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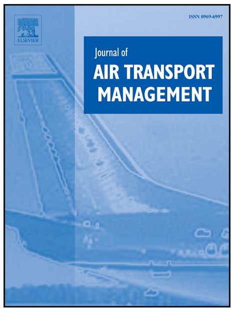

Influence of COVID-19 on air travel - A scenario study toward future trusted aviation

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INFLUENCE OF COVID-19 ON AIR TRAVEL - A SCENARIO STUDY TOWARD FUTURE TRUSTED AVIATION

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Abstract

This paper develops three scenarios for the aviation industry's recovery from COVID-19 until 2030 by utilizing the scenario methodology. Besides the short- and mid-term pandemic development, the study takes into account the industry's adaptation to changes in the market environment, e.g., toward sustainability and hygiene requirements. The resulting scenarios include the expected point in time of full air traffic recovery to pre-crisis levels. Subsequent implications suggest that most COVID-19-related hygiene measures along the travel chain disappear after the pandemic is contained. Some measures might serve as a differentiator between airline business models, while others are expected to become a new standard. Implications for environmental awareness and resulting operational and technical measures include changes in society's attitude toward traveling post-pandemic, especially in light of varying levels of environmental awareness. The presented scenarios help to identify the range of plausible development paths, thus building the basis for future model-based research.

Keywords

Future air travel, COVID-19, Post-COVID air travel, Scenario development

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Keywords

Future air travel, COVID-19, Post-COVID air travel, Scenario development

1. Introduction

Over the years, we heard that "air traffic doubles every 15 years". However, the COVID-19 crisis has become a long-term challenge for the entire airline industry, has caused the commercial aviation industry to nearly collapse and has severely affected the aviation value chain. COVID-19 triggered an almost complete shutdown in air transport due to travel bans or quarantine restrictions, including lockdowns that affected nearly 50 % of the world population. Many airlines reduced their number of flights by more than 90 % and some stopped flying entirely, leading to a trickle-down impact on airports, some of which closed completely.

Over the last 20 years, the aviation industry has been involved in several crises, e.g., the terror attacks in 2001, the SARS pandemic in 2003 and the financial crisis in 2008. These crises had a different global spread, speed, impact on economies and aviation markets and have assumed different shapes of recovery. The COVID-19 crisis, however, looks like a severe combination of past crises applied at a global level. The 2020 International Air Transport Association (IATA) traffic statistics showed a decrease of 56.7 % in worldwide passenger capacity (Available Seat Kilometers—ASK). Passenger traffic (Revenue Passenger Kilometers—RPK) was lower at -65.9 %, leading to lower load factors. The drop in RPKs has seriously affected revenues: IATA estimated a net industry loss of $126.4 billion in 2020, with a net profit margin of -33.9 %, reducing to $47.7 billion in 2021 (net profit margin of -10.4 %). This crisis cut deeper into the airline industry than any crisis before and it will take years for a full recovery (IATA, 2020a).

There is a great deal of uncertainty regarding the further pandemic development and recovery paths. Industry experts expect that domestic travel, e.g., as seen in China and the US, will recover first, followed by regional travel, where passenger health can be safeguarded at each end, and last of all international travel. Depending on pandemic- and economy-related factors, the relevance of different passenger segments might shift post-pandemic. Taking a long-term perspective, the question arises as to what the "new normal" will look like and how the aviation industry solves environmental sustainability challenges (EUROCONTROL, 2020a).

Scenario studies can help to shed light on some of these uncertainties and to build a foundation for informed decision-making within the industry. The goal of this paper is to derive possible developments and drivers for the aviation industry on its highly uncertain path to recovering from the current crisis, contributing to the assessment of basic aviation management

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strategies dealing with the consequences of the pandemic. Further, the connection between the current pandemic crisis and issues regarding environmental sustainability is acknowledged. Hence, the present scenario study will answer the following questions:

- How will COVID-19 change passenger expectations and flying behavior (i.e., leisure and business travel)?
- How will the aviation industry meet all safety and sustainability aspects for restoring passenger trust?
- What are the key future drivers that will help commercial aviation to recover fully, e.g., environmental sustainability, regulation, investors, media and the public, and which will help institute successful airline business models?
- What are the implications for passengers, airlines, airports and OEM (Original Equipment Manufacturers)?

We have chosen the decade from 2020 to 2030 as a timeframe for this study. The research work on the presented scenarios was finalized in January 2021, and most of the sources used were current at that time. Owing to the highly dynamic development of the current crisis, some information stated here may change quickly. The authors acknowledge this drawback but hope that the presented results will help the reader critically assess general and personal assumptions drawn over the pandemic. Furthermore, the general trends depicted here are expected to remain valid. The resulting scenarios show the range of possible developments along plausible and consistent development paths. These scenarios are not supposed to provide a basis for assuming the probability of a specific future state of affairs. Furthermore, they do not yield quantified results but show significant trends and the prerequisites for those building the basis of further model-based research and quantifications.

The paper starts with a literature review in Section 2. Section 3 presents the methodological background of this study. Section 4 follows with an in-depth description, a comparison and an implications of the three scenarios developed. A summary, limitations of this study and indications for further research are presented in Section 5.

2. Literature review

The first section gives an overview of the environment setting for this study by reviewing the COVID-19 pandemic development and its influence on the aviation sector. The second section deliberates on previous scenario studies in aviation.

2.1. State of affairs: COVID-19 and implications for aviation

After World War II aviation faced many crisis, however always returned to a trend of growth after few years (Cambier et al., 2020; Oxley and Jain, 2015). These past crisis furthermore showed that often different regions of the world are not equally concerned. Such regional differences could be observed in the 2008 financial crisis (Cambier et al., 2020) or the SARS pandemic in 2003 (Willis-RE, 2020). The latter as well as other prior pandemics sparked research on the influence of health crisis on aviation, including hygiene measures (Gold et al., 2019) and travel restrictions (Epstein et al., 2007). COVID-19, however, constitutes the most severe crisis in the history of civil aviation. The review of the current situation as of spring 2021 regarding the COVID-19 pandemic forms the basis for the scenario construction in subsequent sections.

The average global GDP (gross domestic product) declined by 3.3 % in 2020, however is expected to increase by 6 % in 2021, following a V-shaped economic recovery pattern (IMF, 2021). In contrast, important air traffic indicators show only a slow recovery, well below pre-crisis levels, after the substantial decrease in air traffic volume at the beginning of the second quarter of 2020 (EUROCONTROL, 2021). The International Civil Aviation Organization (ICAO) reports similar statistics with a 60 % decline in global air traffic volume over 2020 (ICAO, 2020a). Compared to the general economic development, this might indicate an intermediate decoupling of economic and air traffic growth.

