A web-based environment employed at the post-processing stage for design space exploration and studies analysis;

Three example Use Cases (UCs) 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.

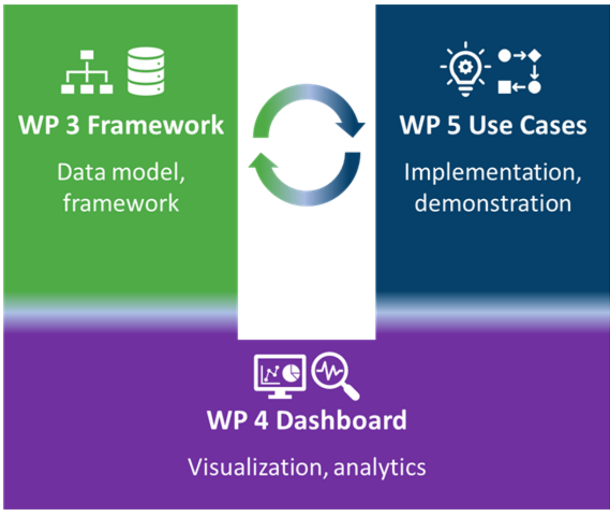

Figure 1: Impact Monitor Work-breakdown Structure for Technical Development and Implementation.

More specifically, every UC targets an environmental-, economic- and/or societal-impact assessment of an exemplary (although hypothetical) R&I innovation in aviation; and covers one or more assessment levels (i.e., aircraft, airport and/or air-transport system level). Every UC has been implemented in the Impact Monitor framework developed in WP3 and its results can be accessed through the Impact Monitor Dashboard Application from WP4.

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 have been carried out by all three demonstration UCs.

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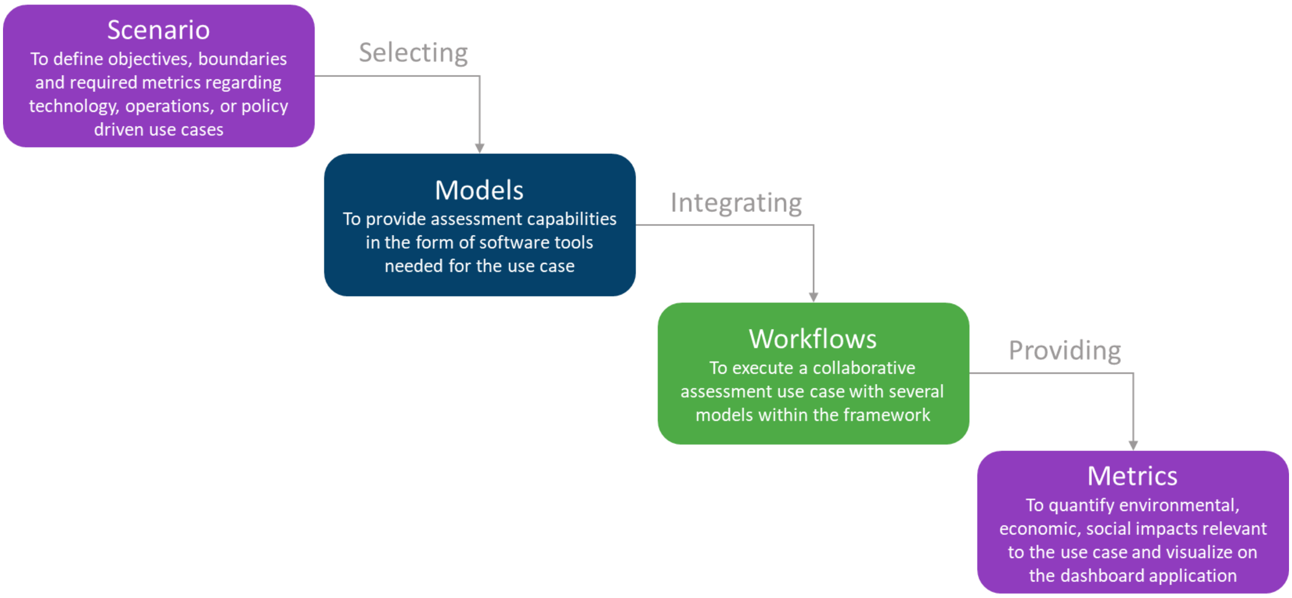

Figure 2: Implementation Steps for the Demonstration Use Cases

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 Fuels.

Next to the general demonstration of the Impact Monitor framework in the three Use Cases, each Use Case also focussed on specific aspects.

- Use Case 1: demonstration of the framework's capabilities with the MDA loop and DOE loop, as well as the data conversion and exchange between different standards (CPACS and BADA)
- Use Case 2: demonstration of the framework's capabilities with a large number of tools, as well as the collaborative versatility with the use of both BRICS and Uplink.
- Use Case 3: demonstration of the framework's capabilities to include complex / costly models not natively exchanging data, and scalability assessment for larger data sets containing global passenger flights in future years.

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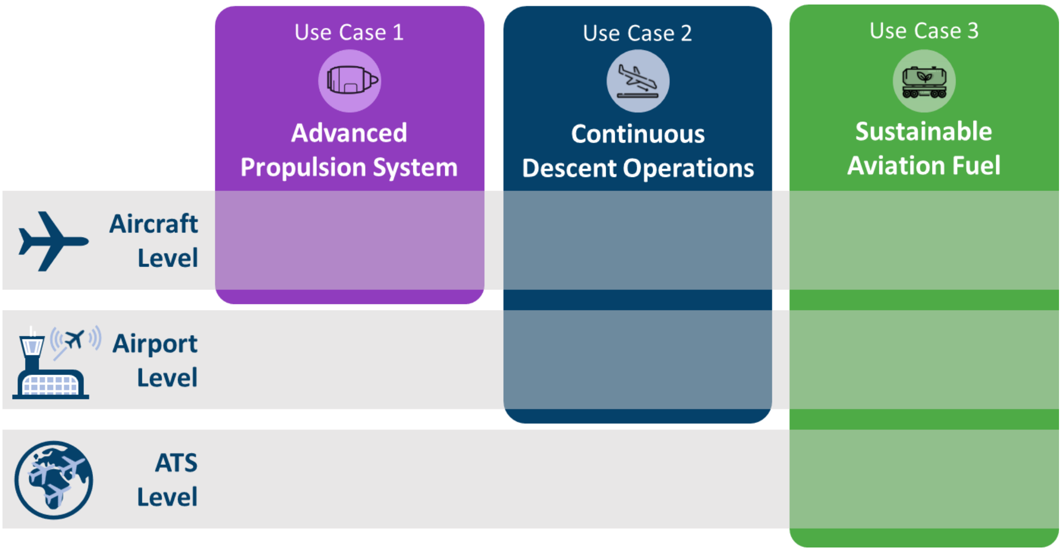

Figure 3: Schematic Representation of the Demonstration Use Cases and Assessment Levels

The first WP5 deliverable (D5.1 [1]) introduced and described the pre-existing models and capabilities available in the consortium at the beginning of the project. The second one (D5.2 [2]) described 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. The third one (D5.3 [3]) refined the operating scenarios of three demonstration use cases, as well as the status of their implementation with a preliminary example of partial execution for each one.

The present deliverable (D5.4) concludes the WP5 activities and provides the final results of the operating scenarios of three demonstration use cases of the Impact Monitor project, as well as the lessons learnt regarding their implementation and execution in the Impact Monitor collaborative assessment framework.

It is organised as follows:

- Section 2 highlights the main results obtained by each UC, in terms of workflow execution and studies at the end of the Impact Monitor project
- Section 3 collects all the lessons learnt through all the four phases of the UC development, from scenario definition until results post processing
- Section 4 provides the roadmap of collaborative framework development for improvement and extension of scope
- Section 5 concludes the document, summarising the information provided herein.

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2. Use Case Results

This chapter summarises for each Use Case the general set-up of the use case and gives an overview of the finalisation of the technical activities in the last months of the project, as well as the Use Case results.

In November 2024 each of the Use Cases was presented at the 14th EASN Conference in Thessaloniki, Greece. In addition to the overview in this chapter, Annexes A to C include for each Use Case a paper published in the proceedings of the EASN Conference, with more detailed information on the technical implementation and results.

2.1 Use Case 1: Advanced Propulsion Systems

2.1.1 General

Use Case 1 (UC1), aimed at aircraft level for the advanced propulsion systems has been implemented using the Impact Monitor framework and the results are presented through the Dashboard (see D4.3 [4]). UC1 involves the collaborative design and analysis of a single-aisle, tube-and-wing, low-wing configuration, with two wing-mounted turbofan engines, and conventional empennage. For airframe sizing, top-level aircraft requirements and design variables (e.g., wing area and aspect ratio) are utilized to calculate the engine thrust requirements, which are then transferred in a CPACS file to the engine sizing model using the Uplink protocol. These thrust requirements are then used to generate engine performance deck which is transferred again through CPACS file. This process is repeated iteratively until the thrust requirements stabilize (i.e., convergence is reached).

The two tools employed for sizing airframe and engine cycle analysis are SUAVE (Aircraft Modelling Tool) and TURBOMATCH (Engine Modelling Tool), respectively. Once the convergence between airframe and engine design teams is achieved, the optimized aircraft can be utilized for emissions assessment, where 4D trajectory analysis is performed by utilizing the tools DYNAMO (Trajectory Amendment for contrail avoidance) and AECCI (Aircraft Emissions and Contrails for Climate Impact). These tools require BADA model (.opf and .apf) as input to conduct 4D trajectory analysis. A tool for automated generation of BADA model (called CPACS2BADA Convertor) was developed which takes the CPACS files and produce the corresponding BADA .opf and .apf files.

All the four tools (SUAVE, TURBOMATCH, DYNAMO, and AECCI), along with CPACS2BADA convertor tool, were integrated through the Impact Monitor Multidisciplinary design optimization (MDO) framework using Remote Connection Environment (RCE) to conduct design studies.

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2.1.2 Progress in technical implementation since Deliverable 5.3

The table below provides an overview of the status of UC1, as documented in Deliverable 5.3 (indicated in black), along with the additional steps implemented since then (highlighted in green).

Table 1: UC1 tool integration status – in green: additional steps since Deliverable 5.3

Tool	**CPACS connection**		**RCE integration**		
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink server established	Complete remote workflow tested and verified
TURBOMATCH	☑	☑	☑	☑	☑
SUAVE	☑	☑	☑	☑	☑
DYNAMO	☑	☑	☑	☑	☑
AECCI	☑	☑	☑	☑	☑

In addition to the general demonstration of the Impact Monitor framework, the implementation of UC1 also demonstrates the RCE capabilities with the MDA loop and DOE loop, as well as the data conversion and exchange between different standards (CPACS and BADA).

For UC1 the paper submitted to the conference proceedings is included in Annex A, which also contains a description of the technical implementation of UC1. The following graphs illustrate the two main components of studies which combine the full remote workflow conducted for UC1.

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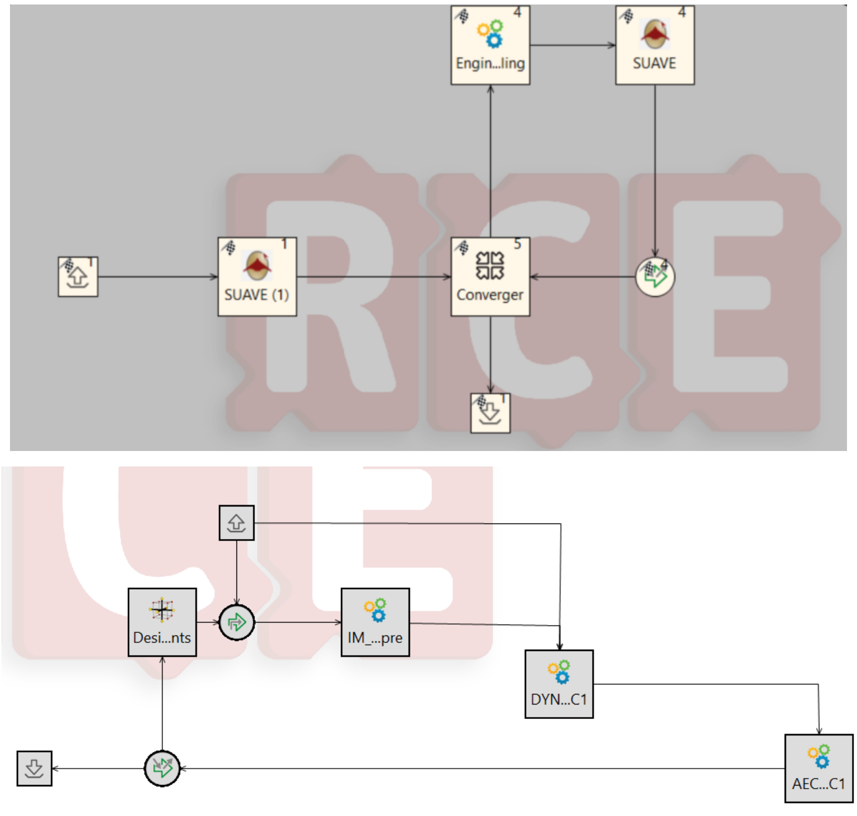

Figure 4: Remote workflow for UC1

2.1.3 Selection of Use Case 1 results

To demonstrate the Impact Monitor Framework and Dashboard Application features and capabilities at Airport Level, the Use Case 1 study was conducted as explained in previous sections. The study began with the parameters provided below and involved tweaking the parameters to achieve an engine and aircraft convergence to create a concept aircraft.

Table 2: Problem formulation for airframe and engine design

Airframe Design Problem Formulation

Airframe Design Variables	Wing Area (m^2)	[120, 140]
	Aspect Ratio	[9, 12]
Top-Level Aircraft Requirements	Take-off Field Length (m)	≤ 2000
	Time to Climb (min)	≤ 25
	Range (nm)	≥ 4000
	Block Fuel (lb)	Minimize
Thrust Requirements	End of Runway Thrust (lbf)	Calculated
	Top of Climb Thrust (lbf)	
	Mid-Cruise Thrust (lbf)	

Engine Design Problem Formulation

Engine Design Variables	Bypass Ratio	[9, 14]
	Fan Pressure Ratio	[1.6, 2.0]
	Low Compressor Pressure Ratio	[2.8, 3.2]
	High Compressor Pressure Ratio	[9, 15]
	Inlet Airflow Rate (kg/s)	[400, 600]
Performance Output	End of Runway Thrust (N)	Calculated
	Top of Climb Thrust (N)	
	Mid-Cruise Thrust (N)	
	Turbine Inlet Temperature (K)	≤ 1750
	Specific Fuel Consumption ($kg/(N \cdot s)$)	Minimize
	Complete Engine Deck	Cpacs files

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As the study focused on two different setups of engines, one being High Bypass Ratio and the other being Ultra High Bypass Ratio, once the concept aircrafts have been achieved, we can see a designs of both the engines in the plots illustrated in Figure 5.

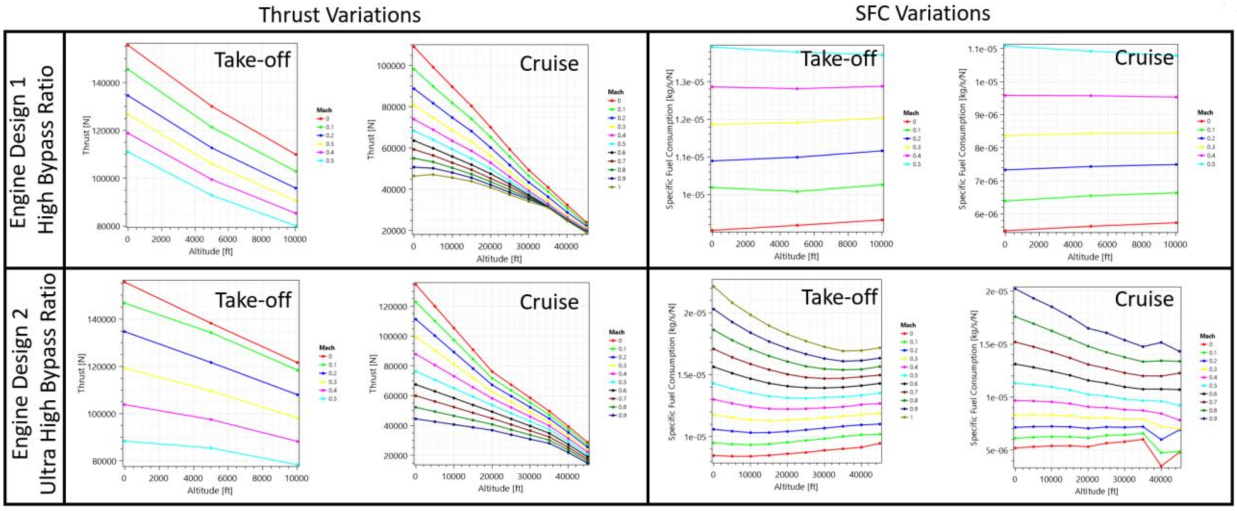

Figure 5: Engine Design Results for UC1

The aerodynamic performance (i.e., the low speed and high speed drag polars) of the aircraft are presented in Figure 6.

