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Scenarios for Operational and Techno-Economic Analysis of the Hydrogen Value Chain for Aviation

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Abstract

Introduction: Hydrogen (H_2) is currently being investigated as a sustainable energy carrier for aircraft to decarbonise primarily short- and medium-haul aviation. Although hydrogen-powered aircraft can eliminate in-flight carbon dioxide and possibly reduce non-CO_2 effects [1], research is required to initiate and mature the hydrogen supply infrastructure and daily airport operations for such aircraft. The GOLIAT (Ground Operations of LIquid hydrogen AircrafT) project [2] seeks to overcome the current obstacles in technologies, regulations, processes, and economics to make widespread daily use of hydrogen at airports.

In the GOLIAT project, we will develop comprehensive liquid hydrogen (LH_2) demand and supply-matching models for air transport ground infrastructures. Future analyses will provide techno-economic insights by comparing forward-looking scenarios. To initiate the modelling and analyses, we first need to define the scope and develop new scenarios based on currently available literature and knowledge.

Objectives: This paper aims at **developing the multi-horizon scenarios** which can be used to perform operational and techno-economic analyses of the hydrogen value chain for aviation. The scenarios are built upon variations of factors, drivers, and barriers from several disciplines which impact the value chain of hydrogen. The goal of the scenarios is to analyse possible future situations, not to predict or impose the future of a hydrogen value chain. This paper elaborates upon the method for scenario construction and presents the scope and a set of five main scenarios for future operational and techno-economic scenarios.

Material and methods: Figure 1 presents the method employed for scenario development. In each of these five high-level steps, we use a combination of literature review and expert consultation to gain exhaustive insights. First, the problem is clarified and the scope if defined. Second, factors and drivers possibly impacting the value chain of hydrogen for aviation are gathered and categorized. We examine 51 factors from seven categories including policy, economics, airport infrastructure, hydrogen availability, air traffic growth, aircraft technology, and disrupting events. These factors are assessed in terms of their uncertainty and the impact they can have on demand, supply chain sizing and economics, and ground operations.

Figure 1 - Scenario Development Method

Key factors are selected based on the impact and uncertainty evaluation, with variations proposed for each. Eight conceptual scenarios are then constructed by combining these variations into logical narratives. The next step is to validate these scenarios by checking their plausibility, consistency, relevance, and novelty [3]. Additionally, we select the most relevant and novel scenarios. This validation and selection step is performed through a workshop with H_2 supply and operations experts, internal and external to the GOLIAT project. Figure 2 shows the expert's ranking of the conceptual scenarios in terms of relevance and novelty.

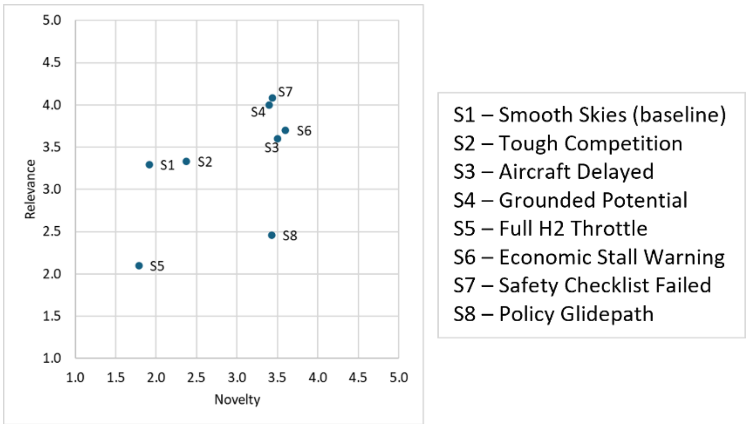

Figure 2 - Ranking of conceptual scenarios in terms of relevance and novelty (green indicates high levels of relevance and novelty, orange corresponds to low levels of relevance and novelty)

Results: The scope for the operational and techno-economic analysis is presented in Figure 3. Considering the scenarios, three key axes of driving forces are identified: 1) hydrogen availability and the energy market, 2) the readiness of airport infrastructure, and 3) the level of aircraft technology development. Furthermore, disrupting economic and safety forces should be considered in the techno-economic analysis. To capture varying levels of development along these three axes and these disrupting factors, the following five main scenarios are defined:

A. Smooth Skies – A baseline scenario with "mid-level" developments from literature.

B. Aircraft Delayed – This scenario considers delayed arrival of hydrogen aircraft which are expensive to operate (factor misalignment).
C. Grounded Potential – Many EU airports are not ready to support H2 refuelling operations, and H2 aircraft cannot be operated at full potential (factor misalignment).
D. Economic Stall Warning – After investments in infrastructure and aircraft technology, an economics crisis lowers the overall air travel demand (disruptive scenario).
E. Safety Checklist Failed – Major safety issues lower the social and regulatory acceptance of hydrogen aircraft and their operations at airports (disruptive scenario).

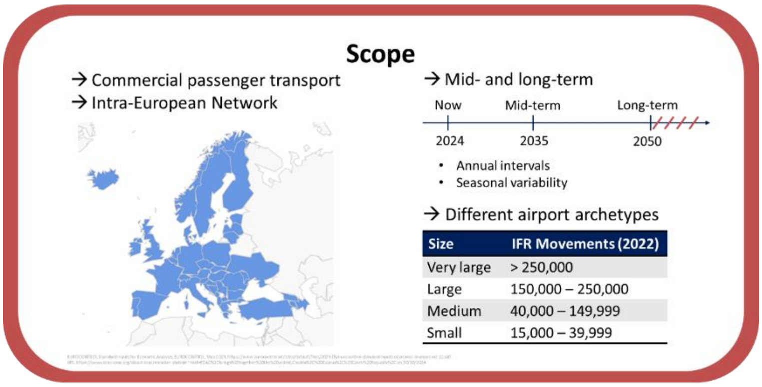

Figure 3 - Scope of techno-economic analysis

Conclusions: Based on literature review and expert consultation, five main scenarios are created for analysis of the future hydrogen value chain for aviation. The scenarios are based on variations in hydrogen availability, airport readiness, an aircraft technology, as well as economic and safety disruptions. These scenarios will be used to assess the demand, supply chain size and cost, and ground operations for hydrogen-powered aviation in Europe.

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