The COVID-19 crisis is the subject of various aviation-related studies. Lamb et al. (2020) and Song and Choi (2020) study factors influencing passenger willingness to fly during and after COVID-19 in the USA and South Korea. While the threat of the virus and passenger fear are identified as significant determinants for traveling by air, factors such as trip purpose, social perceptions, choice of destination and local self-isolation regulations, transparent communication efforts, and the airlines' preventative measures are mentioned as implications for restoring passenger confidence. The willingness to travel during and after COVID-19 is influenced by a complex set of factors and is often not supported by the variety of measures and regulations put in place by different countries or stakeholders along the travel chain. Examples are hygiene measures such as wearing a mask or maintaining social distancing and regulations regarding health certificates and quarantine obligations. Many factors depend on the country of arrival. Some countries allow quarantine-free traveling in flight corridors, and nations with a large share of vaccinated population might ease restrictions and controls, often depending on the appearance of new virus variants (Airport Research Center, 2020; Sydney Airport, 2021; Gostin et al., 2021). Most work focus on single countries or markets, and further research might confirm the determinants for passenger willingness to re-travel after COVID-19.

Changes are as well discussed regarding passenger structures, especially if the share of high-yield business-related air travel will recover to pre-COVID-19 levels. Forecasts assume a permanent drop between 19 % and 36 % (IdeaWorks, 2020). Business air trips eventually depend on the trip background. Maintaining personal relationships might recover sooner than air trips for meetings or conferences (Suau-Sanchez et al., 2020). The extent and impact of the further adoption of remote working solutions are still discussed. Various studies depict different factors influencing productivity when working remotely, such as having a workplace or no children to take care of (Birkinshaw et al., 2020; Beno and Hvorecky, 2021; Etheridge et al., 2020; Choudhury et al., 2021) while some even suggest a decrease in productivity (Bucurean, 2020; Bao et al., 2020). Leisure travel might recover before business-related travel, and affordable holiday destinations can gain momentum due to lower household income levels (Suau-Sanchez et al., 2020). Moreover, the emergence of new business models in the wake of COVID-19 is exemplarily described by Bauer et al. (2020), who describe advantages and subsequent scenarios for ultra long-haul flights in a post-pandemic world.

Most aviation stakeholders work with scenarios that consider plausible pandemic developments to gain indications about

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the pace of traffic recovery. They expect a return to 2019 traffic levels in the mid of the current decade (Boeing, 2020), while the Airport Council International (ACI, 2021) details this to a timeframe between 2023 and 2024. EUROCONTROL (2020b) determines detailed scenarios for Europe, not anticipating a recovery to 2019 levels before 2024. Pearce (2020) describes a similar timeframe. All these stakeholders develop scenarios with a distinct focus on one detail, some very short-term such as ICAO (2021), giving only an outlook for 2021, others mid-term until full recovery from the pandemic, and some long-term, like Boeing (2020). At the same time, regional differences are expected owing to diverse developments of key factors for recovery and mirroring the abovementioned, heterogeneous measures of different countries. The factor mentioned most is the progress in vaccination with its wide variation from country to country (Ritchie et al. (2021)) and its unclear extent of preventing or easing infections with further mutations of SARS-COV-2 (Luchsinger and Hillyer, 2021). In 2021, many countries across the globe still need to handle a high number of infections (WHO, 2021).

2.2. *Scenario studies in aviation*

This section[1] discusses aviation-related studies where scenarios are utilized. Table 1 summarizes the literature review according to important study parameters, including the method used, the time horizon, the relevant scenario category, the hierarchical environment level, and the scenario type. These categories are also the reference for the methodological choice.

Aviation scenarios are used for a wide range of topics, usually including analyses of future markets and business models, focusing on profit opportunities, capacity constraints, and risks arising from market changes or regulations, which can be traced using the respective study scopes (EUROCONTROL, 2018; IATA, 2018). The risk due to unprepared future events should thus be minimized in strategic planning (Gausemeier et al., 1995; IATA, 2018). Scenarios can further be used for developing a new technology or product by evaluating customer requirements at an early stage (Randt and Wolf, 2014; Randt, 2015). Technology scenarios include diverse topics such as issues related to infrastructure performance (Matti et al., 2020), aviation staff training (Moallemi et al., 2019), and tools for simulating airport management scenarios (Suikat et al., 2017). Furthermore, scenarios are used for operational aspects of aviation for some time, see e.g., Moyer (1996) with an overview of the scenario methodology at British Airways. Future operational topics, such as door-to-door air travel, are often addressed using scenario methods (Kluge et al., 2020). Operational topics also include more specific issues such as improving pilot training by developing scenarios using data from past aircraft accidents (Crider, 2017; Niedermeier et al., 2018) or mapping flight missions, e.g., for exploring safety limits in the operation of unmanned aircraft systems (Torens et al., 2018; Jafer et al., 2016). Finally, an essential research question for aviation scenarios concerns the environmental impact of aviation with a focus on carbon and noise emissions and their decrease with future aircraft generations (Liu et al., 2020; Torija et al., 2016a). The extent of achievable emission reductions and the most promising technologies toward that goal were initially estimated based on scenarios. An example are Sustainable Aviation Fuels (SAF), which are covered extensively by literature (Bauen and Nattrass, 2017; Cremonez et al., 2015).

A variety of *methods* besides the “classical” scenario methodology (Gausemeier et al., 1995) is applied in literature. Simulations are often the method of choice when dealing with issues where quantitative results are of interest, for example, emission scenarios (Berghof et al., 2005; Owen et al., 2010) and scenarios for air traffic control or airport capacities (EUROCONTROL, 2018; Liu et al., 2016). For future business models and industry-related topics, interviews with industry players helped develop a sense of industry evolutions and expectations, while the Delphi technique offers a way to gain insight into the aviation industry’s current situation (Kluge et al., 2020; Linz, 2012). Scenarios can also be created based on available literature to represent the current state of research, e.g., for technology topics such as 5G technology in aviation or aviation fuels (Matti et al., 2020; Nygren et al., 2009).

For the classification into *hierarchical environment levels,* the breakdown by Randt and Wolf (2014) is used. On the broadest scale, the *global or macro* level is distinguished from the *meso or air transport* level, dealing with issues that influence the entire aviation system. If only one specific topic inside the air transport system was analyzed, the paper was classified as *micro* level (cf. Table 1). Research on future airline business models starts at a global perspective, as airlines operate worldwide, detailing the air transport level when required (IATA, 2018; Will et al., 2016). Technology studies often proceed on the micro level when the effect of a specific technical system on aviation could be considered separately from global events (e.g., Matti et al., 2020; Torens et al., 2018). A global view becomes necessary when studying the impact of novel technologies or emissions and aviation climate impact, e.g., within scenario-based fleet models (Tay et al., 2018; Randt, 2013). To address more specific issues, e.g., the air transport level (Mayor and Tol, 2010) or single countries could be examined (Liu et al., 2016; Torija et al., 2016b).