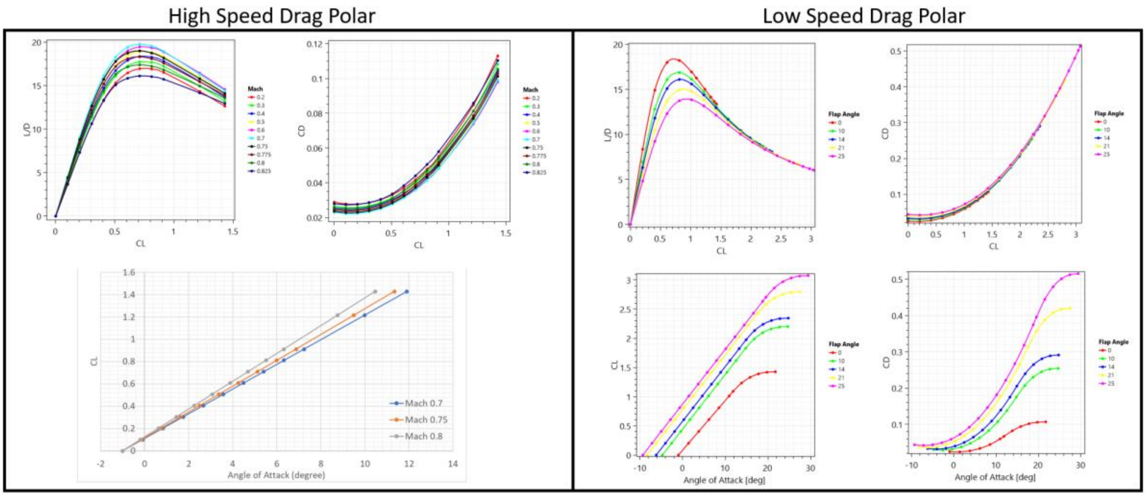

Figure 6: Airframe Design Result for UC1

Similarly generated concept aircrafts are then passed into the trajectory analysis and emission assessment tools which in turn provide results illustrated in Figure 7 and Figure 8.

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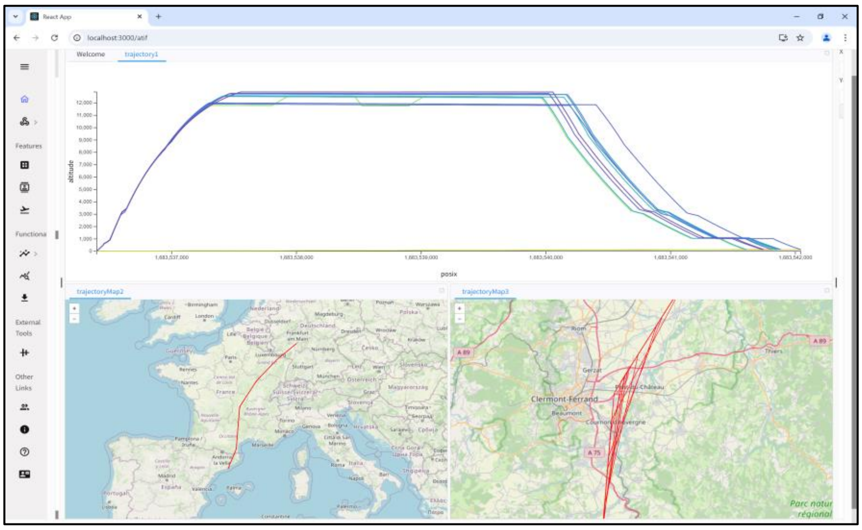

Figure 7: 4D Trajectory Analysis

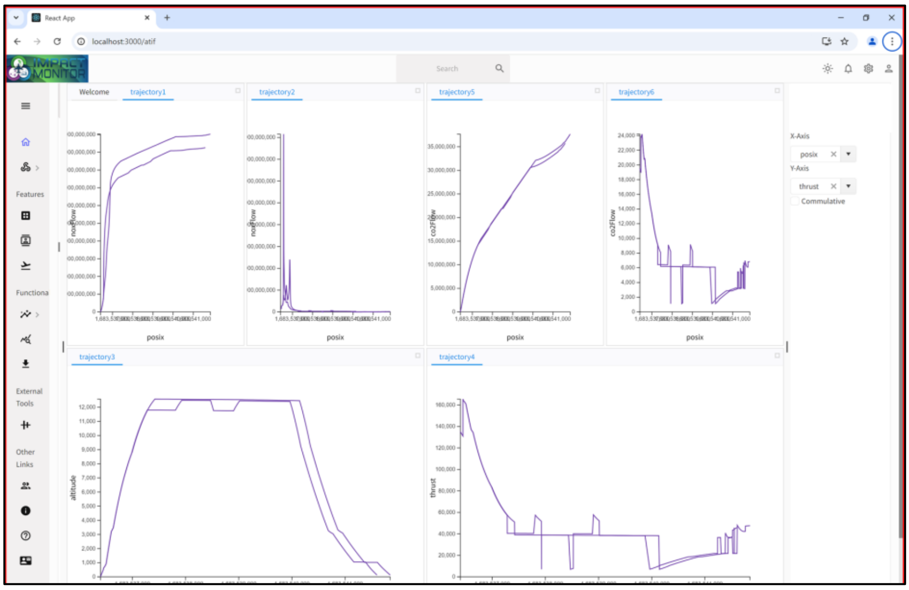

Figure 8: Emissions Assessment

For Use Case 1 the paper that was presented at the 14th EASN Conference is included in Annex A. This annex provides a description of the implementation of the use case, as well as the preliminary results obtained.

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2.2 Use Case 2: Continuous Descent Operations

2.2.1 General

Use Case 2 (UC2) is aimed to the analysis of the airport level assessment. The focus of the UC2 is on the arrival operations, and more specifically the implementation of Continuous Descent Operations (CDO), or what is the same the Continuous Descent Arrival (CDA). As described in D5.3 [3], CDO is expected to reduce emissions and noise annoyance in the daily operations. In order to enable an accurate analysis of the real impact of the implementation of this strategy the tools involved in the use case are:

- AirScheduler (DLR): provides a flight schedule from a list of origin and destinations
- AirTOp (NLR): provides the flight trajectories around an airport given the schedule of flights
- Dynamo – Farm (UPC): provides accurate analysis of the flight trajectories, adding additional parameters to the ones calculated by AirTOp. (*)
- TUNA (NLR): provides analysis of the noise annoyance given a flight trajectory and an area of interest.
- LEAS-iT (NLR): provides analysis of the emissions given a flight trajectory and an area of interest.
- AECCI (ONERA): provides accurate analysis of the emissions of a given trajectory (*)
- TRIPAC (NLR): provides analysis of the risk associated to the operation and its associated flight trajectory
- SCBA (TML): provides the global assessment of the impact taking the data from the previous steps and comparing with a baseline design

The reader can see that the list of tools is quite large, including 8 tools. Dynamo – Farm and AECCI, marked with an (*) can be considered as a secondary branch of the workflow. This is due to the fact that data from AirTOp is enough to feed TUNA, LEAS-iT and TRIPAC, while these three tools can provide enough data to the SCBA to perform the impact assessment. The reason to define this second branch is the complementarity and the more accuracy one can obtain with the two additional tools.

2.2.2 Progress in technical implementation since Deliverable 5.3

Deliverable D5.3 [3] provided a description of the status of the implementation at that moment. From then, progress has been done. The previous and current status is described in the following table. The previous covered steps are highlighted in black, while the new ones are shown in green.

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Table 3: UC2 tool integration status – in green: additional steps since Deliverable 5.3

Tool	CPACS connection		RCE integration		
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink/BRICS server established	Complete remote workflow tested and verified
AirScheduler	☑	☑	☑	☑	☑
AirTOp	☑	☑	☑	☑	☑
Dynamo-Farm	☑	☑	☑	☑	☑
TUNA	☑	☑	☑	☑	☑
LEAS-iT	☑	☑	☑	☑	☑
TRIPAC	☑	☑	☑	☑	☑
AECCI	☑	☑	☑	☑	☑
SCBA	☑	☑	☑	☑	☑

In addition to the general demonstration of the Impact Monitor framework, the implementation of UC2 also demonstrates the capabilities of the framework with a large number of tools, as well as the collaborative versatility with the use of both BRICS and Uplink.

For UC2 the paper that was presented at the 14th EASN Conference is included in Annex B. This annex provides a description of the implementation of the use case, as well as the preliminary results obtained.

2.2.3 Selection of Use Case 2 results

The Impact Monitor assessment for Use Case 2, at Airport level, is based on the comparison of two scenarios. The first one is the reference baseline. It considers the null application of continuous descent operations. The second one already considers CDO. More specifically, the operation of interest is the approach, so the scenarios focus on continuous descent approaches (CDA). An example of this comparison is shown in Figure 9, which compares the noise contour for a non-CDO and a CDO operation.

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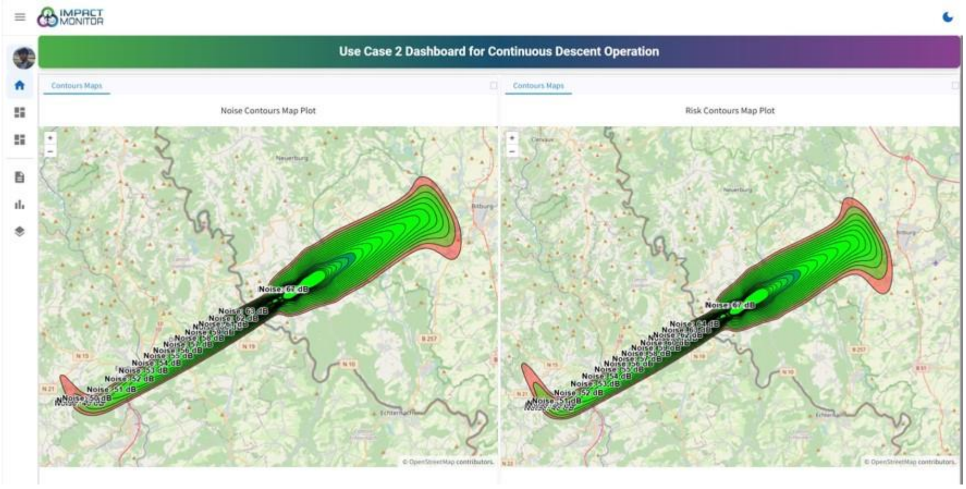

Figure 9: Comparison of the Noise Contour in Use Case 2

As described in the Annex B, the way each scenario is defined and executed is almost the same. Starting from the list of flights, a flight schedule is obtained and simulated to get all the trajectories. Then each trajectory is analysed to get the emissions, noise and risk associated to the operation. The comparison between to two scenarios, with and without CDO, is providing the final impact assessment. As a reminder, it is important to keep in mind that the degree of implementation of the CDO strategy depends on the number of operations. With an increase on the number of operations we could reach a point where CDO is no longer applicable due to ATC (Air traffic control) restrictions.

Annex B provides a detailed description of the results obtained so far. The work done from last November has been focused on the issues concerning the integration of the tools, so the results described in the EASN paper are the last and most updated ones.

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2.3 Use Case 3: Sustainable Aviation Fuels

2.3.1 General

Use Case 3 demonstrates the Impact Monitor framework at the ATS level, focusing on policies for the uptake of sustainable aviation fuels (SAF). The following table gives an overview of the tools involved. Three of the tools involved have already been combined in the past for analyses though not yet using the framework (Scheduler, Emissions tool and ECOIO), and other hand for a new combination of tools (TRAFUMA with the other tools). Scheduler, ECOIO and TRAFUMA analyze different dimensions of the economic impacts of policies, while the environmental impacts are covered in the Emissions tool and TRAFUMA. For the purpose of the project, Scheduler and the Emissions tool have been optimized to integrate them smoothly in the workflow.

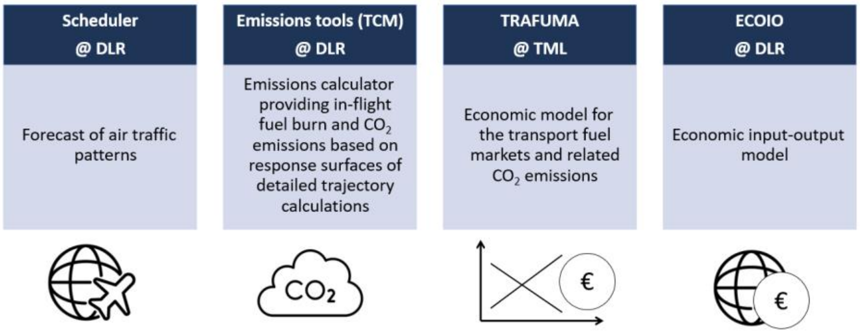

Figure 10: Tools used in the ATS Use Case

2.3.2 Progress in technical implementation since Deliverable 5.3

The following table gives an overview of the status of UC3 as reported in Deliverable 5.3 (in black), and of the additional steps that have been undertaken since then (in green).

Table 4: UC3 tool integration status – in green: additional steps since Deliverable 5.3

Tool	CPACS connection		RCE integration		
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink server established	Complete remote workflow tested and verified
AirScheduler	☑	☑	☑	☑	☑
Emissions Tool	☑	☑	☑	☑	☑
ECOIO	☑	☑	☑	☑	☑
TRAFUMA	☑	☑	☑	☑	☑

In addition to the general demonstration of the Impact Monitor framework, the implementation of UC3 also demonstrates the framework's capabilities to include complex / costly models not natively exchanging data, and scalability assessment for larger data sets containing global passenger flights in future years.

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For UC3 the paper that was presented at the 14th EASN conference is included in Annex C. The paper gives a description of the technical implementation for UC3. The following graph reports the remote workflow that was carried out for UC3. TRAFUMA and Scheduler compute the results immediately for all scenarios and years, while the other tools do so per year. The figure at the left shows the workflow when ECOIO and the Emissions Tool work for one year, while the figure at the right gives the full workflow for all scenarios and years.

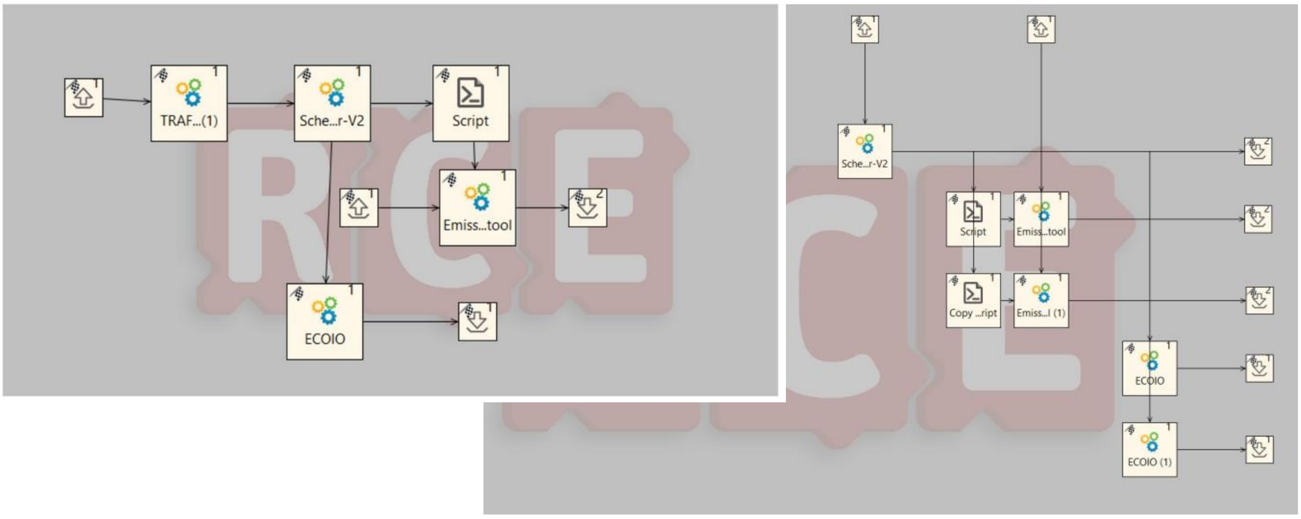

Figure 11: Remote workflow for Use Case 3

2.3.3 Selection of Use Case 3 results

In order to demonstrate the Impact Monitor framework at ATS level, the UC3 tools were used to analyze the impacts of two policy scenarios for 2035 and 2050: the introduction of a global carbon tax in aviation (ENVTAX scenario), and the implementation of a global blending mandate for sustainable aviation fuels (BLENDING scenario).

In this section a selection of results are shown. The definition of the reference scenario and the two policy scenarios is detailed in Annex C. As the main focus of the exercise is on the demonstration of the Impact Monitor framework, rather than the exact finetuning of the scenario components, the scenario results should be considered as exploratory.

In the UC3 workflow TRAFUMA first calculates the impact of the policy scenarios on the fuel costs (Figure 12). In 2035 the impact of the blending mandate on the fuel costs for fuel bought in the EU is relatively small. As the SAF count for the broader REDIII transport target, they are cross-subsidized by higher fossil fuel costs not only in aviation but also in the other transport sectors. Moreover, no ETS allowances need to be surrendered for SAF. Outside of Europe in 2035 and for all flights in 2050, when the blending mandate is much stricter, it leads to a substantial increase in the fuel costs. The ENVTAX-scenario, which imposes a tax of 200 euro/tonne of CO_2 emissions globally (on a WTW with ILUC basis) leads to similar prices in all aviation market segments. The ETS no longer applies for aviation in this scenario, leading to only a small change in this segment, that is related to the fact that the tax is now based on the WTW with ILUC emissions of the fuels that are used. In the other market segments the price increases are substantial.

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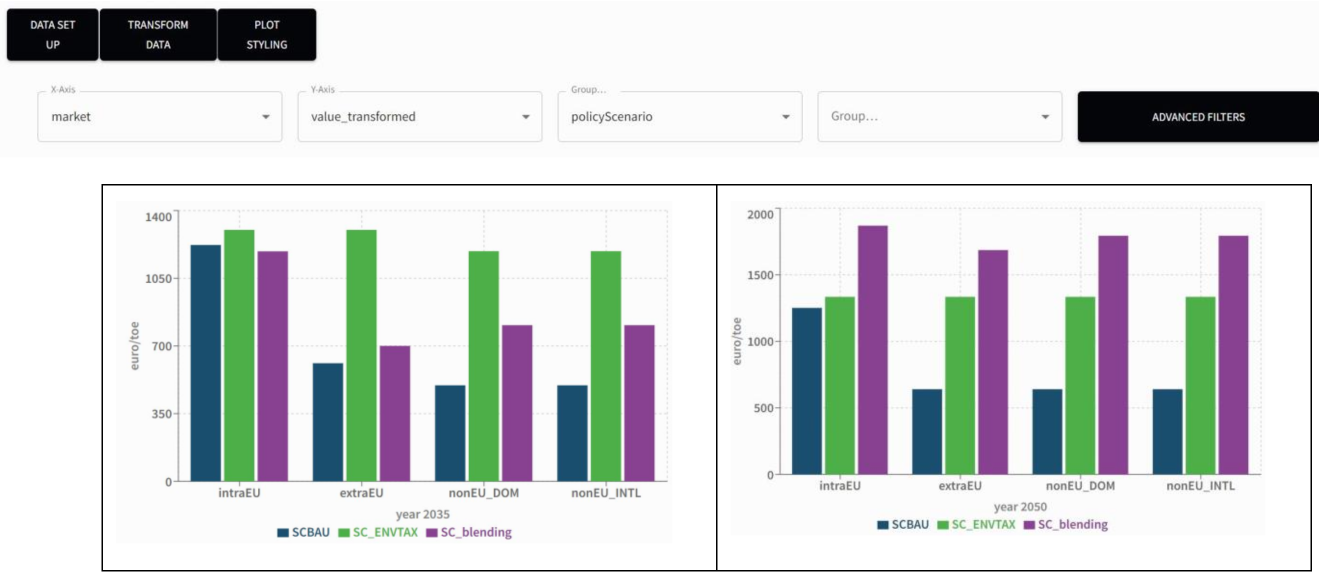

Figure 12: Fuel cost in the reference scenario and the two policy scenarios (euro2016/tonne of oil equivalent). Source: TRAFUMA

The scenarios lead to the following impact on the number of revenue passenger kilometres (RPK) and flights for the whole fleet (as calculated by Scheduler): in 2035 the ENVTAX scenario leads to the lowest level of RPK and flights, whereas in 2050 the lowest demand comes through the scenario with a blending mandate.

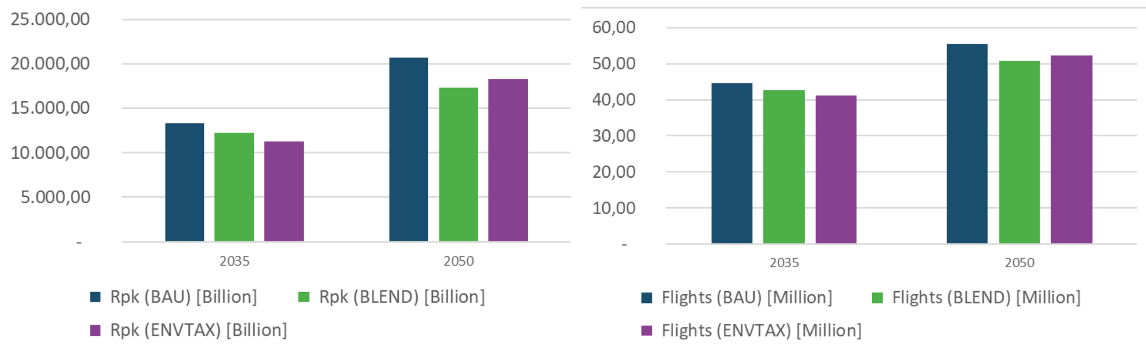

Figure 13: Revenue passenger kilometres (left; in billions) and number of flights (right; in millions) in the reference scenario and the two policy scenarios. Source: Scheduler

Regarding the impact on the fuels used, which is calculated with TRAFUMA, with the blending mandate, the shares of the different types of fuels are in line with the blending mandate. In the ENVTAX-scenario the level of the tax that is assumed does not lead to an uptake of SAF.

Concerning the CO_2 emissions to in-flight fuel burn for the whole fleet, the following impacts are simulated by the Emissions Tool: in 2035 the best result is achieved through the environmental tax scenario, whereas in 2050 the blending mandates yield the lowest emissions.

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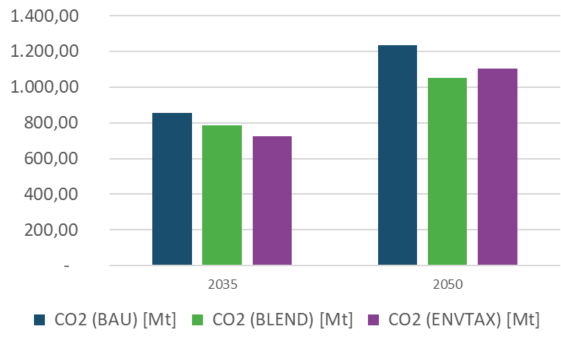

Figure 14: CO_2 emissions from in-flight fuel burn (Million tonnes CO_2). Source: Emissions tool

As there is no uptake of SAF in the environmental tax scenario, all CO_2 emission reductions are related to the reduction in fuel demand. In the scenario with the blending mandate emissions are reduced via two mechanisms: via a reduction in fuel demand (see Figure 14), and via the reduction in the emissions from the WTW with ILUC perspective. Figure 15 gives the percentage change in the average WTW with ILUC emissions per tonne of oil equivalent of fuel that is consumed, for the scenario with the blending mandate. For the environmental tax scenario there is no change in the emission intensity of the fuels used.

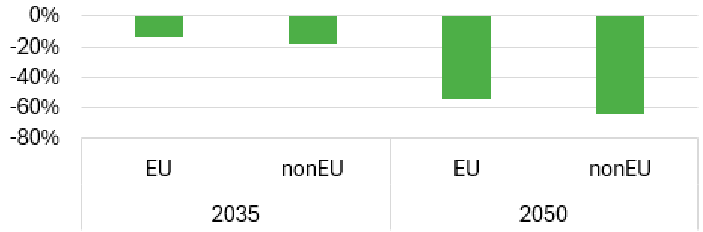

Figure 15: Average CO_2 emissions per tonne of oil equivalent – percentage change compared to the baseline scenario. Source: TRAFUMA

To investigate the cost-effectiveness of the policies in the two scenarios, TRAFUMA calculates the social cost per tonne of CO_2 abated (Figure 16). This is calculated by taking the sum of the change in consumer surplus, producer surplus and government revenue, and by dividing this sum by the change in emissions (WTW with ILUC perspective). As can be expected based on previous literature, the social welfare cost per tonne abated is high for the blending mandates, which impose a costly technology (SAF) to reduce emissions. Under the environmental tax scenario emissions will be reduced up to the point where the marginal cost of an additional unit of emission reduction equals the level of the environmental tax (200 euro/tonne CO_2). The resulting average social welfare cost is about 100 euro/tonne CO_2. These social welfare costs can be compared with those in other sectors, for other policies or for other levels of the two policies considered here. By comparing them with the benefits of emission reductions, they can also be used in social cost-benefit analyses to evaluate the policies and compare them with other policies.

Finally, the ECOIO tool presents information on the economic impacts of the policy scenarios. Since both the blending mandates and the environmental taxes lead to a lower demand for air travel, the gross value added and employment created by the aviation industry decrease in both scenarios

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compared to the business-as-usual scenario. Figure 17 shows these results in detail for the European Union, broken down by each sub-sector of the aviation industry (e.g., air transport = AT), scenario, and year. The value added and employment effects are an aggregate of direct, indirect, and induced effects. Direct effects result from activities within the aviation industry itself, while indirect effects arise from the activities of suppliers to the aviation industry (e.g., fuel providers). Induced effects, on the other hand, are generated by the consumer spending of employees in both the direct and indirect sectors, which in turn stimulates further economic activity.

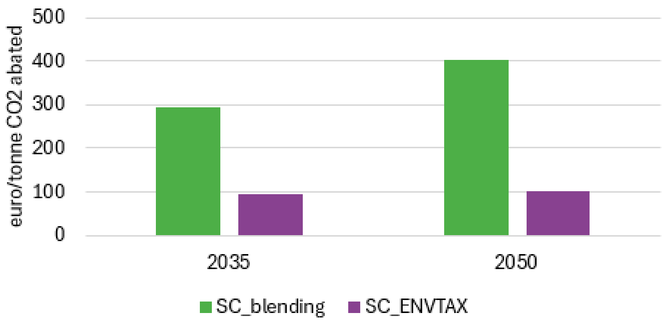
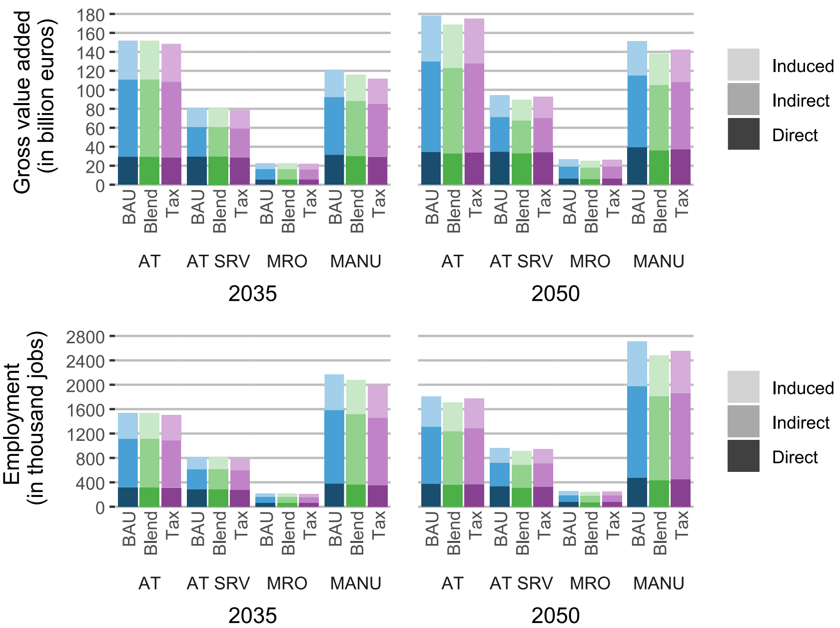


Figure 16: Social welfare cost per tonne of CO_2 emission abated (WTW with ILUC perspective) – euro2016/tonne CO_2 abated. Source: TRAFUMA



Notes: AT = Air transport, AT SRV = Air transport related services (e.g., airport services, air traffic management), MRO = Maintenance, repair and overhaul, MANU = Manufacture of aircraft and aircraft components; BAU: reference scenario; Blend: scenario with blending mandate; Tax: environmental tax scenario

Figure 17: The economic impacts of the policy scenarios in the European Union. Source: ECOIO

As indicated before, the results should be seen as exploratory, as the focus lied on the demonstration of the framework. A full evaluation of SAF policies would require also the consideration of a wider range of policy assumptions: different definitions of the policies than the ones considered here (e.g.

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different tax levels, different modalities for the blending mandates, etc.) as well as the consideration of other policy instruments (e.g. subsidies). The advantage of the Impact Monitor framework is that it greatly facilitates such additional work once the workflow with the different tools has been set up. Moreover, it allows to bring in additional tools that can shed light on additional policy impacts, such as, for example, tools that inform on the reduction of the non-CO_2 climate impacts of SAF policies.

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3. Lessons Learnt and Roadmap

3.1 Introduction

The objective of this final section of the deliverable is twofold:

- First, to gather and analyse the feedback from all relevant partners at the conclusion of the WP5 activities. This aims to identify what worked well, what did not, and areas for improvement. These insights are covered in the Lessons Learnt section (Section 3.2).
- Second, to outline future projections for extending the Impact Monitor. This includes addressing more complex workflows, conducting more advanced studies, and enhancing its overall capabilities. This is detailed in the Roadmap section (Section 3.3).

The inputs for these two sections were collected through a targeted survey conducted during month 23 of the project, which was distributed to a selection of partners involved in WP3, WP4, and WP5, encompassing all Use Cases (UCs). The activities related to the UCs were divided into four distinct phases (see Table 5) to ensure the collection of detailed information. For each phase, three consecutive sections were presented to the partners:

- The first section focused on gathering their feedback regarding the complexity of activities in each phase.
- The second section addressed lessons learnt, including a list of proposed improvements for validation and placeholders for additional input on lessons learnt and roadmap actions.
- The third section was dedicated to roadmap proposals, offering a similar structure to capture detailed suggestions for future developments.

Table 5: Overview of Use Case implementation phases

Phase 1	**Creation of assessment scenarios and selection of models** This step consists of defining the UC scenario in terms of objectives, focus (depending on the UC), assessment levels and boundaries. Required metrics are also defined at this stage. The scenario drives the requirements of competences needed to be included in the workflow. The models are then selected among the partners capabilities. The choice is made, for instance, depending on the assessment levels covered and the required metrics. In addition, the models should provide the right level of accuracy. From collaborative workflow considerations, the selected models should be easily made executable and allowed to be remotely accessible
Phase 2	**Workflow definition and visualisation** In this phase, once the models have been selected, the partners agree on the way they are connected to one another. First, a mock-up of the workflow is created using MDAx, in order to highlight the expected coupling between the models. Then, all models are progressively wrapped in CPACS while, in parallel, CPACS is extended to

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	cover the specificity of Impact Monitor focus. At the end of this step, all models are wrapped in the latest version of CPACS_IM and the latest MDAx version reflects the target status of the workflow.
Phase 3	**Execution of collaborative workflow** In this step, the workflow defined in MDAx in the preceding step is executed in RCE in a collaborative way. First, each model is integrated in RCE as local tool able to read/write CPACS_IM file. Then, they are made remotely accessible through Uplink or BRICS. Once every tool is integrated and accessible, the workflow is created (ideally from MDAx workflow output in RCE format) and full workflow connection and execution is checked.
Phase 4	**Running assessment studies and postprocessing results** In this phase, the scenarios defined initially are operated using the executable collaborative workflow adapting the studies parameters. Assessment results are produced and stored (at least in CPACS files). The results of the studies are post processed through the Dashboard. Results can be visualized, tables generated and studies results can be compared.

3.2 Lessons learnt

3.2.1 Overall feedback

The overall feedback on the framework was collected to assess the extent to which it achieved its goal of enabling partners to efficiently set up and operate collaborative workflows for impact assessment. According to the survey results, the framework was found to be useful for integrating models, creating, and running workflows collaboratively. Some partners also highlighted that it improved communication beyond the models, fostering exchanges between researchers working on different topics. Additionally, partners gained knowledge of the framework's various components and are now better equipped to use it in future projects. However, some respondents noted that newcomers would still require support. These aspects will be further addressed in the detailed *Lessons Learnt* and *Roadmap* sections.

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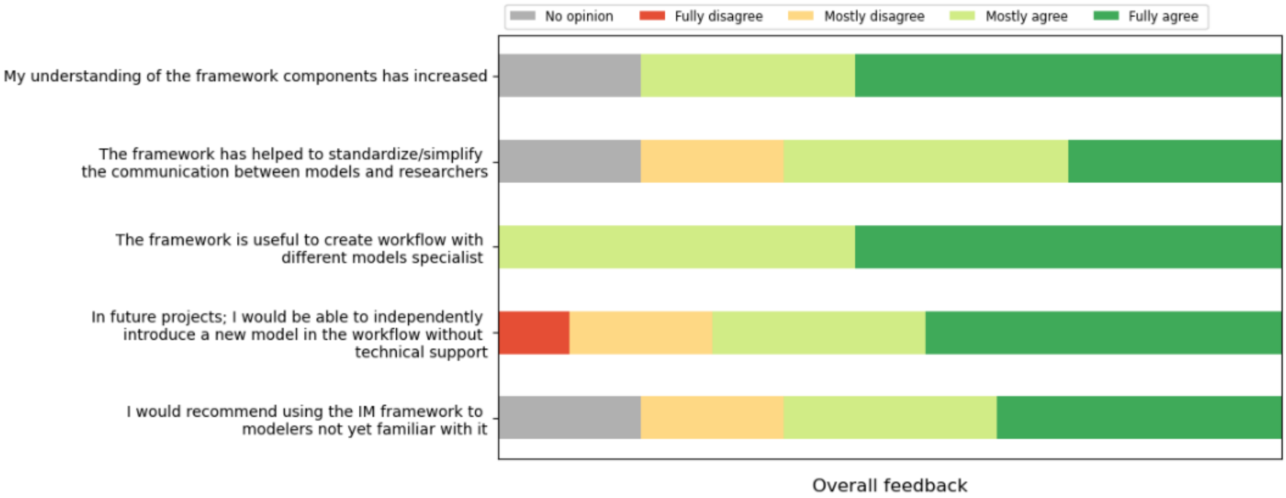

Figure 18: Overall feedback (main outcomes)

3.2.2 Creation of assessment scenarios and selection of models

This step has been divided in three sub-steps to collect finer feedback:

- 'Define scenario',
- 'Define boundaries',
- 'Select models'.

The first type of feedback focused on how easy it was for partners to perform this task. As shown in Figure 19, partners generally considered this step to be of medium difficulty. Several factors explain this: first, it took place at the beginning of the project, when most participants were new to this type of activity. Additionally, the specificities and capabilities of the models, particularly in terms of data exchange, were not fully defined at that stage. Nevertheless, no major bottlenecks were identified, and the step was successfully completed across all use cases.