The scenario literature that focuses on generating a tool for a specific purpose is often *normative* because it is related to a specific goal, such as increasing safety or reducing costs. An example of normative scenario analysis is the work of Itani et al. (2015), who create national civil aviation strategies for developing countries. An exception is the CONSAVE 2050 tool, which is designed to develop possible scenarios through 2050 (Berghof et al., 2005). It is, thus, explicitly *exploratory* (meaning beginning-state-driven), in contrast to *anticipative* (end-state-driven) scenarios (Gausemeier et al., 1995).

Choosing an appropriate *time horizon* incorporates a compromise between uncertainties in the future and decisions that can only take effect from a certain point in time. The longest time horizons are found in emission scenarios, as increasing emissions are only noticeable in a long-term perspective (Mayor and Tol, 2010; Owen et al., 2010). Business model scenarios mainly extend over 10 to 20 years. In such a period, costs need to be covered, and profits be generated (IATA, 2018; Will et al., 2016). Time horizons between 20 and 40 years are selected for fleet models (Tay et al., 2018; Randt, 2013). Scenarios considering, for example, new technologies stretch over 20 to 30 years due to their expected implementation timeframe (EUROCONTROL, 2018; Bauen and Nattrass, 2017). The shortest periods are seen for specific micro-level topics such as volcanic ash clouds from Iceland due to the short eruption duration and subsequent quick air traffic recovery (Reichardt et al., 2019). Other work has no timeframes, as the primary focus is to develop a tool that enables scenario work for a particular topic in the first place (Randt, 2015; Moallemi et al., 2018).

[1] Depicting all available examples for the use of scenarios in aviation is out of the scope of this paper.

Table 1
Scenario-papers in the field of aviation.

Paper	Time Frame	Study Scope	Method	Level[i]	Type[ii]
Kluge et al., 2020	2035	Projections of European passengers, requirements for door-to-door air travel	Delphi technique	a.t.l.	ex.
EUROCONTROL, 2018	2040	Find challenges in the European commercial aviation growth, risk assessment	Emissions modeling; delays modeling; SESAR[iii] impact;	g.l., a.t.l.	ex.
IATA, 2018	2035	Identify drivers, opportunities and challenges	Interviews	g.l., a.t.l.	ex.
Randt and Wolf, 2014	2050	Developing new products (high level requirements)	Foresight study	g.l., a.t.l.	ex.
Randt, 2015	-	Future customer needs by deriving robust customer needs under uncertainty	Consideration of alternative future scenarios	g.l., a.t.l.	ex.
Will et al., 2016	2025	Applying scenario technique to environmental topics in commercial aviation	Scenario planning in strategic foresight	g.l., a.t.l.	ex.
Moyer, 1996	2006	How British Airways develops and uses scenarios	Interview & discussions	g.l., a.t.l.	ex.
Matti et al., 2020	-	Application of 5G technology in aviation industry	Literature study	m.l. (tech.)	no.
Moallemi et al., 2019	-	Building an en-route ATC[v] simulator with en-route scenarios for practice	Requirement engineering approach for ATC simulation	m.l. (ATC)	no.
Suikat et al., 2017	-	Tool to create and edit simulation scenarios for airport management simulations	Scenario creation, scenario editing and simulation	m.l. (airport)	no.
Crider, 2017	-	Lessons learned from accidents and incidents, scenarios for future safety goals	Use accident and incident data for training scenarios	m.l. (pilot training)	no.
Niedermeier et al., 2018	-	Design of training scenarios for Evidence-based Training	Training scenario design approach	m.l. (pilot training)	no.
Torens et al., 2018	-	Operational restrictions by risk assessment, formalization of documents for stakeholders	Simulation Language to express flight scenarios	m.l. (UAS[iv])	no.
Tay et al., 2018	2033	Quantitative simulate the development of future air transport scenarios	Scenario-based fleet system dynamics model	g.l., a.t.l.	ex.
Randt, 2013	2050	Assessment of future aircraft technologies to determine the impact at fleet-wide level	Scenario-based fleet system dynamics model	g.l., a.t.l.	ex.
Jafer et al., 2016	-	Verification and execution of flight scenarios (flight phase: landing)	Simulation Language to express flight scenarios	m.l. (lan-ding phase)	no.
Berghof et al., 2005	2050	Sustainable aviation, competitiveness and sustainable growth, clean propulsion	Analysis key factors ->design scenarios	g.l., a.t.l.	ex.
Itani et al., 2015	-	Role of macro environment and industry in implementing national civil aviation strategies	Performance benchmarking technique + regression	g.l., a.t.l.	no.
Liu et al., 2016	2030	Exploring possibility and feasibility of achieving carbon emission reduction target	Monte Carlo simulation	g.l., a.t.l.	ex. & no.
Torija et al., 2016a	2050	Effectiveness of each considered noise reduction rate in reducing aviation noise around airports is discussed	Technology and aviation growth scenarios-> noise metrics estimation method	a.t.l.	ex.
Bauen and Nattrass, 2017	2050	Analysis of the supply of sustainable aviation fuels, contribution for carbon-neutral growth	Estimating economic capacity; political focus	g.l., a.t.l.	ex. & no.
Cremonez et al., 2015	-	Use of aviation biofuels in Brazil	Literature review	g.l., a.t.l.	ex.
Mayor and Tol, 2010	2100	Scenarios of future tourist air travel and carbon dioxide emissions	Model for impact of climate change on tourism	g.l., a.t.l.	ex.
Torija et al., 2016b	2050	Analysis between the reduction in noise and CO_2 emissions of imminent and future generations that will replace current aircraft	RPK Projection and fuel burn reduction scenarios	g.l., a.t.l.	ex.
Owen et al., 2010	2050	Global aviation emissions w.r.t technology, aircraft movement, economic growth	Calculating future global aviation emissions scenarios	g.l., a.t.l.	ex.
Reichardt et al., 2019	2-24 weeks	Two scenarios for potential scale of volcanic eruption; identify opportunities, weaknesses	Interview & discussion & simulating ash distribution	m.l. (eruption)	ex.
Moallemi et al., 2018	-	Generated scenario script to show defining/validating aviation scenarios	Simulation Language to express flight scenarios	m.l. (tech.)	no.
Linz, 2012	2025	Develop long-term strategies in the aviation industry for aviation managers	Delphi technique	g.l., a.t.l.	ex.
Nygren et al., 2009	2026	Find oil production forecast and compare to demand	Oil production forecast by literature	g.l.	ex.
Zhou et al., 2016	2030	Influences from key influential factors for CO_2 emissions from the aviation industry	Scenario for CO_2 emissions and mitigation measures	g.l., a.t.l.	ex.
Connelly et al., 2015	-	Political, economic and technological conditions to secure the supply of biojet fuel	Risk analysis	g.l., a.t.l.	no.
Rinehart et al., 2014	-	Verification and validation to assure system performance and safety	Sc. development, story-boards, risk assessment	m.l. (systems)	no.