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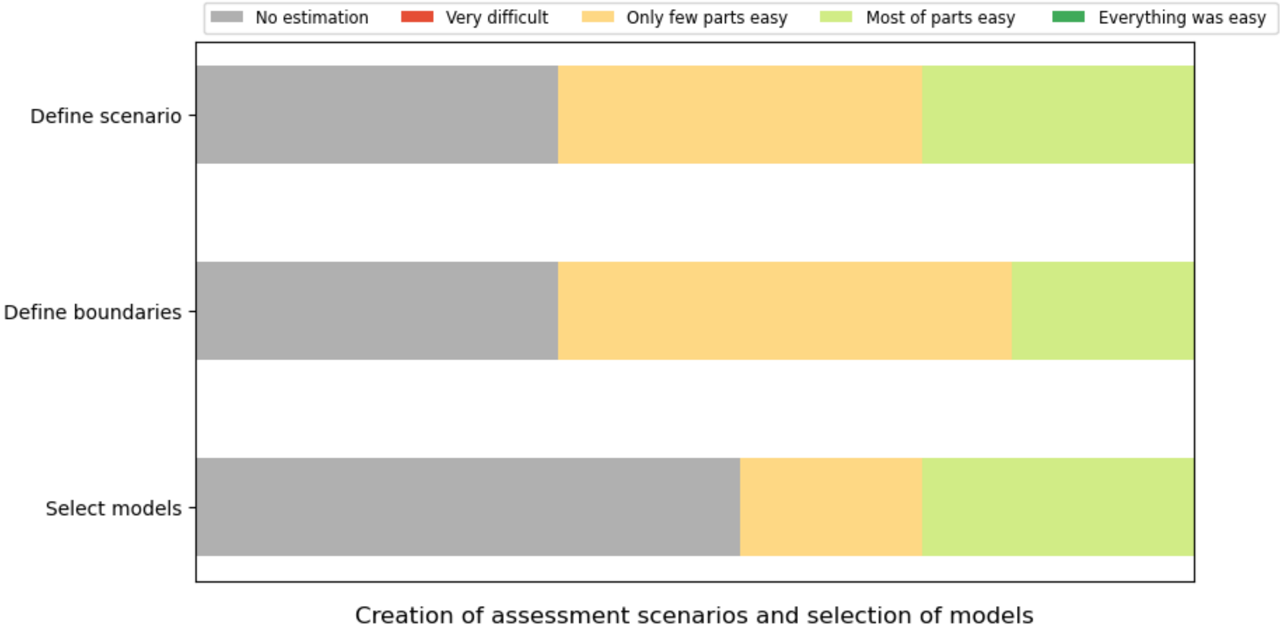

Figure 19: Ease of use – Creation of assessment scenarios and selection of models

The second type of feedback addressed the lessons learnt from this specific step (Figure 20). Partners were invited to react to several proposals and had the opportunity to add additional insights. The outcomes confirmed previous observations: the lack of initial knowledge about the capabilities of all models and the fact that many were not initially compliant with the data model were considered valuable feedback. Another key point was that many tools were initially rigid, with limited flexibility in handling inputs and outputs.

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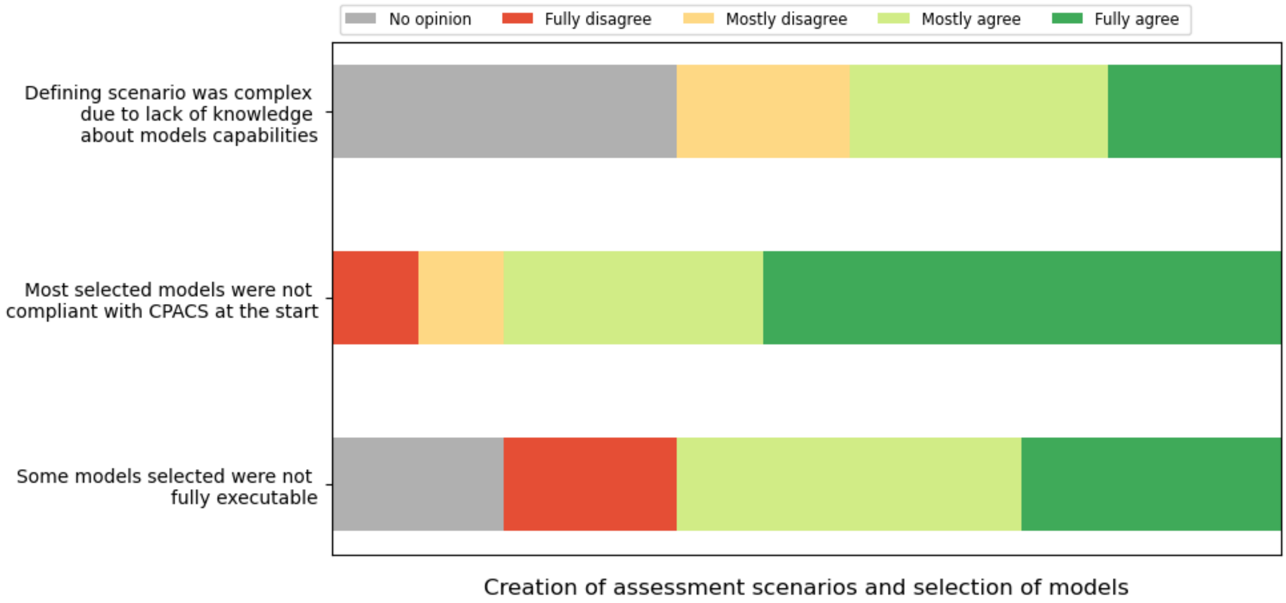

Figure 20: Lessons learnt - Creation of assessment scenarios and selection of models

Regarding scenario definition, partners emphasized the importance of ensuring that model metrics align with scenario objectives and improving the ease of running multiple scenarios. Beyond framework-related issues, it is also crucial to establish a common understanding of the concepts used across different models. People from different backgrounds may interpret the same metric differently, highlighting the need for clear and explicit definitions of key metrics and concepts. This will help ensure proper alignment between model metrics and scenario objectives while allowing for some flexibility in scenario definition.

3.2.3 Workflow definition and visualisation

This step has been divided in four sub-steps :

- 'Mock up workflow activities (MDAx)',
- 'Model CPACS wrapping ',
- 'Contribution to CPACS schema extensions',
- 'Workflow upgrade using models I/O in CPACS (in MDAx)'

Regarding the ease of performing this task, partners found it generally easier than the first step (Figure 21). The mock-up activities with MDAx were relatively straightforward for most partners, while the CPACS schema extension activities proved more complex to handle.

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Figure 21: Ease of use – Workflow definition and visualisation

A more detailed analysis of the lessons learnt confirms expected challenges (Figure 22). The CPACS integration process requires significant initial development effort from tool owners, with the time needed varying widely depending on model complexity—ranging from a few days to several months. While CPACS is flexible enough to accommodate new models, the absence of a fixed schema at the start introduced additional complexity and delays. Moreover, defining CPACS inputs and adding outputs for a specific model depends on the prior CPACSization of previous models. This dependency led to delays and additional work as the CPACS structure evolved throughout the process. Nevertheless, the flexibility of the schema remains an advantage, allowing for the seamless integration of new models. Partners also noted that tutorials and technical support played a crucial role in facilitating tool integration and ensuring the successful implementation of CPACS.

Regarding MDAx, once partners became familiar with the tool, they found it highly effective in designing workflows and identifying the appropriate inputs and outputs through continuous collaboration.

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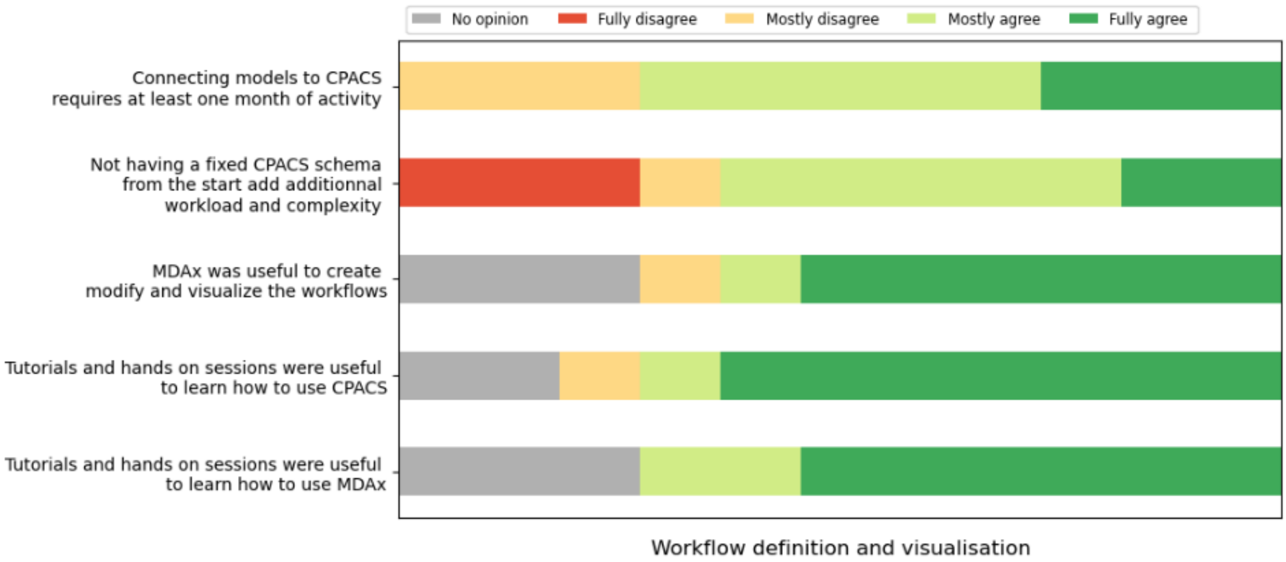

Figure 22: Lessons Learnt – Workflow definition and visualisation

3.2.4 Execution of collaborative workflow

This step has been divided in three sub-steps:

- 'Integrate model as RCE tool',
- 'Allow remote access through Uplink and /or BRICS',
- 'Check collaborative workflow executions'

In terms of ease of use, no significant bottlenecks were identified (Figure 23). Integrating models into RCE and enabling remote access via Uplink were generally considered straightforward. However, for BRICS integration, since only NLR models utilized it, the amount of feedback was insufficient to draw a clear conclusion. The collaborative workflow validation—achieving a complete run of all models—was perceived as slightly more challenging.

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Figure 23: Ease of use – Execution of collaborative workflow

Regarding lessons learnt (Figure 24), tool integration in RCE was generally smooth and standardized, particularly when using RCE and Uplink, which were simpler compared to the more complex BRICS process. However, BRICS provided valuable functionality for users requiring full control over remote tool calls. Concerning the overall workflow validation, one key challenge highlighted was that the verification of the final tools depended on the completion of previous models, which sometimes led to delays and reduced time for modifications. As with previous steps, partners also appreciated the tutorials and technical support provided by the framework team.

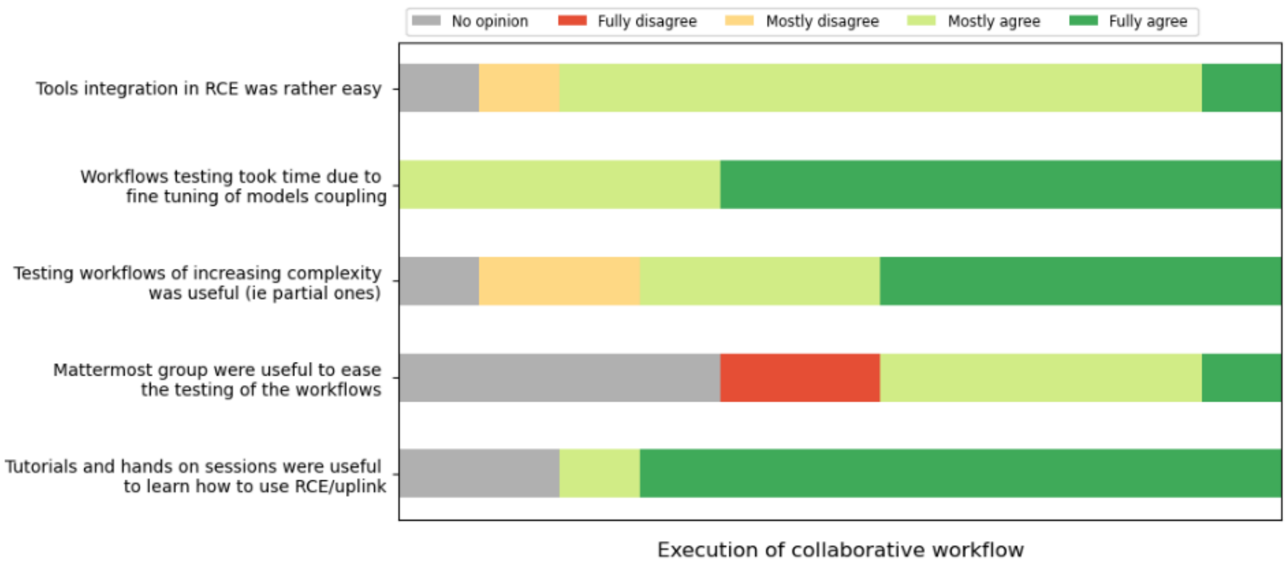

Figure 24: Lessons Learnt – Execution of collaborative workflow

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3.2.5 Running assessment studies and postprocessing result

This last step has been divided in four sub-steps:

- 'Run baseline reference study',
- 'Run scenario studie(s)',
- 'Export results to Dashboard',
- 'Generate table and figures in Dashboard'

Partners generally considered this step to be of medium difficulty (Figure 25), particularly when running the scenario studies. This was mainly due to the fact that these activities took place in the final phase of the project, requiring the simultaneous availability of all partners. Regarding the dashboard, many partners selected “no opinion,” primarily because its development had been delayed. As a result, they did not use it directly but instead had to transfer their results to the dashboard development team, leading to limited feedback.

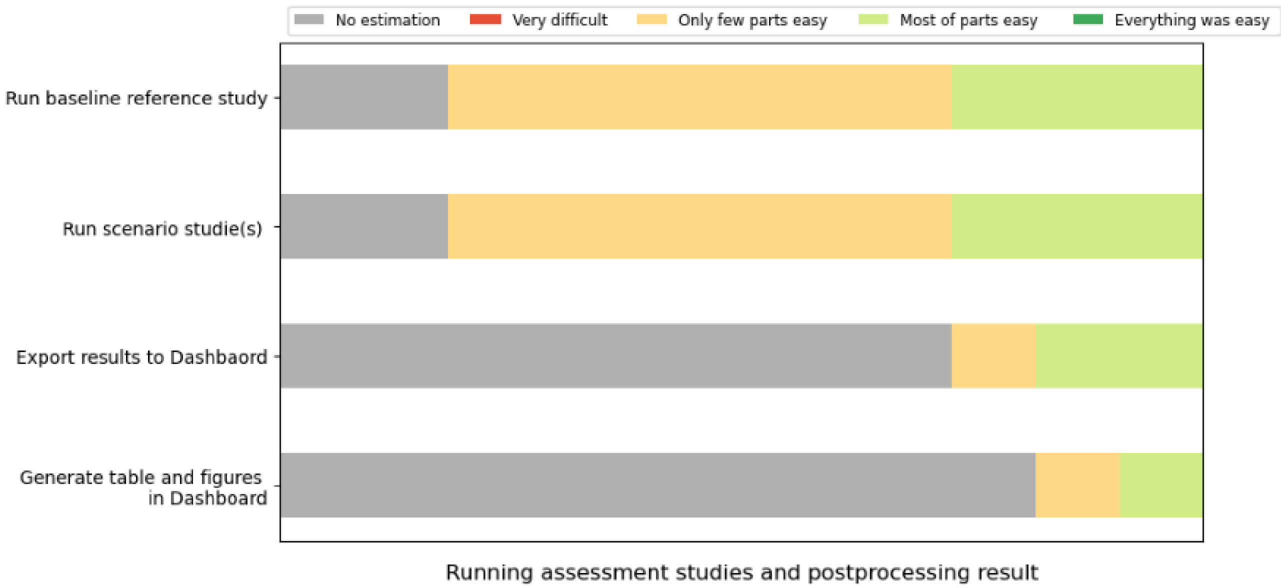

Figure 25: Ease of use – Running assessment studies and postprocessing results

The lessons learnt provide a more detailed analysis of this step (Figure 26). One key takeaway regarding scenario studies was that fine-tuning the CPACS schema was sometimes necessary to facilitate information transfer and post-processing analysis. As for the dashboard, developers noted that generating visualizations often required additional data processing of CPACS files, such as collating, accumulation, or multiplication. This resulted in extra manual work at the dashboard level.

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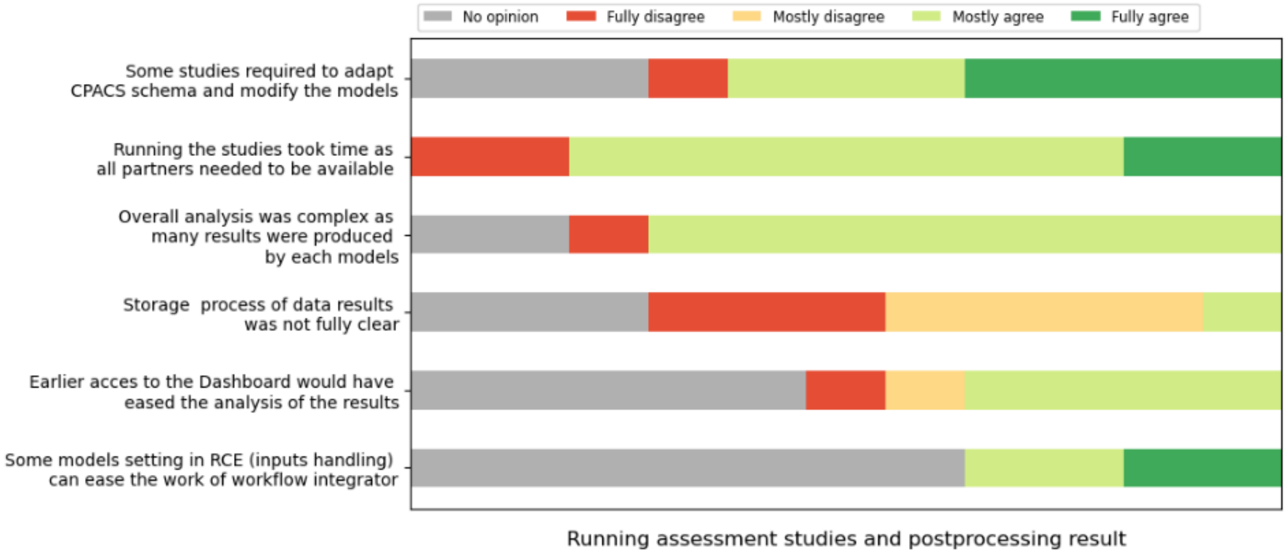

Figure 26: Lessons Learnt – Running assessment studies and postprocessing results

3.3 Roadmap for Impact Monitor Framework

This roadmap section is based on survey responses. Similar to the lessons learnt section, partners could express their agreement with proposed recommendations and also suggest their own roadmap elements. However, unlike the previous section, the roadmap proposals are less specific to each step, as they represent the users' perspective on the future evolution rather than concrete development solutions.

The following graphs summarise the survey answers regarding the roadmap.

Figure 27: Roadmap – Creation of assessment scenarios and selection of models

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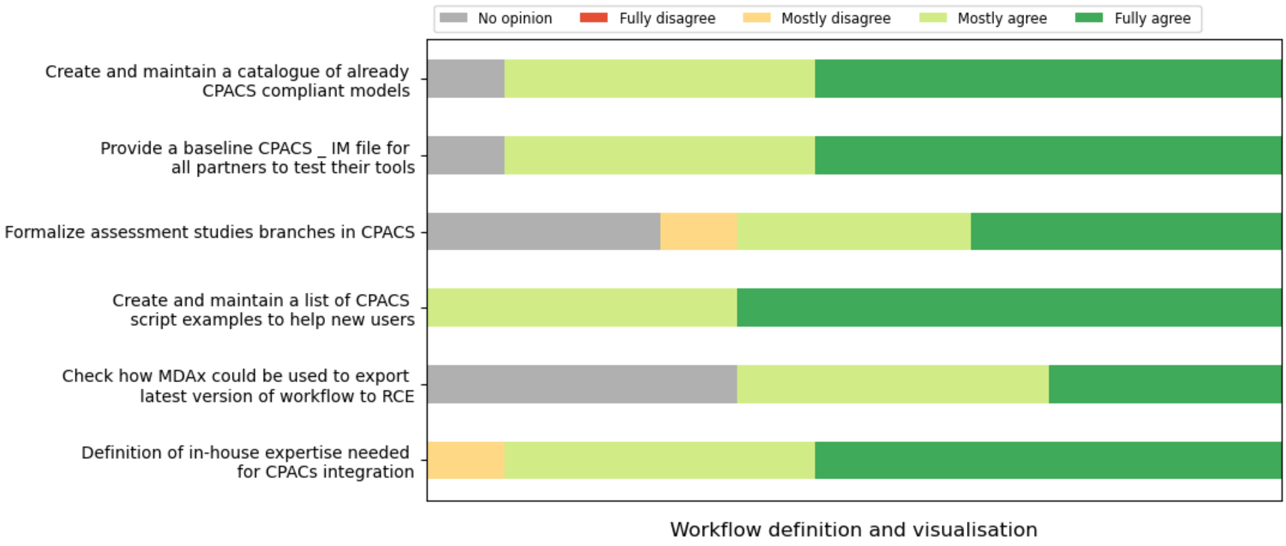

Figure 28: Roadmap – Workflow definition and visualisation

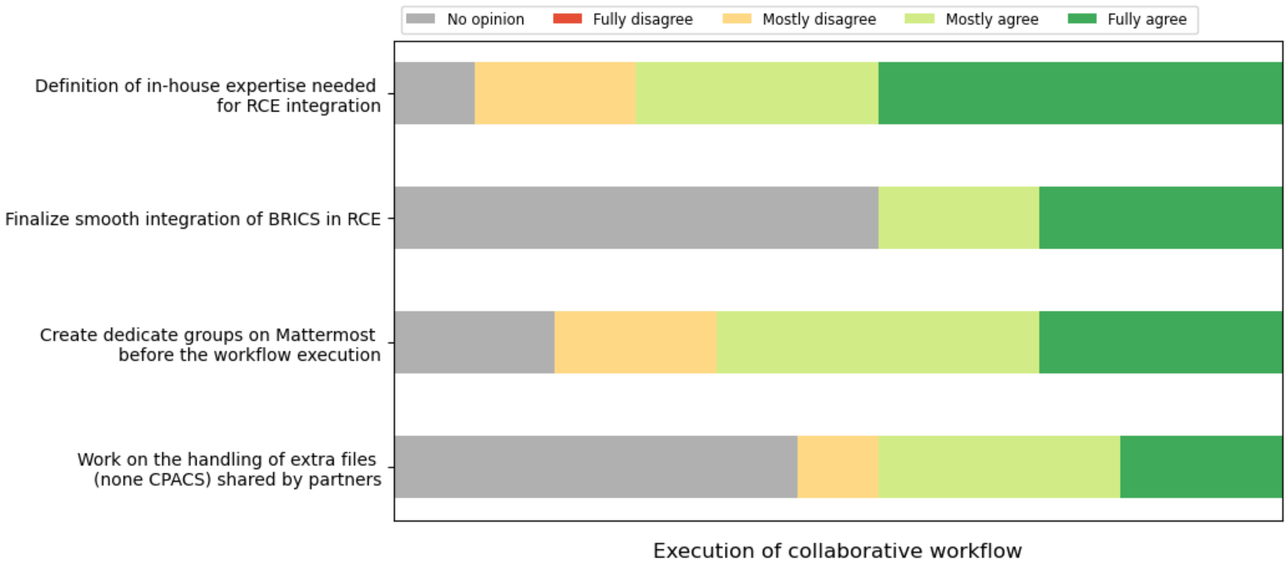

Figure 29: Roadmap – Execution of collaborative workflow

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Figure 30: Roadmap – Running assessment studies and postprocessing results

3.3.1 Accelerating the overall impact monitoring process

As mentioned earlier, the scenario definition step lacked some formalization, and certain sub-steps took time to be clearly defined. To address this, it is proposed to leverage MBSE formalization (and tools) to implement the Impact Monitor Toolbox in a systematic way, ensuring traceability from initial stakeholder needs to the final assessment results. This MBSE approach has already been explored and applied in other EU projects, such as AGILE 4.0 and COLOSSUS. While existing solutions are available, they need to be adapted to the specificities of Impact Monitor activities.

Another aspect to consider is improving the ease of workflow development. Proposed improvements include creating a model catalogue, clearly specifying model requirements for framework integration, anticipating dashboard post-processing needs (e.g., through predefined scripts and UC templates), and enabling the reuse of existing workflow components.

3.3.2 Enhancing the framework with new capabilities

In Impact Monitor, the framework was developed primarily for demonstration use cases, with workflows designed to evaluate a limited set of scenarios. Enabling more comprehensive assessment studies will require more complex workflows that incorporate high-fidelity tools, handle a larger number of evaluations, and analyse a broader range of quantities of interest to support trade-off studies.

To achieve this, integrating advanced methods such as surrogate models and uncertainty quantification & propagation is essential. Surrogate models can replace computationally expensive models, significantly reducing evaluation costs while maintaining accuracy. Additionally, surrogate models could enhance the dashboard by storing results from multiple studies, allowing stakeholders to explore the solution space interactively. Other capabilities, such as optimization methods and trade-off analysis tools, may also be valuable additions.

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3.3.3 Reducing the entry barrier for newcomers

Feedback from partners highlighted that using the framework required familiarity with multiple technologies (e.g., CPACS, MDAx, RCE), which many were initially unfamiliar with. While support from the development team was highly appreciated, it is recommended to use this feedback to streamline the learning process.

Proposed improvements include enriching the existing tutorials with a one-page cheat sheet and more tailored example scripts for CPACS parsing. Additionally, involving developers from the very beginning of the process and enabling direct exchanges when necessary, could further accelerate the learning curve for new users.

3.3.4 Improving collaboration efficiency

While this aspect is less directly related to the framework itself, it plays a crucial role in the success of collaborative projects. Many of the proposed improvements align with the MBSE approach. For example, clearly defining partner roles within the team—such as an "Integrator" responsible for overall workflow setup and execution, and a "Model Expert" responsible for providing a specific model—could enhance efficiency. These roles could be associated with different access rights within the MBSE framework.

Furthermore, each model should be linked to a designated "owner" to ensure direct involvement whenever needed. Additionally, relying on integrated direct messaging capabilities for study execution within each use case was found to be beneficial for coordination and real-time collaboration.

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4. Summary and Conclusions

The Impact Monitor deliverable D5.4 delivers the final results of the operating of the three demonstration use cases:

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

These use cases have successfully demonstrated the capabilities of the framework to assess the impact of R&I innovation in aviation at the appropriate assessment level(s). Moreover, almost fifteen different models from all the partners are now compliant with the Impact Monitor framework covering all assessment levels, providing a variety of metrics ready to be integrated into new assessment workflows in follow-on projects.

In addition, this deliverable collects and analyses the lessons learnt of their implementation and execution in the Impact Monitor collaborative assessment framework. Furthermore, a roadmap for the enhancement of collaborative framework development is also provided.

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ANNEX A

Gupta, U. A. Riaz, F. Brenner, T. Lefebvre, P. Ratei, M. Alder, P.S. Prakasha, L. Weber, J. Pons-Prats, D. Markatos (forthcoming), Assessing Advanced Propulsion Systems using the Impact Monitor framework, Proceeding paper of the 14th EASN Conference, Thessaloniki, Greece, Engineering proceedings.

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Proceeding Paper

Assessing Advanced Propulsion Systems using the Impact Monitor framework †

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† Presented at the 14th EASN International Conference, Thessaloniki, Greece, 8-11 October 2024.

Abstract: Presented in this paper is the Impact Monitor framework and interactive Dashboard Application (DA) validated through the use case focused to investigate the viability and competitiveness of future propulsion architectures for next generation aircraft concepts. This paper presents a novel collaborative framework for integrated aircraft-level assessments, focusing on secure, remote workflows that protect intellectual property (IP) while enabling comprehensive and automated analyses. The research addresses a key gap in the aerospace domain: the seamless matching and sizing of aircraft engines within an automated workflow that integrates multiple tools and facilitates real-time data exchanges. Specifically, thrust requirements are iteratively shared between aircraft and engine modeling environments for synchronized sizing. Subsequently, the fully defined aircraft data is transferred to other tools for trajectory analysis, emissions and other assessment. The Impact Monitor framework and Dashboard Application demonstrates improved efficiency and data security, promoting effective collaboration across institutions and industry partners.

Keywords: Engine Aircraft Matching; Advanced Propulsion Systems; MDO Framework

1. Introduction

The Impact Monitor Project, funded by the EU, aims to develop an impact assessment framework for European aviation. Coordinated by the German Aerospace Center (DLR), this initiative leverages digital technologies for collaborative engineering across the aviation sector, thereby streamlining the assessment processes at aircraft, airport, and system levels.

Recent research has focused on developing collaborative frameworks for aircraft-level assessments, addressing the need for efficient integration of engine manufacturer knowledge into preliminary aircraft design. These frameworks enable remote collaboration while protecting intellectual property [1]. Cloud-based approaches using microservices have shown significant time reduction in design iterations compared to traditional methods [2]. Automated workflows integrating disciplinary modules from different sites have been implemented for conceptual design and trade studies [3]. These collaborative design processes utilize centralized data formats and engineering frameworks to facilitate communication between analysis modules and partner organizations [4]. The frameworks allow for simultaneous optimization of airframe and subsystems, considering their synergies and impacts on overall aircraft performance. Case studies have demonstrated the effectiveness of these approaches in evaluating different subsystem architectures, mission scenarios, and optimizing aircraft designs [4].

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The aerospace industry increasingly relies on complex simulations and data exchanges across institutions to optimize aircraft design. However, protecting intellectual property while collaborating across multiple organizations remains a significant challenge. Current methodologies often involve manual or partially integrated processes, which are inefficient and prone to data inconsistencies. This research introduces a collaborative framework to address these challenges, emphasizing automation and secure workflows for aircraft and engine sizing, and subsequent performance and environmental impact analyses. We discuss existing approaches and highlight the pressing need for an integrated and IP-protected solution.

In this study, the design of an airframe and an aeroengine will be used to demonstrate the benefits of automated collaborative optimization and how this approach compares to the traditional isolated design process that usually only allows a limited number of iterations and manual data exchanges between airframe and engine manufacturers.

A traditional joint airframe and engine design process is more aptly illustrated in Fig. 1 and it entails the sequential design of airframe and engine in an iterative loop until the requirements are met to satisfaction and one or more overall system objectives are minimized/maximized (e.g. specific fuel consumption, range, etc.). In particular, the aircraft design team will conduct their design studies using either an iteration of a physics-based engine model or a surrogate of it such as performance deck, produced by the engine design team. The latter will in turn have been obtained by designing the engine while relying on an iteration of the airframe thrust requirements. As mentioned before, in an industrial scenario, this process, while ripe for automation, is usually only partially automated – the airframe and engine design disciplines will themselves be automated while the transfer of information between the two will rarely be so. Often, it relies on both manually processed and controlled transfers of interface data (i.e., thrust requirements and engine performance deck) thus both limiting the pace at which design iterations can take place, and their usability in automated design studies (e.g., as part of design of experiments or system level optimization studies) [5].

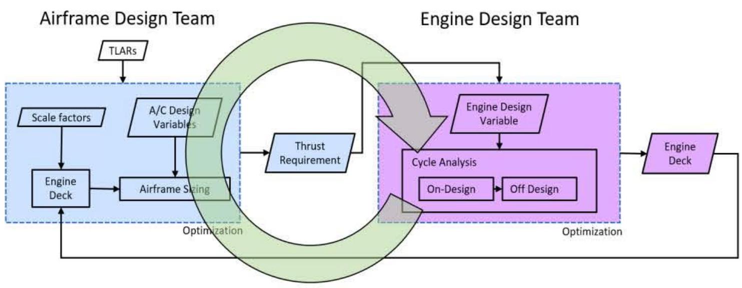

Figure 1: Airframe-engine matching design process

In this research project, the entire process is fully automated, enabling the collaborative execution of tools hosted across different locations within a workflow, while ensuring the protection of their intellectual property (IP). Further details have been discussed in next sections on how this framework and dashboard application helps to create and execute such workflows. The next section first describes the methodology of this use case. Next, the use case overview and results of the demonstration exercise are presented. The final section discusses the first conclusions that can be drawn from the exercise as well as the next steps that are still planned for this use case in the Impact Monitor project.

2. Methodology

The proposed framework employs a distributed, automated workflow for aircraft-level assessments. It integrates multiple modeling and simulation tools, each operated remotely while maintaining IP protection through secure communication protocols and data handling techniques. The methodology consists of the following tools and processes for this use case.

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This use case employs four tools from different organizations with specific capabilities combined to create an operational workflow which is developed in MDAx (MDO Workflow Design Accelerator) tool [6], as illustrated in Fig. 2. Tools/models involved in this use case are SUAVE (Aircraft Modelling Tool), TURBOMATCH (Engine Modelling Tool), DYNAMO (Trajectory Amendment for contrail avoidance), and AECCI (Aircraft Emissions and Contrails for Climate Impact).

Further, these tools are integrated and workflow created in MDAx is replicated in a collaborative platform RCE (Remote Component Environment) tool [7], which enables the tool integration and execution using the Uplink connection for the models/tools integrated anywhere in the world while protecting their IPs. Once all the tool integration and the workflows connection with all data communication has been set up in the RCE, the workflow is ready to be executed.

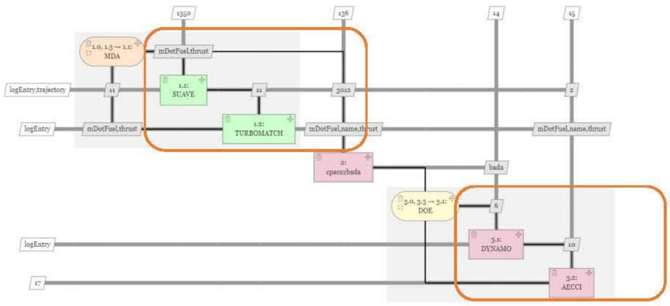

Figure 2: Computational workflow create in MDAx

The aim of the use case is to demonstrate the collaborative approach of the Impact Monitor framework with the integration of the four tools and the use of collaborative strategies enabled by CPACS (Common Parametric Aircraft Configuration Schema) and RCE, where CPACS [8] is the standardized way of data handling and communication among the tools which helps data transfers between various tools. In Fig. 2 the two boxes depict two studies performed in this workflow:

- Study 1: Design Variables: Fan Pressure Ratio, Low Pressure Compressor Ratio, High Pressure Compressor Ratio, Inlet Airflow Rate, Aspect Ratio, Wing Reference Area
- Study 2: Design Variables: Cruise Altitude, Cruise Speed/Mach No.

The workflow begins with preliminary aircraft and engine matching as mentioned in Fig. 3. A dedicated tool simulates the thrust and performance characteristics required for different flight conditions. This data is automatically sent to the engine sizing model, which adjusts the propulsion system parameters to meet these requirements. The refined engine specifications are returned to the aircraft model for further iteration. Once convergence is achieved, the complete aircraft data is shared with external analysis tools for trajectory simulations and emissions quantification. This use case highlights the framework's ability to manage complex, multi-disciplinary workflows across organizational boundaries.