[i] g.l.: global level; a.t.l.: air transport level; m.l.: micro level
[ii] ex.: explorative; no.: normative
[iii] Single European Sky ATM Research Programme
[iv] UAS: Unmanned Aircraft Systems
[v] ATC: Air Traffic Control

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2.3. Contribution to the literature

While literature scenarios often concentrate on factors depicting the pandemic development and its influence on economy and passenger needs (EUROCONTROL, 2020b; ICAO, 2021), aviation faces environmental challenges and decarbonization targets, see e.g. (Destination 2050, 2021). The COVID-19 crisis could be a starting point for transiting into a novel, user- and environment-focused air transport system (Dube et al., 2021; Gössling et al., 2021). However the financial situation of airlines and OEM following the crisis negatively affects their ability to invest in new technologies (Sharmina et al., 2021; Ing and Nicolaï, 2020). Help might come through state support, e.g., the German National Hydrogen Strategy (German Federal Government, 2020). Bailouts in the aviation industry amount to approximately $203 billion globally, going mainly to airlines, OEM, and suppliers (Mariz, 2021). Consequently, there are different views on the priority of environmental sustainability in state investments (Bobylev, 2020). Considering the difficult financial situation and low oil prices in 2020 and 2021, less focus on sustainability is often expected as a mid-term effect of COVID-19. Conversely, some state bailout programs are coupled with environmental obligations, supporting a possible paradigm shift toward prioritizing environmental considerations within economic stimulus packages (Schumacher, 2020). Thus, outlooks on the nature of COVID-19's influence on the environmental footprint of mankind are diverse, reflecting the high level of uncertainty on this topic. However, an interdependence between both topics is expected by most scholars and forms the basic assumption of this study. It will, thus, contribute to this discussion by not only focusing on COVID-19 effects but also by reflecting on the relation to developments in environmentally friendly air travel.

3. Methodology

This section describes the methodological approach utilized within this paper, along with complementary information about alternative process steps depicted by literature. Remarks regarding the project setup and limitations of the field of research are provided, followed by a presentation of the approach in chronological order of the single process steps.

3.1. Scenario methodology and set-up

Outlooks into a field characterized by uncertainty and complexity are often connected with prognostics and forecasts. They imply one future development, usually coupled with an exclamation of the probability of occurrence. However, forecasts often turn out wrong (Gausemeier et al., 1995; de Neufville and Odoni, 2013), given a single possible future and projections based on mostly subjective notions.

To deal with the highly uncertain future of a complex system, a methodological approach is required, which considers the entire range of possible system states (de Neufville and Odoni, 2013) by offering multiple paths of development. Such "multiple futures," as Gausemeier et al. (1995) report, are the basis for robust future planning. Scenario techniques are used to systematically depict these multiple futures while dealing with the related complexity, showing the path from the present toward the future (Gausemeier et al., 1995). A scenario should be plausible and consistent. Assigning a probability for the scenario's occurrence is not part of the methodology. Literature gives many examples for scenario techniques (Gausemeier et al., 1995; von Reibnitz, 1992). Many analyses use simulations, especially dealing with environmental or technology questions. Conversely, a simulation would not be able to cover all relevant aspects, especially in the case of political or regulatory issues. The scenario process applied in this study (cf. Fig. 1) follows the approach which has been conducted at TUM for more than two decades (cf. Michelmann et al., 2020; Will et al., 2016). It is based on scenario literature, mainly on Gausemeier et al. (1995), building also the basis for the following sections unless indicated differently. Discrepancies might occur in single process steps and are referred when appropriate.

First, the dimensions of the scenario project are defined, starting with the scenarios' scope. This study describes the development of global scenarios, as they are not limited to any product, company, or regional entity. The study deals with environment scenarios, i.e., scenarios that are characterized by comprising only non-steerable environment factors. Furthermore, our scenarios are explorative and descriptive. Descriptive scenarios depict the current condition at a given time rather than prescriptive scenarios, which depend on a user's targets. In line with that, our scenarios are process scenarios containing the target year's final state and the path toward this final state across various decision points. We focus on developments in commercial passenger aviation[2] in the ten-year-timeframe from 2020 to 2030 (mid- to long-term scenarios). Therefore, the scenarios include the assumed end of the COVID-19-crisis as well as recovery, which most sources expect within the next five years (cf. Section 2.1). Furthermore, this timeframe depicts long-term consequences resulting from the current crisis and technological and societal changes toward more environmentally sustainable aviation, expected at earliest by the end of the decade.

The quality of results depends on how scenario studies are designed. It is proven to organize scenario processes with an interdisciplinary team as a structured communication process. The interdisciplinary team composition ensures that the problem area is adequately defined and all relevant areas of influence are identified (Becker and List, 1997). Such an approach was followed in the present scenario process, conducted at the Technical University of Munich (TUM). A team of five senior experts employed at aviation research institutions, an OEM, and an airport operator, set up the project. All process steps were supervised and actively accompanied by those experts. Furthermore, twelve postgraduate students from aerospace engineering and similar degree programs and two research assistants with previous experience in scenario development participated in the project. The student perspective was particularly valuable to the project as it frequently questioned the experts' common expectations, which might not have been open to identifying possible developments outside common company practice. Further, the students are the next generation of aviation experts, and many of them have gained work experience in aerospace companies (e.g., internship, working student jobs, and thesis cooperation). This interdisciplinary team composition with mixed seniorities ensured an adequate definition of the problem field and all relevant

[2] Cargo flights and the effects of the COVID-19 pandemic on airfreight and belly cargo are out of the scope of this research.

influence factors due to various views on aviation-related topics.

3.2. Scenario approach

The process cycle (see Fig. 1) is followed clockwise, as indicated by the arrows. The first step to be conducted is the problem definition and the description of the corresponding field of research. The goal of this process step is to set the scope as well as the project goal in the form of major research questions to be answered. The problem definition has to be clear, concise, and unambiguous to all project participants. The results of this project step are presented in Section 1. The current state of affairs of the field under research is discussed in Section 2.1.