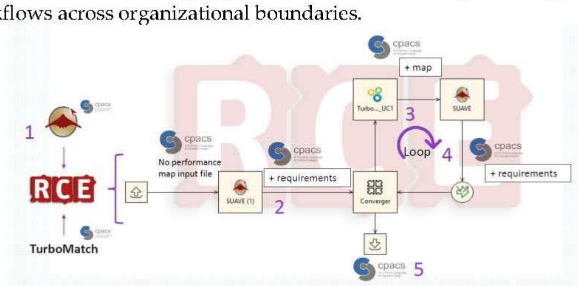

Figure 3: Computational workflow in Remote Connection Environment (RCE)

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The detailed methodology for the tools involved and the process for Use Case 1 is outlined above. Fig. 4 below illustrates the complete architecture for this use case, utilizing the Impact Monitor framework and Dashboard Application, which suggests that once a workflow is created and executed, the following steps are performed:

1. An iterative loop where thrust requirements are exchanged and refined between engine and aircraft models, ensuring optimal performance matching to generate one complete aircraft.
2. This CPACS file of generated aircraft is then sent to CPACS2BADA converter which helps to convert CPACS file data to the standard BADA files which is used in few of the tools further in the use case.
3. These CPACS and BADA files are used as inputs for the remaining tools to perform Trajectory and Emission analyses and other studies.
4. Once all the analyses are performed using specific tools and the workflow is completed, the final output CPACS file is then uploaded to the cloud data storage.
5. Finally, the stored file can be accessed through the Dashboard Application for the various types of visualization and plots for the studies and further analyses.

Dashboard Application not only provides visualization for the data but also encompasses the capabilities of interactive and interlinked plots, data processing and tools to perform Multi Object Optimization as well.

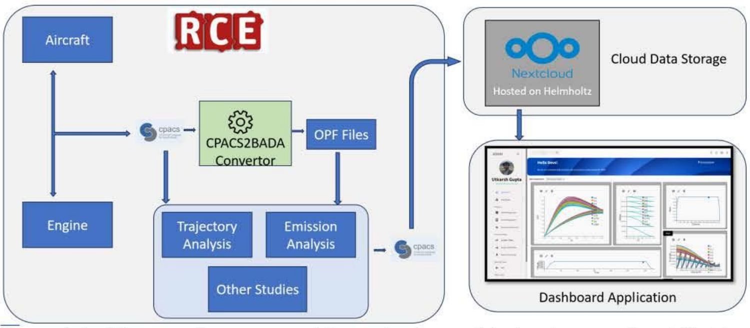

Figure 4: Architecture of use case workflow using Impact Monitor framework and Dashboard Application

3. Use-Case Implementation

In this section, the advanced propulsion systems use case is implemented using the Impact Monitor framework and the results are presented. The use case involves the collaborative design and analysis of a single-aisle, tube-and-wing, low-wing configuration, with two wing-mounted turbofan engines, and conventional empennage. The mission considered for the baseline aircraft definition includes taxi-out, take-off, climb, cruise, descent, landing, and taxi-in, where fixed schedules for climb, cruise, and descent segments are employed.

As mentioned in the previous section, the computational workflow is divided into two studies. For study 1, iterative convergence between airframe and engine design tools are performed using fixed-point iteration method. During these iterations, two distinct local optimizations were conducted for airframe and engine sizing. The optimization problem formulations for the airframe and engine sizing are presented in Table 1 and Table 2, respectively.

For airframe sizing, design variables (wing area and aspect ratio) and top-level aircraft requirements (as shown in Table 1) are utilized to calculate the engine thrust requirements, which are then transferred in a CPACS file to the engine sizing model using Uplink protocol. Two objectives, i.e., minimize block fuel and maximum take-off weight, are considered for the airframe sizing optimization.

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Table 1: Optimization formulation for airframe sizing

Airframe Design Variables	Wing Area (m^2)	[120, 140]
	Aspect Ratio	[9, 12]
Top-Level Aircraft Requirements (TLARs)	Take-off Field Length (m)	≤ 2000
	Time to Climb (min)	≤ 25
	Approach Velocity (m/s)	
	Cruise Altitude (m)	≥ 11000
	Cruise Mach Number	0.78
	Ceiling Altitude	≥ 12000
	Maximum Operating Mach Number	0.82
	Range (nm)	≥ 4000
Objectives	Block Fuel (kg)	Minimize
	Maximum Take-off Weight (kg)	Minimize
Calculated Parameters	Take-off Thrust (N)	Calculated by airframe design team, and passed to engine design team
	Second Segment OEI Thrust (N)	
	Climb Thrust (N)	
	Initial Cruise Altitude Thrust (N)	
	Cruise at 37,000 ft Thrust (N)	
	Ceiling OEI Thrust (N)	

On the other hand, for engine sizing, design variables (bypass ratio, fan pressure ratio, low and high compressor pressure ratio, and air mass flow rate) and engine thrust requirements (as shown in Table 2) are utilized to calculate the engine performance deck, which is transferred in a cpacs file to the airframe sizing model using Uplink protocol. For engine sizing optimization problem, specific fuel consumption, and engine weight are considered as minimization objects.

Table 2: Optimization formulation for engine sizing

	Fan Pressure Ratio	[1.6, 2.0]
	Low Pressure Compressor Ratio	[2.8, 3.2]
	High Pressure Compressor Ratio	[9, 11]
	Inlet Airflow Rate (kg/s)	[400, 600]
Thrust Requirements (T.R.)	Take-off Thrust (N)	Values provided by airframe design team
	Second Segment OEI Thrust (N)	
	Climb Thrust (N)	
	Initial Cruise Altitude Thrust (N)	
	Cruise at 37,000 ft Thrust (N)	
	Ceiling OEI Thrust (N)	
	Take-off Thrust (N)	
Objectives	Specific Fuel Consumption ($kg/(N.s)$)	Minimize
	Engine Weight (kg)	Minimize
Calculated Parameters	Complete Engine Deck	Calculated by engine design team, and passed to airframe design team

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As mentioned in the previous section, the two tools employed for sizing airframe and engine cycle analysis are SUAVE and TURBOMATCH, respectively. The first step in the aircraft engine sizing loop is to define the basic aircraft and mission in SUAVE. Initially, the aircraft uses a low-fidelity engine performance model. This low-fidelity turbofan model calculates thrust and fuel consumption based on atmospheric conditions, throttle settings, and Mach number using simplified empirical relationships. It outputs thrust as a 3D vector and fuel flow rate, integrating these into the aircraft's performance framework. The model assumes ISA atmospheric conditions, a modern turbofan throttle ratio, and a constant specific heat ratio for quick, conceptual-level analyses. As part of the post-processing for the converged aircraft, a number of thrust requirements are calculated. Same is presented in Table 3 including the initial values:

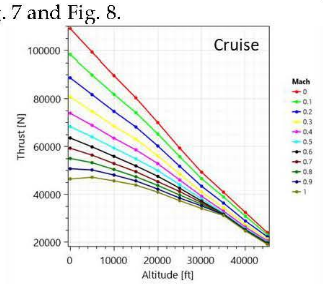
Table 3: Thrust requirements calculated

Phase	Altitude (m)	Mach Number	Calculated Thrust Requirements (N)
Takeoff	0	0.00	150,914
Second Segment OEI	122	0.22	86,255
Climb (2500 ft/min)	0	0.38	63,489
Initial Cruise Alt	10,439	0.76	25,051
Cruise (37,000 ft)	10,668	0.78	24,278
Service Ceiling	11,887	0.78	26,756
Ceiling OEI	7,620	0.57	26,616

These requirements are stored in a CPACS file. When both SUAVE and TurboMatch are connected in RCE, the output file is transferred to TurboMatch automatically. TurboMatch reads the thrust requirements and creates an engine map for various altitude and Mach number combinations. The engine map includes information on Mach number, altitude, throttle ((actual thrust)/(maximum thrust at a given point)), thrust, and SFC. The output is again stored in a CPACS file and transferred back to SUAVE in RCE.

SUAVE extracts and converts the engine map from CPACS into a .csv file. With the engine map available, SUAVE's performance calculation logic is updated to a surrogate model-based engine simulation. This approach allows thrust and fuel consumption to be predicted using the pre-loaded CSV file, leveraging a surrogate model (e.g., linear, Gaussian Process, KNN, or SVR) to approximate engine performance metrics like thrust and specific fuel consumption (SFC). The model dynamically evaluates these metrics under varying conditions and blends data for extended throttle ranges if needed.

Using this updated logic, the aircraft is sized again. Based on the new calculations, the thrust requirements are updated and transferred to TurboMatch. This process is repeated iteratively until the thrust requirements stabilize (convergence is reached). At this stage, it is assumed that the provided engine map is highly accurate, requiring no further scaling of engine performance in SUAVE. Therefore, to finalize the calibration of the aircraft, only its aerodynamic performance is adjusted. With the updated aerodynamics, the low-fidelity engine performance is recalculated, and the loop is restarted. This process continues until the aircraft and engine meet the desired performance criteria. The results of the optimized engine and airframe are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8.



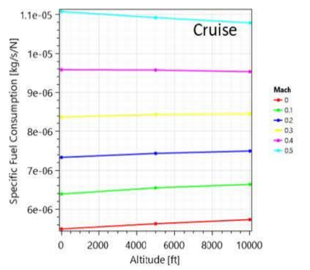


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Figure 5: Engine Deck Performance (Thrust vs Altitude)

Figure 6: Engine Deck Performance (SFC vs Altitude)

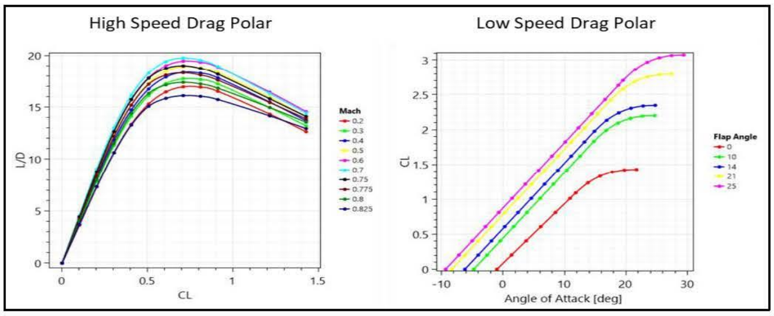

Figure 7: Hight speed and low speed drag polars

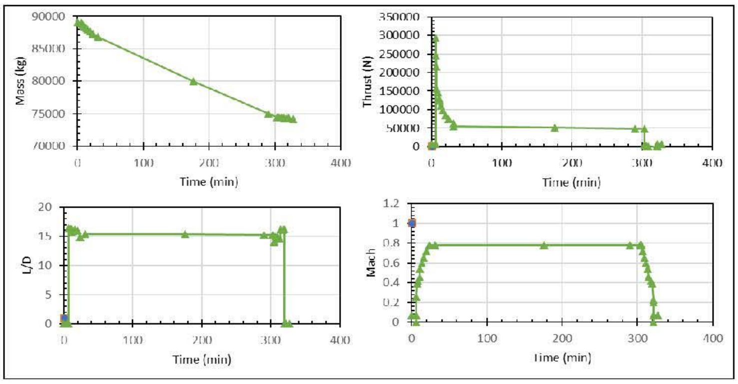

Figure 8: Mission performance

Once the convergence between airframe and engine design teams is achieved, the optimized aircraft can be utilized for study 2, where 4D trajectory analysis is performed for emissions assessment. Here, the cpacs2bada convertor is employed which generates BADA .opf and .apf files from the cpacs file obtained from study 1. The results from study 2 are shown in Fig. 9.

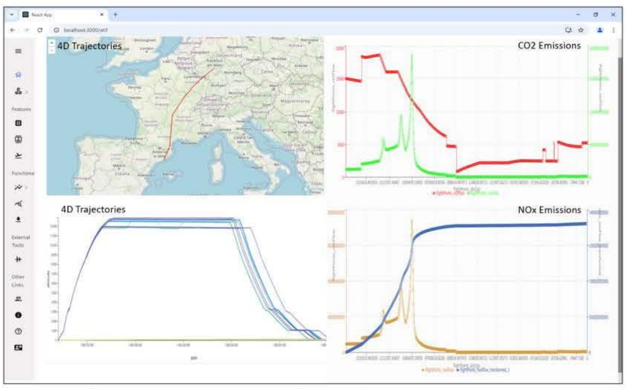

Figure 9: 4D trajectory analysis and emissions assessment

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The Impact Monitor framework enables the collaborative design of airframe with advanced propulsion systems. Key findings from the presented use case include efficiency gains, data security, scalability and flexibility and trajectory and emissions analysis. Compared to manual approach which take approximately one week to complete manual iteration between airframe and engine matching, the proposed automated approach using the collaborative Impact Monitor framework takes around 35 minutes on average to complete the workflow.

5. Summary and Conclusions

This paper introduces a secure, automated, and collaborative Impact Monitor framework for various levels including aircraft-level assessments, addressing critical research gaps in engine-aircraft integration and cross-institutional cooperation. By automating data exchanges and protecting IP, the framework enhances efficiency and fosters innovation. Future work will focus on expanding the framework's capabilities to support additional tools and exploring machine learning techniques for further optimization.

Author Contributions

Writing – original draft preparation: U. Gupta, A. Riaz, F. Brenner; Writing – review and editing: all; Use case coordination: A. Riaz, T. Lefebvre, P.S. Prakasha, P. Ratei; Funding acquisition: P.S. Prakasha; Conceptualisation of the Impact Monitor framework: M. Alder, A. Riaz , T. Lefebvre, P.S. Prakasha, P. Ratei; Operationalisation of the Impact Monitor Framework to the use case: U. Gupta , A. Riaz , F. Brenner , T. Lefebvre , P. Ratei , M. Alder , L. Weber , J. Pons-Prats , D. Markatos; Analysis and visualisation: U. Gupta , A. Riaz , F. Brenner , T. Lefebvre , J. Pons-Prats.

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ANNEX B

Pons-Prats, J., X. Prats, D. de la Torre, E. Soler, P. Hoogers, M. van Eenige, S. Chatterjee, P.S. Prakasha, P. Ratei, M. Alder, T. Lefebvre, S. van der Loo, E. Peduzzi (forthcoming), Assessing continuous descent operations using the Impact Monitor Framework, Proceeding paper of the 14th EASN Conference, Thessaloniki, Greece, Engineering proceedings.

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Proceeding Paper

Assessing continuous descent operations using the Impact Monitor Framework†

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† Presented at the 14th EASN International Conference, Thessaloniki, Greece, 8-11 October 2024.

Abstract: The Impact Monitor Project is a European initiative to develop an impact assessment toolbox and framework, targeting the European aviation sector. The proposed framework is aiming to environment, economics, operations, but also societal impacts of new technologies and aircraft configurations. The toolbox is a way of working by setting out the key steps in the impact-assessment cycle and presenting guidance, tips, and best practice. Led by DLR, the consortium includes research institutions and universities who contribute with expertise and tools to develop the collaborative assessment toolbox and framework.
The project defines three use cases which consider three assessment levels; namely aircraft, airport and air transport system ones. This paper presentation focuses on the use case number 2 on the Continuous Descent Operations (CDO) at aircraft and airport levels. It describes the workflow proposal, together with the tools involved. The collaborative approach is a showcase with the integration of these tools and the use of collaborative strategies enabled by the use of CPACS (Common Parametric Aircraft Configuration Schema) and RCE (Remote component environment). The list of tools includes Scheduler (DLR, flight schedule simulation), AirTOp (NLR, TMA simulation), Dynamo/Farm (UPC, Trajectory simulation and assessment), LEAS-iT (NLR, Emissions simulation), Tuna (NLR, noise simulation), AECCI (ONERA, emissions simulation), TRIPAC (NLR, third-party risk simulation) and SCBA (TML, social and economic impact assessment).
The interaction with other use cases of the project will be demonstrated with the use of new aircraft configurations coming from the use case at aircraft level of the project.
The results presented demonstrate the feasibility of the workflow, the cooperation among the tools to obtain and refine the outcomes, while analyzing the operational scenario of a generic airport, named CAEPport, which has been extensively used in previous Clean Sky 2 projects.

Keywords: Impact Monitor, Airport, Continuous Descent Operations, CDO, Noise, Emissions, Third-party Risk

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1. Introduction

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The Impact Monitor Project, funded by the EU, aims to develop an impact assessment toolbox and framework for European aviation. Focused on environmental, economic, and societal impacts, particularly greenhouse gas emissions, air quality, and noise, the toolbox focuses on a way of working by setting out the key steps in this cycle and presenting guidance, tips, and best practice, while the framework facilitates the integration of advanced design and evaluation tools. Coordinated by the German Aerospace Center (DLR), this initiative leverages digital technologies for collaborative engineering across the aviation sector, thereby streamlining the assessment processes at aircraft, airport, and system levels.

The project defines three use cases that consider three assessment levels: aircraft, airport and air transport system level. This paper presents the modelling and simulation of an impact-assessment at the airport level, focusing on the implementation of continuous descent operations (CDO). The aim of the paper is to give an interim demonstration of the capabilities developed by the Impact Monitor framework and the interactive dashboard application at Airport level. This demonstration will be completed in the final months of the project. The paper describes the workflow proposal, together with the tools involved. The collaborative approach showcases the integration of these tools and the use of collaborative strategies enabled by the use of CPACS (Common Parametric Aircraft Configuration Schema) and RCE (Remote component environment). The list of tools includes Scheduler (DLR, flight schedule simulation), AirTOp (NLR, TMA simulation), Dynamo/Farm (UPC, Trajectory simulation and assessment), LEAS-iT (NLR, Emissions simulation), Tuna (NLR, noise simulation), AECCI (ONERA, emissions simulation), TRIPAC (NLR, third-party risk simulation) and SCBA (TML, social and economic impact assessment).

The framework, with the involved tools, allows assessing the impacts of the implementation of the CDO with regards to emissions, noise and third-party risk, leading to an assessment of the social benefit.

The next section describes the technical implementation of the Airport Use Case. Next, the set-up and results of the demonstration exercise are presented. The final section discusses the first conclusions that can be drawn from the exercise as well as the next steps that are still planned for this use case in the Impact Monitor project.

2. Technical Implementation

The aim of the Use Case is to demonstrate the collaborative approach of Impact Monitor with the integration of the eight tools and the use of collaborative strategies enabled by CPACS (Common Parametric Aircraft Configuration Schema) and RCE (Remote Component Environment).