The environment factors influencing on the topic under research are defined in an environment analysis by brainstorming and subsequent discussion among all participants. This method was chosen as opposed to discursive factor generation due to the heterogeneity of the scenario team. The resulting environment factors were grouped according to different classifications used to identify and avoid a one-sided concentration on only some relevant factors while unknowingly neglecting others. One classification follows the hierarchical environment levels described in Section 2.2. Other examples, such as the STEEPV (sociological, technological, economic, environmental, political, and value change) classification (Wiggert, 2011), distinguish the environment factors according to their thematic area. In this study, we classify factors in the fields of “economics, politics and regulations,” “energy, environment and technology,” “social and passengers,” as well as “airlines and airports.”

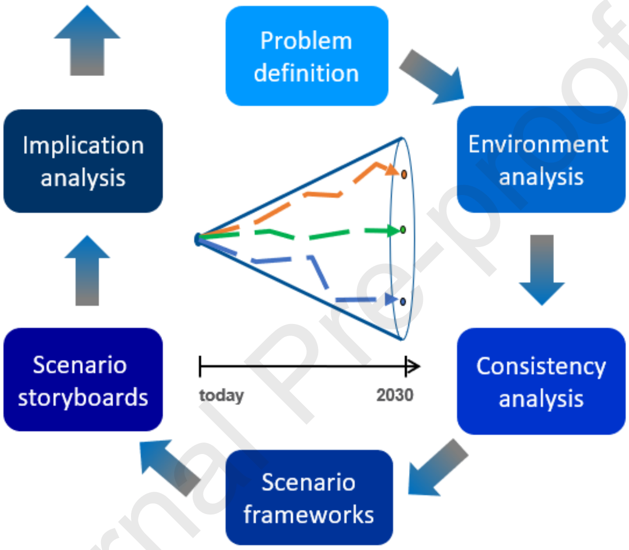

Fig. 1. Applied scenario process with scenario funnel (Michelmann et al., 2020).

The initially large number of environment factors is reduced in the following process step by omitting negligible factors. This serves two main goals: first, core messages can be elaborated more clearly and second, the workload is reduced. However, it should be kept in mind that by neglecting factors with seemingly low influence, additional influences on the system under investigation might still be lost overall. The initial set of environment factors is narrowed down to the relevant key scenario factors using an Uncertainty-Impact (UI) analysis, which quantifies the impact and the uncertainty of a scenario factor’s development on a scale of 0 to 4 as shown in Table 2. In order to avoid overly subjective results, the assessments for impact and uncertainty were derived by three groups of participants working in parallel, whose factor assessments were subsequently summed up and depicted in a UI diagram. Thereby, the assessments’ standard deviations help to identify outliers due to fundamentally different evaluations within the project groups, which were discussed and, if necessary, revised. An alternative method for deriving key scenario factors is the influence analysis, which depicts the influences of each environment factor on the other environment factors within a matrix. However, such an analysis would be laborious and time-consuming (Gausemeier et al., 1995). Furthermore, when depicting explorative scenarios in a long-term investigation, the value added by an influence analysis compared to a UI analysis is questionable since, in both cases, the relevant evaluations would depend on subjective assessments of the project participants.

Table 2
UI classification.

Value	Meaning (uncertainty/impact)
0	Development certain/no impact
1	Development almost certain/rather low impact
2	Development rather certain/medium impact
3	Development rather uncertain/rather high impact
4	Development uncertain/high impact

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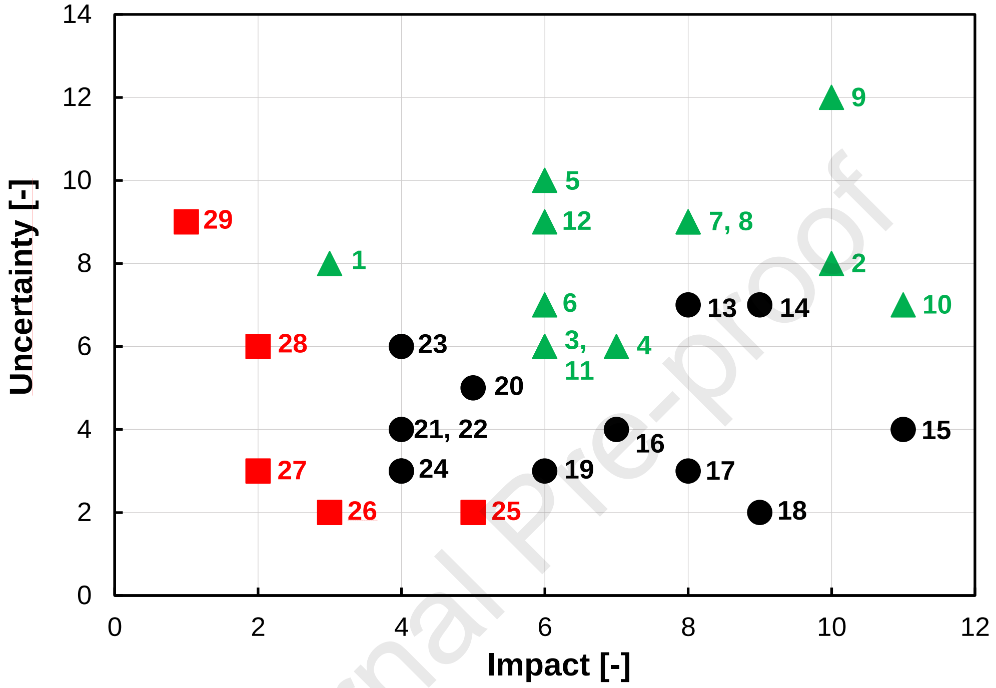
Figure 2 shows the resulting UI matrix with all environment factors. The assessment was performed by three groups in parallel to reduce the influence of individual views. The results for the three groups were added, therefore, the maximum matrix value amounts to twelve. Factors with low uncertainty (premises) and impact (in red) will be disregarded in the following process steps. From the set of remaining factors, the twelve factors with the highest values for impact and uncertainty are chosen as key scenario factors (in green), see Table 3 for a detailed factor description, including the sources of reference. These key scenario factors will be used to derive basic scenario frameworks in the following consistency analysis, while the remaining factors (in black) will be added intuitively to the scenario frameworks later. The key scenario factors cover a wide range of topics, with further pandemic development being identified as the most uncertain factor. Further key factors cover issues regarding the development of economic indicators and environmental considerations. A peculiarity is the choice of air traffic development as key factor, despite its low impact score. This is due to this factor being core to the central research question. Factors dealing with subsidies in aviation and vaccine availability were not chosen as key factors, as connected factors already cover their impact (e.g., pandemic development highly depends on vaccination availability).