2.1. Brief description of CDO

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.[1] , [2], [3] and [4]). *Figure 1* 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 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

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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 below 3,000 ft) 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.

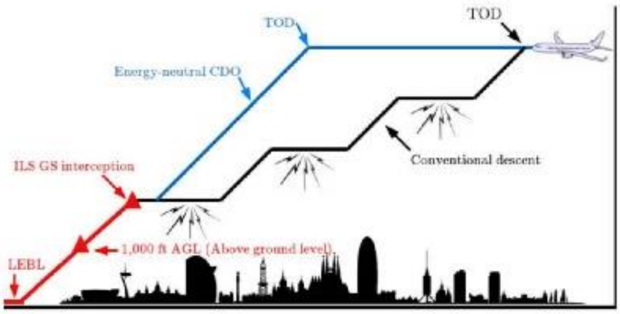

Figure 1. Illustrative comparison of a CDO and a conventional descent operations (Source UPC)

2.1. Workflow

The Use Case 2 implementation is based on the set of tools listed in the previous section. These tools are arranged on the workflow shown in Figure 2. It has been updated and adjusted along the project discussions, and the one shown here is the latest version.

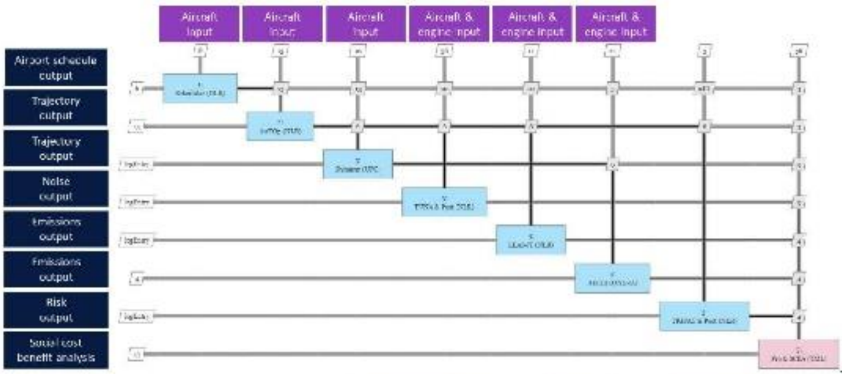

Figure 2. Use Case 2 Workflow with labeled inputs and outputs

Associated to this workflow, the CPACS file schema requires to fulfil some relevant items:

- Flight schedule: SCHEDULER will fill CPACS with the information about flight schedule, meaning OD (Origin-Destination) pair, and arrival and departure time

- Airport: Information about the airport (CAEPport) will be included to be used by AirTOp and DYNAMO

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- Aircraft information for new configurations will be included providing the path to the OPF[1] file, which will reproduce the BADA data, and some parameters will be also inserted directly at CPACS, like engine reference. Aircraft information for standard and existing configurations will be defined through the BADA database. A nomenclator list has been already used to verify the definition of the aircraft models.

- Trajectories; a single set of trajectories will be available. AirTOp will provide a first output, which will be refined by DYNAMO. DYNAMO, using its FARM module, will add information about fuel consumption, flight time, thrust level, weather conditions among others.

- The execution of DYNAMO also enables to incorporate weather data into the CPACS file, which will later be used by AECCI tool for the calculation of emissions

- Three alternate branches are available for this workflow. The first and the main one is to use the whole set of proposed tools since they are fully complementary to each other. The second and third branches consist on using either Leas-iT, TUNA and TRIPAC tools or using DYNAMO (and its FARM module) and AECCI. Tools like AirTOp and DYNAMO, as well as Leas-iT and AECCI can complement the results of the other tool. This is the reason the two secondary branches can be proposed.

- The final step on the workflow is the social and economic impact assessment. SCBA tool, by TML, is used to compare and compute the impact (considering delays, operational costs, emissions, noise and risk) associated to the implementation of CDO with regards to a non-CDO scenario.

2.2. Integration of the tools in CPACS, RCE and the dashboard application

In order to run the workflow, a RCE framework with UPLINK and BRICS connection has been established. The framework enables the creation of a network, which can be later used to connect and communicate the tools while running the simulations.

The data sharing is based on the use of CPACS, which conforms the low-level communication language between the tools. While RCE manages the interaction between tools, CPACS is the data container to share data. Either the partial and the final outcomes of each tool can be visualized through the use of the Impact Monitor dashboard. In order to store all these outputs, a Next-Cloud repository is provided. The dashboard takes the data from the repository in order to provide results visualization (see *Figure 3*)

Figure 3. Integration of the tools for the Use Case 2 in CPACS, RCE and the dashboard application

In order to conduct the case study, the CPACS data model has been extended in several ways.

[1] EUROCONTROL BADA file about Aircraft Operational performance (Aircraft Performance Operational File)

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3. Demonstration exercise: scenarios and preliminary results

The Impact Monitor assessment for the Use Case 2, at Airport level, is based on the comparison of two scenarios. The first one is the reference baseline. It considers the null application of continuous descent operations. The second one already considers CDO. More specifically, the operation of interest is the approach, so the scenarios focus on continuous descent approaches (CDA).

3.1. Scenario definition: baseline scenario and CDO scenarios

Both scenarios are initially defined by a flight schedule. This is independent of the implementation of CDO or not. Scheduler tool provides the arrival and departure times ties of a set of flights, linked to its origin-destination (OD) pair. AirTOp tool uses the scheduled flights to simulate the arrival and departure trajectories while assessing Air Traffic Management criteria, like capacity or conflicts. The generated trajectories are later used by each of the two branches of the workflow to get the emissions and fuel consumption (branch that incorporates DYNAMO/FARM and AECCI tools, by UPC and ONERA respectively), or to get emissions up to 3000ft, noise and risk (branch that incorporates Leas-IT, TUNA, and TRIPAK, by NLR). The final step on the workflow is the final social and economic impact assessment, done by SCBA tool of TML.

AirTOp is the tool which manages the implementation of the CDO. It enables to activate or deactivate CDO, but does not enable to select the level of implementation. It means that CDO will be implemented according to the capacity of the airspace to accept a larger or lower number of such operations.

SCBA requires the computation of two scenarios, the baseline design and the CDO one. The baseline design does not include any continuous descent approach (CDA), while the CDO scenario does. The number of flights considered on the scenarios is crucial to ensure that when requesting the implementation of CDO, it is feasible, and, at least, some flight follow this procedure. One should also consider that fact that a continuous increase on the number of flights will increase the CDO implementation up to a certain level. At some point the air space structure and the airport capacity will limit the CDO implementation. It could happen that at some point the number of flights using CDA would start decreasing.

3.2. Scenario Results

Partial results are already available demonstrating the connection and data transfer among the tools of the workflow. A dashboard to visualize all the available results, including partial and final ones has been developed as a project outcome. The dashboard has been already tested and it is under further development to refine and upgrade the amount and quality of the results and its visualization.

For the particular case of the Use Case 2, the reader should consider the large number of tools involved in the workflow. Having partial results for all of them, and enable the user of the dashboard to visualize all them is a challenge.

What the user can expect is the following:

- Scheduler output; Scheduler only offers output on a text format, following CPACS rules, Scheduler is offering a list of flights. The CPACS stores the flight schedule generated by Scheduler. It contains a description, and the information about the date and time of all the flights, and aircraft type.
- AirTOp output: AirTOp takes the list of flights and simulate all them to obtain the best trajectories according to the airspace structure and airport characteristics. The trajectory is stored in the CPACS file, creating a node that belongs to the flight node, which related this information with the schedule. Figure 4 is a graphical representation of a set of trajectories obtained by AirTOp. All these trajectories fulfill the ATC regulations.

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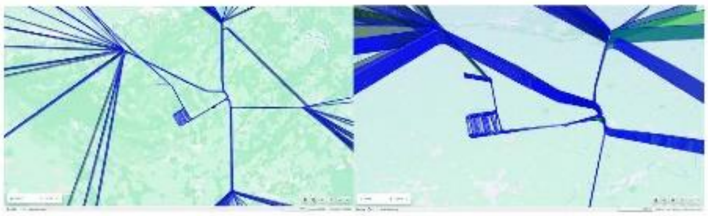

Figure 4. Graphical representation of all AirTOp trajectories. General view (Left), close-up view (Right)

- DYNAMO/FARM postprocesses the AirTOp trajectories to get refined and additional data related to the trajectories. DYNAMO/FARM deals with individual trajectories, simulating each trajectory from an individual point of view, without considering the effects from other trajectories. The postprocess adds data like Distance, speed CAS and Mach, thrust level, fuel flow and weather data for each trajectory point. Calculating the fuel flow, DYNAMO/FARM can easily calculate the amount of CO2 emissions.

- AECCI takes the DYNAMO/FARM trajectory in order to complement and complete the emission calculation. AECCI calculates the amount of NOx, CO, H2O, SO2 and HC. In this case, the calculation also provides the total final values. Figure 7 and Figure 8 are two examples of the analysis of CO2 and NOx calculated by AECCI.

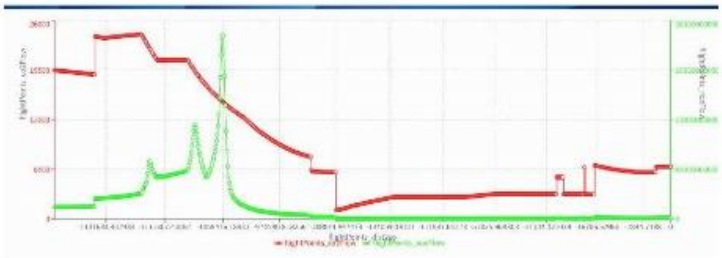

Figure 5. CO2 and NOx emissions by AECCI

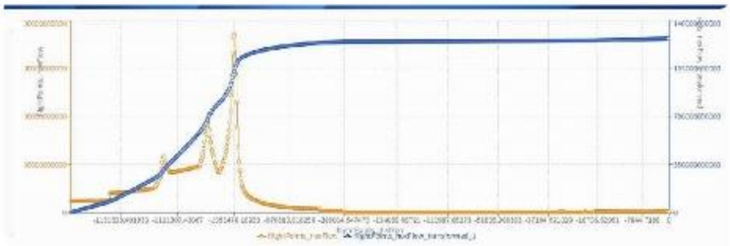

Figure 6. NOx and accumulated NOx values by AECCI

- TUNA provides the calculation about noise footprint of the approach section of the trajectory. An example of this output is shown in Figure 9.

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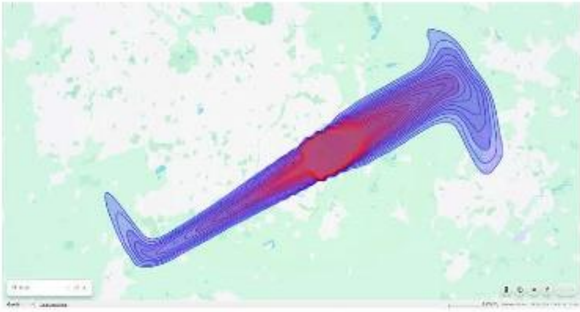

Figure 7. Noise footprint

- LEAS-it provides the calculation of emissions below 3000ft. A footprint, similar to the one about noise, can also be obtained
- TRIPAC provides the calculation about third-party risk footprint of the approach section of the trajectory.
- SCBA is the last step in the analysis taking care of the final social and economic assessment. It aims to compare. Using the outputs of the above-mentioned tools (such as delays, fuel consumption, emissions, noise and risks) for the two scenarios, it aims to assess the economic and societal benefits or costs of CDO. Results by SCBA includes the effect on passengers, airlines and operators, but also the costs related to the emissions, air pollution, noise and accidents as shown in Figure 10.

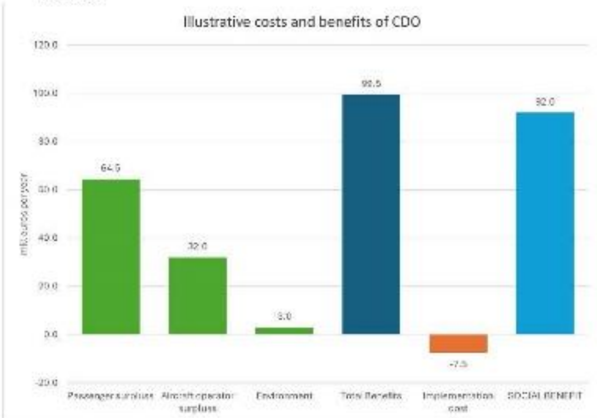

Figure 8. Illustrative costs and benefits of CDO

4. Conclusions for the Impact Monitor Framework

The paper describes the effort of the Impact Monitor consortium to define and apply a collaborative assessment framework for airport level. This effort led to the definition of a specific Use Case, the so-called Use Case 2 (UC2). UC2 integrated several tools from DLR, NLR, ONERA, TML and UPC. The results presented are preliminary results that demonstrate the feasibility of the workflow. The challenge to make a long list of tools working together has been demonstrated to be a major one, but it finally works smoothly and seamlessly. The use of CPACS provided a common language for all the tools, implying the simplification of the format of the input and output files.

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The presented results are preliminary ones, aimed to demonstrate the communication of the complete set of tools involved in the use case workflow. This communication is managed by the use of the RCE tool by DLR, a cooperative environment. All the tools in the use case have been successfully integrated in this environment. Two scenarios have been tested, one with no CDO at all, and a second one with CDO. The level of CDO implementation in this second scenario depends on the number of flights and the potential congestion produced with the level of demand. The results could be inaccurate or showing unfeasible outcomes due to the fact that scenario refinement is still required.

The way forward clearly demands to refine the workflow connections and the scenarios. The full automation of the workflow execution is the main issue to solve, already been tackled.

Author Contributions: Conceptualization, JPP, XP, PH, MVE, PSP, PR, TL, SVDL, methodology, JPP, XP, DDLT, PH, MVE, PSP, PR, MA, TL, SVDL, software, JPP, DDLT, ES, PH, SC, PR, MA, TL, SVDL, EP, validation, JPP, PH, PR, MA, TL, EVDL, EP, formal analysis, JPP, PH, PR, TL, SVDL, investigation, JPP, XP, DDLT, ES, PH, MVE, SC, PSP, PR, MA, TL, SVDL, EP, resources, JPP, DDLT, ES, PH, MVE, writing—original draft preparation, JPP.; writing—review and editing, JPP, PR, TL.; visualization, JPP, ES, SC, PR, TL, SVDL, EP.; supervision, PR, TL.; project administration, PSP, PR.; funding acquisition, PSP, PR. All authors have read and agreed to the published version of the manuscript.

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ANNEX C

Mayeres, I., E. Peduzzi, M. Alder, F. Baier, K. Buchtal, S. Chatterjee, M. Clococeanu, D. Ennen, M. Gelhausen, A. Junior, A. Leipold, P.S. Prakasha, P. Ratei, Z. Zengerling, T. Lefebvre (forthcoming), Assessing policies for the uptake of sustainable aviation fuels using the Impact Monitor framework, Proceeding paper of the 14th EASN Conference, Thessaloniki, Greece, Engineering proceedings.

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engineering proceedings

MDPI

Proceeding Paper

Assessing policies for the uptake of sustainable aviation fuels using the Impact Monitor framework †

Inge Mayeres [1]*, Emanuela Peduzzi [1], Marko Alder [2], Fabian Baier [3], Kuno Buchtal [3], Sreyoshi Chatterjee [3], Maximilian Clococeanu [3], David Ennen [3], Marc Gelhausen [3], Alf Junior [3], Alexandra Leipold [3], Prajwal Shiva Prakasha [2], Patrick Ratei [2], Zarah Zengerling [3], Thierry Lefebvre [4]

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† Presented at the 14th EASN International Conference, Thessaloniki, Greece, 8-11 October 2024.

Abstract: The Impact Monitor Project, funded by the EU, aims to develop an impact assessment framework for European aviation. This paper uses the framework for the modelling and simulation of an impact-assessment at the air transport system level, focusing on policies for the uptake of sustainable aviation fuels. It aims to demonstrate the capabilities developed by the Impact Monitor framework and the interactive dashboard application for the air transport system level.

Keywords: Impact Monitor, Air transport system, demonstration

1. Introduction

The Impact Monitor Project [1], funded by the EU, aims to develop an impact assessment framework for European aviation. Focused on environmental, economic, and societal impacts, particularly greenhouse gas emissions, air quality, and noise, it facilitates the integration of advanced design and evaluation tools. Coordinated by the German Aerospace Center (DLR), this initiative leverages digital technologies for collaborative engineering across the aviation sector, thereby streamlining the assessment processes at aircraft, airport, and system levels.

The project defines three Use Cases that consider three assessment levels: aircraft, airport and air transport system level. This paper presents the modelling and simulation of an impact-assessment at the air transport system (ATS) level, focusing on policies for the uptake of sustainable aviation fuels (SAF). The aim is to give an interim demonstration at the ATS level of the capabilities developed by the Impact Monitor framework and the interactive dashboard application. This demonstration will be completed in the final months of the project.

Figure 1 gives an overview of the tools involved in the ATS Use Case, as well as the tool owners. The Use Case aims to demonstrate the framework on the one hand for three tools that have already been combined in the past for analyses though not yet using the framework (Scheduler, Emissions tool and ECOIO), and other hand for a new combination of tools (TRAFUMA with the other tools). Scheduler, ECOIO and TRAFUMA analyze different dimensions of the economic impacts of policies, while the environmental impacts are covered in the Emissions tool and TRAFUMA. For the purpose of the project, Scheduler and the Emissions tool have been optimized to integrate them smoothly in the workflow.