Environment Factors

1 Air traffic volume / Passenger demand
2 Development and utilization of environmentally friendly propulsion systems and fuels
3 Operational intervention into air traffic
4 Environmentally aware travelling
5 Development of kerosene price
6 Teleworking / Mobile working
7 Trade policy / Gloablization
8 Development of COVID-19 travel regulations
9 Economic development
10 Global pandemic development
11 Implementation of changes in airline customer service driven by COVID-19
12 Customer / Passenger structures
13 Number of countries which subsidize aviation
14 Availability of a vaccine
15 Superspreading aboard aircraft
16 Change in hygiene awareness of passengers
17 Development of reliable and standardized quick tests
18 Innovations into cabin products, services, technologies
19 Airline marketing investments
20 Integration of mobility services
21 Handling of passenger data
22 Airline business models
23 Market share of aviation in the modal split on short-range routes
24 Automation alongside the travel chain
25 Emerging markets (movement to Asia)
26 Selective remembrance
27 Cyber security
28 Development of demand in point-to-point connections
29 Development of terrorist avtivity

▲ : key scenario factors ● : further scenario factors ■ : disregarded factors

Fig. 2. UI Matrix, environment factors and their UI classification.

The following process step introduces future development alternatives by assigning unique projections to every scenario factor, depicting the range of the factor's possible development. These projections are presented in Table A.1 in the appendix. Subsequently, correlations and dependencies among the scenario factors are identified for building a basic scenario framework. This process step is accomplished using a Consistency Matrix that depicts the consistency of the simultaneous appearance of two scenario factors' projections for all possible pairwise combinations of projections. Figure A.1 in the appendix depicts the resulting Consistency Matrix. The preparation of projections and the allocation of consistency values was performed intuitively, based on available literature (see Table 3) and adopted after thorough

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discussion within the project team. Alternative methods for this process step include plausibility as well as cross-impact balance analyses. The former was not included in this project since it deals with probabilities for the occurrence of projections, and the latter due to requiring an extensive workload[3].

The results of the Consistency Matrix hint at drivers for our scenarios. Out of the key factors in Table 3 those dealing with economic development (factors 7 and 9), pandemic development (factors 8 and 10), and the interlinking between both (factor 12) could be identified as such drivers. The same counts for the passengers' environmental awareness (factor 4), although for this factor no strong interdependence with COVID-19 can be concluded from the Consistency Matrix. This can be interpreted as a change in the passengers' mindset during the pandemic, influencing an otherwise independent factor.

The results of the consistency matrix are inserted into the *Foresight Strategy Cockpit* software which was made available by 4strat (2021). The software develops scenarios as combinations of factor projections by utilizing a branch-and-bound algorithm (Wiggert, 2011). It thereby considers the total consistency of a scenario and the completeness of the process by ensuring that every projection appears at least once, and it rejects scenarios that would include inconsistent projection pairs. The branch-and-bound algorithm searches for a user-defined number of most-consistent projection combinations. Afterward, an agglomerative hierarchical clustering algorithm (Wiggert, 2011) clusters the raw scenarios.

The final scenarios are chosen out of these clusters of the most consistent scenarios to depict the widest range of developments possible. These basic scenario frameworks are then extended intuitively with the most appropriate projections of the remaining scenario factors (see Fig. 2) and developed into scenario storyboards, as covered in Section 4. Storyboards describe the future situation and pathways from the present toward this situation in prose. They enable the reader to easily get acquainted with the scenario and increase its acceptance. Furthermore, specific implications of the scenarios for the research questions defined at the beginning of the scenario process are developed in Section 4.2. These implications show the effects of the scenarios for specific fields of interest.

Table 3
Key scenario factors and their classification according to factor level as well as factor description.

Factor	Based on	Level	Description applied in this scenario study
1 Passenger demand	EUROCONTROL, 2011; IATA, 2020a; ICAO, 2020a; ICAO, 2020b; Pearce, 2020	Meso	Annual passenger demand growth in percent averaged across the entire investigation period.
2 Environmentally friendly propulsion systems and fuels	Destination 2050, 2021; German Federal Government, 2020; Gössling et al., 2021; ICAO, 2021; Ing and Nicolaï, 2020	Micro	The development of eco-friendly aircraft propulsion mainly depends on: a) Degree of SAF usage b) Development of new propulsion systems, ranging from evolutionary (e.g., increase in Bypass Ratio BPR) to revolutionary (e.g., hybrid electric)
3 Operational inter-vention into air traffic	Albers and Rundshagen, 2020; Ing and Nicolaï, 2020	Meso	Potential political intervention into operational parameters of the air traffic system to reduce aviation climate impact.
4 Environmentally aware traveling	Gössling et al., 2019; McKinsey & Company, 2020; Song and Choi, 2020	Meso	Environmentally aware traveling focuses on reducing or avoiding climate impact due to traveling, e.g., by choosing train services instead of flying.
5 Development of kerosene price	Nygren et al., 2009; Oxley and Jain, 2015	Macro	Main influences on kerosene price: oil price, demand and taxes. Five-year rolling average taken to cope with high volatility.
6 Teleworking / Mobile working	Bao et al., 2020; Bucurean, 2020; Choudhury et al., 2021; McKinsey & Company, 2020; Suau-Sanchez et al., 2020	Meso	Share of business days not physically spent in the office, but rather at home or anywhere off-site.
7 Trade policy / Globalization	Ademmer et al., 2021	Macro	Amount of international trade and degree of cooperation between different companies and countries in connection with trade barriers and custom duties, including degree of intercultural exchange among various countries.
8 COVID-19 travel regulations	Epstein et al., 2007; Gold et al., 2019	Macro	Implementation and degree of worldwide standardization of COVID-19 travel restrictions and transportation rules regarding hygiene measures and recognition of health documents.
9 Economic development	Ademmer et al., 2021; IMF, 2020; IMF, 2021; Sharma et al., 2021	Macro	Measured by the change in global GDP. Thereby, COVID-19-induced recessions seen in many countries take different forms, which influences the speed of post-crisis economic recovery.
10 Global pandemic development	Birkinshaw et al., 2020; ICAO, 2021; Luchsinger and Hillyer, 2021; Mariz, 2021; Ritchie et al., 2021; WHO, 2021	Macro	The pandemic development is measured based on the number of new infections. Due to travel restrictions depending on this number, it directly influences air traffic development.
11 Changes in airline customer service driven by COVID-19	Airport Research Center, 2020; Airport Technology, 2021; EUROCONTROL, 2020a; Gostin et al., 2021; Lamb et al., 2020; Sydney Airport, 2021	Micro	Influence of COVID-19 on airline customer service. The time during which changes in customer service remain as well as the form of implementation are of interest. Changes might be mandatory/standard or subject to additional charges.
12 Customer / Passenger Structures	IATA, 2021; IdeaWorks, 2020; McKinsey & Company, 2020; Suau-Sanchez et al., 2020	Micro	Depending on the customer's reason for traveling, usually differentiation between business and leisure travelers.