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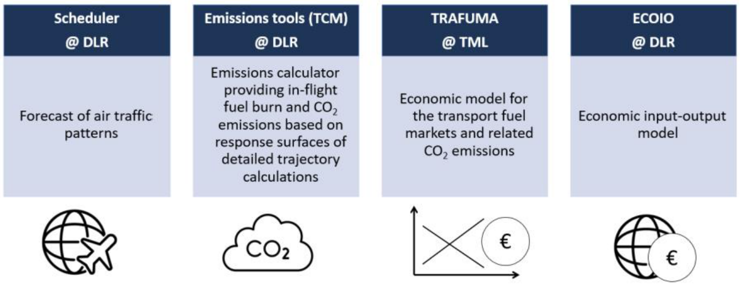

Figure 1. Tools used in the ATS Use Case of Impact Monitor

Together, the four tools allow assessing the impacts of policy scenarios on a range of KPIs for the following impact categories: climate, emissions and air quality, economy, social impacts/quality of life, efficiency and effectiveness (see also [2]).

Section 2 first describes the technical implementation of the ATS Use Case. Next, Section 3 presents the set-up and results of the demonstration exercise. Section 4 concludes.

2. Technical Implementation

The Use Case aims to demonstrate the collaborative approach of Impact monitor with the integration of the four tools and the use of collaborative strategies enabled by CPACS (Common Parametric Aircraft Configuration Schema) and RCE (Remote Component Environment) (see also [3]).

2.1. Workflow

The Use Case analyses two policy scenarios for aviation. The effects of the scenarios are determined compared to a reference scenario. The workflow is presented in Figure 2. First, based on the definition of the scenarios, TRAFUMA computes their impact on the user price of aviation fuel. The outcome is then used by Scheduler to compute the impact of the change in the fuel costs on air travel and the fleet mix. Next, the Emissions tool calculates the effects on aviation fuel consumption and the CO_2 emissions from in-flight fuel burn based on response surfaces per aircraft type, mass and flight distance. These response surfaces called Reduced Emission Profiles have been calculated in a pre-processing step with the Trajectory Calculation Module (TCM) [4,5]. In addition, TRAFUMA provides information on the CO_2 emissions from another perspective, namely well-to-wake emissions considering also indirect land use change (WTW with ILUC). Finally, ECOIO computes the broader economic impacts of the policies, based on the results of the other tools. In addition to the results that are exchanged between the tools, other results are stored for reporting using the Impact Monitor dashboard application [3].

The interaction with other Use Cases of the project is demonstrated with the use in Scheduler and the Emissions tool of new aircraft configurations coming from Use Case 1 (Aircraft level). Background data of the Emissions tool is extended with new aircraft designs received from Use Case 1 in a CPACS format and processed with the TCM.

2.2. Integration of the tools in CPACS, RCE and the dashboard application

The four tools of the ATS Use Case are integrated in CPACS and RCE, as well as the dashboard application. In order to conduct the case study, the CPACS data model has been extended (Figure 3). For TRAFUMA, a new <airTransportSystem> element has been created under the <studies> node and for ECOIO the element <economicImpactAssessment> has been created under the same node. In both cases the new nodes contain a range of sub-nodes. In addition, the new <toolspecific> node contains information about the background scenarios for TRAFUMA and the Emissions tool. For Scheduler and the Emissions tool, extensions have been made to the previously existing nodes. The new CPACS

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structure is flexible and can be extended to include future ATS study elements as required, providing good scalability for future projects and research activities.

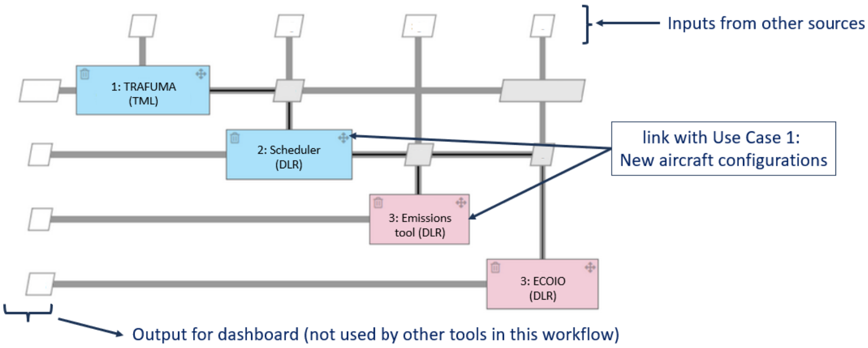

Figure 2. Set-up of computational workflow using MDAx (MDAI Workflow Design Accelerator)

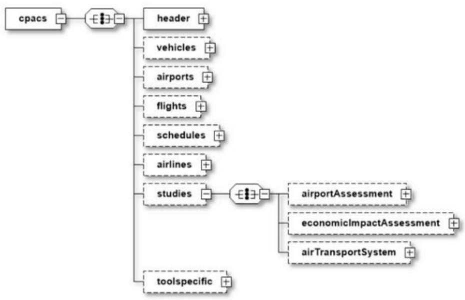

Figure 3. CPACS extension for the ATS Use Case

As in all Use Cases of Impact Monitor, RCE is used with the aim to remotely run the tools. In this process a verification step has been integrated in which the tool owners can verify the tool results before they are used in the next steps of the workflow.

3. Demonstration exercise: scenarios for the uptake of sustainable aviation fuels

The feasibility of the workflow and the cooperation among the tools to obtain and refine the outcomes, are demonstrated while analyzing the impacts of two policy scenarios for 2035 and 2050: the introduction of a global carbon tax in aviation, and the implementation of a global blending mandate for sustainable aviation fuels.

The main focus of the exercise is on the demonstration of the Impact Monitor framework, rather than the exact finetuning of the scenario components. The assumptions of the scenarios that are detailed next should therefore be considered as exploratory. One of the advantages of the framework is that it can be used to simulate the impacts of policy scenarios under alternative assumptions in a structured and documented way.

3.1. Scenario definition: reference scenario and two policy scenarios

The impacts of the two policy scenarios are evaluated compared to a reference scenario. The fuel consumption in the reference scenario is based on the stated policies scenario (STEPS) of the IEA [7] and scenario S1 of the impact assessment of the 2040 Climate Target in the EU [8] for road and maritime transport. For aviation it uses the DLRCON scenario of DLR [9]. The policies included in the reference scenario for 2035 and 2050 are:

- The tax levels in 2015 (assumed to remain constant in real terms)

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- Aviation has to surrender ETS emission allowances for the CO_2 emissions of flights within and between the countries of the European Economic Area (EEA), Switzerland and the UK. Maritime transport is covered by the ETS. In addition, the EU ETS2 applies, with road transport as one of the sectors covered. The future price of the emission allowances in the EU ETS and EU ETS2 is taken to be 200 euro/tonne CO_2.
- The EU CO_2 emission performance standards for road vehicles apply. In combination with the EU ETS2 this leads to an important electrification of road transport, and a substantial decrease in the non-electric fuel demand of the sector in 2035 and 2050 compared to now.
- Policies regarding renewable energy:
  - For non-European countries the share of renewable fuels in the transport sector is based on the stated policies scenario of the IEA [7].
  - For the EU in 2035 a policy similar to the Renewable Energy Directive III is assumed to apply in the reference scenario, with a target share of 60% for transport. The multipliers and constraints on the fuels allowed are the same as in the REDIII.
  - For the EU in 2050 a renewable energy share of 90% is assumed for road transport.
  - The share of renewables in electricity generation is taken to be 77% in 2035 and 89% in 2050 (scenario S1 of [8])

As the aim of the demonstration exercise is to explore the impacts for the uptake of renewable fuels in aviation, no separate target or additional policies are assumed to apply to this sector in the reference scenario. Similarly, it is assumed that there is no separate target for maritime transport.

Two policy scenarios are explored in the demonstration exercise. The definitions should be seen as exploratory. Nor are they designed in order to attain the same emission reduction in any given year. In both scenarios all other policy instruments are the same as in the reference scenario, unless mentioned otherwise.

- SC_blending: a blending mandate is introduced for aviation and maritime transport:
  - Aviation: For the EU this scenario is broadly in line with REFuelEU Aviation: 20% SAF in 2035 and 70% SAF in 2050; for the fuels bought in the EU a minimum share of renewable fuels of non-biological origin (RFNBO) applies: 5% in 2035 and 70% in 2050. No food and feed based fuels can be used in aviation. For the rest of the world, the overall blending mandate is similar, but no sub-mandate is assumed to apply for RFNBO.
  - Maritime transport: for fuels bought in the EU the scenario imposes a blending mandate of 25% in 2035 and 90% in 2050.
- SC_ENVTAX: an environmental tax is levied on aviation fuels in 2035 and 2050, depending on the WTW with ILUC CO_2eq emission factors. The tax is assumed to equal 200 euro/tonne CO_2eq. In this scenario aviation is no longer included in the European emission trading systems.

3.2. *Tool parameters*

For the demonstration exercise TRAFUMA has been recalibrated for air transport such that the price elasticities of fuel demand in the TRAFUMA market segments are in line with those of Scheduler and the Emissions tool. For the other model parameters, the sources and assumptions are taken from previous analyses with the four tools and have been kept unchanged for this project, as the focus of the project lies on the demonstration of the Impact Monitor framework. They are documented in [9], [10], [11] and [12]. Costs for SAF types not yet considered in previous analyses were taken from [8].

3.3. *Scenario Results*

The combination of tools covers various metrics describing the scenario results. Here we show only a selection. The graphs have been produced with Impact Monitor's dashboard application.

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TRAFUMA calculates the impact of the policy scenarios on the fuel costs (Figure 4). In 2035 the impact of the blending mandate on the fuel costs for fuel bought in the EU is relatively small. As the SAF count for the broader REDIII transport target, they are cross-subsidized by higher fossil fuel costs not only in aviation but also in the other transport sectors. Moreover, no ETS allowances need to be surrendered for SAF. Outside of Europe in 2035 and for all flights in 2050, when the blending mandate is much stricter, it leads to a substantial increase in the fuel costs. The ENVTAX-scenario, which imposes a tax of 200 euro/tonne of CO_2 emissions globally (on a WTW with ILUC basis) leads to similar prices in all aviation market segments. The ETS no longer applies for aviation in this scenario, leading to only a small change in this segment, that is related to the fact that the tax is now based on the WTW with ILUC emissions of the fuels that are used. In the other market segments the price increases are substantial.

Figure 4. Fuel cost in the reference scenario and the two policy scenarios (euro2016/tonne of oil equivalent). Source: TRAFUMA

The scenarios lead to the following impact on the number of revenue passenger kilometres (RPK) and flights for the whole fleet: in 2035 the SC_ENVTAX scenario leads to the lowest level of RPK and flights, whereas in 2050 the lowest demand comes through the scenario with a blending mandate.

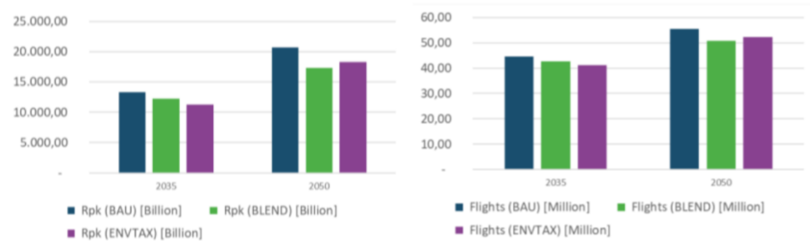

Figure 5. Revenue passenger kilometers (left; in billions) and number of flights (right; in millions) in the reference scenario and the two policy scenarios. Source: Scheduler

Regarding the impact on the fuels used, which is calculated with TRAFUMA, with the blending mandate, the shares of the different types of fuels are in line with the blending mandate. In the ENVTAX-scenario the level of the tax that is assumed does not lead to an uptake of SAF.

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Concerning the CO_2 emissions to in-flight fuel burn for the whole fleet, the following impacts are simulated: in 2035 the best CO_2 result is achieved through the environmental tax scenario, whereas in 2050 the blending mandates yield the lowest emissions.

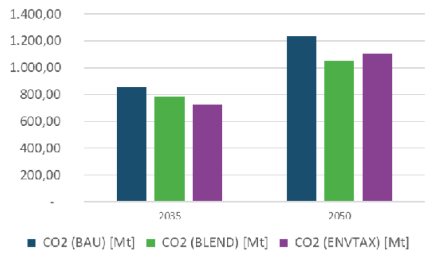

Figure 6. CO_2 emissions from in-flight fuel burn (Million tonnes CO_2). Source: Emissions tool

As there is no uptake of SAF in the environmental tax scenario, all CO_2 emission reductions are related to the reduction in fuel demand. In the scenario with the blending mandate emissions are reduced via two mechanisms: via a reduction in fuel demand (see Figure 6), and via the reduction in the emissions from the WTW with ILUC perspective. Figure 7 gives the percentage change in the average WTW with ILUC emissions per toe of fuel that is consumed, for the scenario with the blending mandate. For the environmental tax scenario there is no change in the emission intensity of the fuels used.

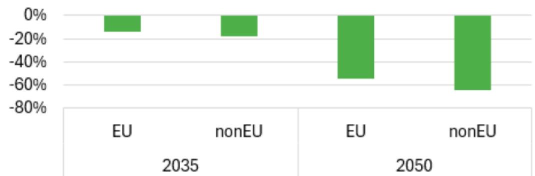

Figure 7. Average CO_2 emissions per tonne of oil equivalent – percentage change compared to the baseline scenario. Source: TRAFUMA

To investigate the cost-effectiveness of the policies in the two scenarios, TRAFUMA calculates the social cost per tonne of CO_2 abated (Figure 8). This is calculated by taking the sum of the change in consumer surplus, producer surplus and government revenue, and by dividing this sum by the change in emissions (WTW with ILUC perspective). As can be expected based on previous literature, the social welfare cost per tonne abated is high for the blending mandates, which impose a costly technology (SAF) to reduce emissions. Under the environmental tax scenario emissions will be reduced up to the point where the marginal cost of an additional unit of emission reduction equals the level of the environmental tax (200 euro/tonne CO_2). The resulting average social welfare cost is about 100 euro/tonne CO_2. These social welfare costs can be compared with those in other sectors, for other policies or for other levels of the two policies considered here. By comparing them with the benefits of emission reductions, they can also be used in social cost-benefit analyses to evaluate the policies and compare them with other policies.

Finally, the ECOIO tool presents information on the economic impacts of the policy scenarios. Since both the blending mandates and the environmental taxes lead to a lower demand for air travel, the gross value added and employment created by the aviation industry decrease in both scenarios compared to the business-as-usual scenario. Figure 9 shows these results in detail for the European Union, broken down by each sub-sector of the aviation industry (e.g., air transport = AT), scenario, and year. The value added and employment effects are an aggregate of direct, indirect, and induced effects. Direct effects

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result from activities within the aviation industry itself, while indirect effects arise from the activities of suppliers to the aviation industry (e.g., fuel providers). Induced effects, on the other hand, are generated by the consumer spending of employees in both the direct and indirect sectors, which in turn stimulates further economic activity.

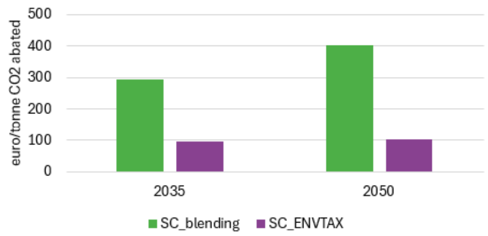
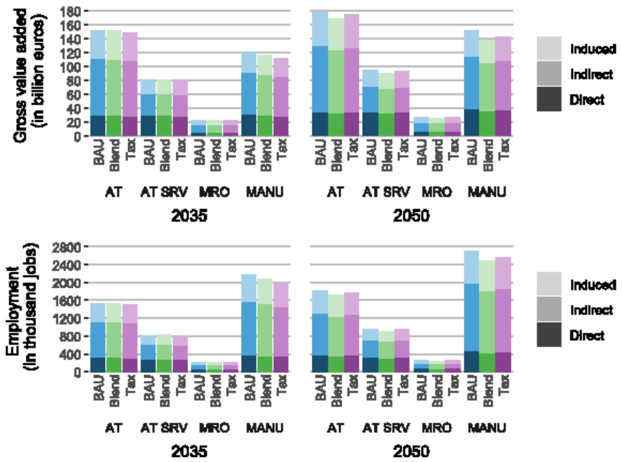


Figure 8. Social welfare cost per tonne of CO_2 emission abated (WTW with ILUC perspective) – euro2016/tonne CO_2 abated. Source: TRAFUMA



Notes: AT = Air transport, AT SRV = Air transport related services (e.g., airport services, air traffic management), MRO = Maintenance, repair and overhaul, MANU = Manufacture of aircraft and aircraft components; BAU: reference scenario; Blend: scenario with blending mandate; Tax: environmental tax scenario

Figure 9. The economic impacts of the policy scenarios in the European Union. Source: ECOIO

3. Concluding remarks

The previous sections have demonstrated that the Impact Monitor framework can indeed be used for scenario studies at ATS level. While some final steps still need to be taken to optimize the workflow further, the intermediate results already confirm that the framework indeed can contribute to the aims that were set forward in the beginning of the project: an enhanced efficiency and productivity, and the associated cost reduction, the facilitation of innovation and knowledge sharing and the possibility to contribute to improved decision making.

Finally, the policy scenarios that were presented in Section 3 should be considered to be exploratory. They are solely intended to demonstrate that the tools can be combined in the framework as well as to show the type of metrics that can be investigated with the different tools, and how they can complement each other in this respect. A full evaluation of SAF policies would require also the consideration of a wider range of policy assumptions: different definitions of the policies than the ones considered here (e.g. different tax levels, different modalities for the blending mandates, etc.) as well as the consideration of

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other policy instruments (e.g. subsidies). The advantage of the Impact Monitor framework is that it greatly facilitates such additional work once the workflow with the different tools has been set up. Moreover, it allows to bring in additional tools that can shed light on additional policy impacts, such as, for example, tools that inform on the reduction of the non-CO_2 climate impacts of SAF policies.

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