[3] For more information on alternative methods, see e.g., Gausemeier et al. (1995) and Weimer-Jehle (2008).

4. Results

This section presents the three scenarios derived in this study: firstly, the three scenarios' storyboards describe the problem-specific situation from the perspective of the year 2030, along with a comparison of some scenario elements with current developments. Secondly, the scenarios are compared among each other, setting the scene for further discussion.

4.1. Scenario storyboards

The three scenarios are named following their core message: Scenario A ("Post-COVID Digivation") represents an optimistic case with growing air traffic development, fast containment of COVID-19, and a focus on economic recovery and growth. In Scenario B ("Clean Restart"), the virus's spread is contained later, while innovations in propulsion technologies reflect strong societal efforts toward environmental friendliness. Scenario C ("Green and Clean New Normal") addresses the differing persistence of COVID-19 in various world regions and, hence, slow air traffic recovery coupled with strict environmental regulations and progressive usage of SAF.

4.1.1. Scenario A: "Post-COVID Digivation"

This scenario's title refers to a fast economic and air traffic recovery and tech companies entering the aviation market. These acquisitions are followed by extensive digitization efforts.

The scenario encompasses a GDP growth of approximately 3.8 % p.a. due to the early containment of COVID-19 by 2023. Internationally coordinated measures lead passengers to trust safe travel options, although isolated outbreaks of COVID-19 still occur. The air traffic volume reaches pre-COVID-19 levels in 2023 and increases by 4.8 % p.a. in the following years. Governmental subsidies granted to airlines during the COVID-19 crisis will be discontinued in 2023. Due to their high loss of market value in the previous economic recession, some established companies in the aviation industry are partnering up or being acquired by data-driven tech companies[4]. This strategic act supports those companies in gaining easy entry into new markets and yields significant returns on investment preceded by a low investment effort. They enable and further develop the digitization of the aviation industry and create a shift toward highly innovative airline business models. For protecting their market shares, traditional airlines have to adapt to this development by accelerating their digitization efforts.

A large amount of customer data enables new market entrants to combine digital services along the air travel chain, such as integrating mobility services, enhanced predictions of travel connections, and consequently, reduced buffer times. These may make short-haul flights a more attractive travel option and help companies enhance offers in their traditional markets. The inflight passenger experience is improved by customized, software-focused offers, such as individualized seating areas, inflight entertainment and on-board services perhaps becoming partially or entirely automated. The amount of processed passenger data increases and leads to significant investments and development activities in cybersecurity.

Passengers gain a moderate level of environmental awareness, expressed in increasing options for offsetting carbon emissions along with ticket purchases. Higher expectations toward environmental sustainability are partially prevented due to a shift in priorities during the pandemic and a wish for fast economic recovery (Schumacher, 2020). Thus, the mentioned options gradually become an integral part of the booking process. Due to political regulations and societal demands, SAF are adopted to reach sustainability goals and serve as a basis for future aircraft propulsion systems. These technological developments are subsidized by governments of developed countries and pursued by the new market players to obtain a green footprint. A positive public profile may further foster their newly tapped market growth. These advances, in turn, lead to increasing production volumes and decreasing costs of SAF and, thus, lower the dependency on kerosene and its price fluctuations. SAF-focused marketing campaigns result in a higher intermodal share of flights on short-haul trips owing to aviation being perceived as a sufficiently environmentally friendly travel option. More investment-intensive options for greener aviation, such as new propulsion technologies, are not demanded by customers and are not implemented in the investigated timeframe.

The lower labor effectiveness of people working remotely leads to no change in the share of remote working compared to 2019. Therefore, the share of people flying short distances to commute to their workplaces does not decrease compared to pre-crisis levels. After declining during the pandemic owing to hygiene measures, in-person meetings quickly regained preference from 2023 onward as their commitment to business relationships is unrivaled by digital options. Thus, there is no decrease in business travel and the passenger structure resembles the one in 2019. New products and cabin layouts are highly price-driven and aim to address various types of passengers, resulting in product fragmentation between economy and business class.

Concerning hygiene consciousness after COVID-19, passengers with low investment in their flight experience do not demand additional hygiene treatments, whereas passengers with high hygiene awareness, such as risk groups, expect additional preventative measures. As mentioned above, this may force airlines to adapt their cabin layouts but leads to more pandemic-related flexibility by offering various anti-virus protective packages, such as left-out middle seats or additional disinfection. Also, no or newly standardized measures may complete the varying service spectrum. In this scenario, air travel is perceived as the most epidemic secure means of transportation.

4.1.2. Scenario B: "Clean Restart"

"Clean Restart" addresses a strong customer focus on environmentally friendly means of transport after the pandemic is contained. Airlines and OEM develop highly innovative propulsion technologies—instead of solely focusing on SAF. The

[4] Although this might sound unrealistic, a Delphi study with 38 European aviation experts reveals the entry of tech companies as a possible wild card scenario for the European market (Kluge et al., 2020). Looking into the market, cargo-airline Amazon Air acquired aircraft in 2021 (BBC News, 2021).

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entire travel chain is impacted due to pervasive automation.

Through widespread vaccinations, COVID-19 is contained by 2025, primarily due to comprehensive hygiene measures implemented along the whole travel chain. These include a thorough cleaning, testing, wearing masks, and adapted in-flight services. From 2025 on, last travel restrictions and mandatory hygiene measures are withdrawn, and passenger confidence in safe traveling is restored. While global GDP growth yields 3.6 % p.a., air traffic reaches its 2019 volume in 2024 and achieves a compound annual growth rate (CAGR) of 4.2 % afterward. Since teleworking is established through enhanced telecommunication technologies, the share of business travelers decreased by 20 % compared to 2019 levels. To counteract this negative development and secure technical innovation, most governments grant subsidies to airlines and OEM.

The generally cautious approach of society toward an external crisis is evidenced not only in terms of heightened hygiene awareness but also in terms of environmental issues. Owing to a gradual shift in passenger travel focus to environmental friendliness, intermodal shares of short-haul trips by aircraft decrease in favor of more environmentally friendly means of transportation, e.g., high-speed rail. Comprehensive and effective carbon dioxide emission trading schemes are deployed, leading to re-investments in research into alternative energy sources, such as hydrogen and electric solutions, and suitable propulsion technologies. The European Union (EU) introduces a growing carbon dioxide taxation from 2023 on, leading to various industry sectors adopting hydrogen as the preferred energy source. The use of SAF remains insignificant as OEM and politics are aiming at the fast implementation of innovative propulsion technologies. This is supported by the mentioned subsidies that enable the necessary investments for such technologies and make their use affordable. The paradigm behind governmental support thus changes from a crisis support measure toward a means of reaching climate protection targets while keeping a technological advantage.

This scenario focuses on leisure travelers and Asia's significantly growing, technology-savvy customer base. Both lead to expanded cooperation with mobility companies involved in the door-to-door travel chain. A larger customer base yields diversified customer groups with similar price sensitivities. This results in fragmented economic classes. With a distinct focus on individualization and comfort, leisure travelers increasingly utilize the remaining shares of business class segments.

The COVID-19 impact on travel technology is illustrated through great automation efforts and touchless travel experiences at airports. These technologies include biometric scanners and real-time travel information, and passenger engagement through various types of smart devices, such as boarding pass scans and luggage tracking. Moreover, large technology companies, airports, and airlines increasingly cooperate to enhance innovation in customer service.

4.1.3. Scenario C: "Green and Clean New Normal"

The last scenario exhibits the slowest economic recovery and deals longest with COVID-19-related hygiene measures, which have become an essential part of traveling and business models. This scenario is characterized by many government airline bailouts and increased investments in marketing expenses to raise market shares. Environmental regulations through emission trading schemes and enforced usage of SAF become an essential part of daily aircraft fleet operations.

Scenario C exhibits a substantial economic recovery, with the global GDP increasing at 3.2 % p.a., while the air traffic volume grows disproportionately slowly at 2.2 % p.a. until 2030. Rare "superspreader" events in aircraft and diverse traveling regulations partly cause this low growth in air traffic volume due to lack of passengers' trust in this transportation mode. Hence, air traffic volumes of 2019 are not reached before 2026. Key players in the aviation industry are bailed out by governments or receive subsidies—some of these aids are linked to obligatory environmental conditions. Airline investments in digitization and automation are delayed and focused instead on marketing expenses to maintain or increase shares in a market substantially decreased in size. The share of business travelers decreased following the widespread utilization of remote-working practices, increased environmental awareness, and new remote-working technologies, which resulted in a reduction in corporate travel expenses.

To regain passengers' trust and comply with regulatory measures, aviation stakeholders are forced to implement new hygiene concepts. With the unequal distribution of vaccines between industrial and developing countries, the pandemic recovery differs substantially among regions. These regional differences lead to varying COVID-19 regulations for airlines and airports. Bilateral agreements, including hygiene standards along the travel chain, are formed mainly in the same regions, gradually creating exclusive travel "bubbles". The hygiene measures are obligatory masks, hand sanitizers inside the aircraft cabins, obligatory testing before flights, and disinfection of contact surfaces. Full Service Carriers (FSCs) incorporate extensive hygiene standards into their brand values, for instance, offering isolated zones in the terminal, complementary rapid testing, and free certified masks onboard. Extended hygiene measures and services result in increased ticket prices. Low Cost Carriers (LCC) focus on no-frills service and only comply with the required hygiene standards. Masks and testing are offered as ancillary services.

As the enduring interruptions to flight travel due to COVID-19 become the "new normal," the public and political attention shifts to strict environmental regulations after pandemic containment in 2027. This means that the EU enforces the usage of SAF by issuing air operator certificates only to airlines that operate a specific share of their fleet on SAF. The EU enacts a strict carbon dioxide emission-trading scheme. Both measures should result in widespread and cost-efficient SAF usage. Most passengers invest in carbon-offsetting in the ticket booking process. This generates additional assets supporting airlines in accounting for the extensive deployment of SAF-based fleet operations. As other countries and regions follow the EU's lead regarding environmental regulations, OEM research efforts and investments in alternative propulsion technologies, such as hydrogen-powered turbofans, gain momentum. Still, the usage of SAF and additional regulations lead to higher ticket prices than today. Together with passenger expectations toward hygiene and digital solutions replacing business travel, high environmental awareness is thus the main reason for the low growth in air traffic volume.

4.2. Comparison and discussion of scenarios

Within the aviation industry, with its long planning and product life cycles of more than 20 years, implications drawn from the above scenarios support strategic managerial decisions as described by Becker and List (1997). The following

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comparative discussion of the scenarios is intended to support such processes with a holistic picture of the scenario space.

All three scenarios are driven by the COVID-19 pandemic but differ regarding the time needed to reach pre-COVID-19 air traffic levels[5]. The key driver for this recovery is global pandemic containment. The impact of COVID-19 on air travel varies from medium (Scenario A) to more long-term (Scenario C), with the assumed recovery years being several years apart and depicting the high uncertainty concerning pandemic development as seen in the UI-Matrix and the timeframes for recovery described in literature (Section 2.1.). The early recovery in Scenarios A and B is mainly driven by a rapidly distributed vaccine, globally harmonized travel standards, reliable rapid testing, and the airlines' flexible adoption of measures in case of local outbreaks. Scenario B presents an even more stable air transport market as COVID-19 is globally under control with fewer regional mitigation strategies. This enables planning reliability and trust in air travel. Conversely, Scenario C experiences long-term COVID-19 impacts due to regional outbreaks and "superspreading" onboard or at the airport. In this scenario, COVID-19 has become part of the "new normal" for almost a decade, mostly due to the limited availability of vaccines. Furthermore, varying levels of hygiene awareness influence travel decisions: While Scenario B describes a more sustainable and universal pandemic containment, even more passengers fly in Scenario A, trusting globally standardized hygiene measures.

Such hygiene measures along the travel chain can be product- or process-based. Figure 3 shows examples of that and the timeline of their utilization according to the three scenarios. All measures are predicted to be in place by at least 2024 in all three scenarios and might be recommended even longer due to local virus outbreaks, as seen in Scenario A with its recommended in-flight masks up to 2030. Such recommended measures are depicted via the colored frame arrow in Fig. 3. In line with the assumed long-lasting battle with COVID-19 outbreaks, the longest durations for most measures are assumed for Scenario C. With hygiene measures being a key driver to regaining passenger trust, Scenario A performs most successful due to globally standardized hygiene measures and the ability to quickly adapt actions in case of regional virus outbreaks. Some measures, such as touchless interfaces (all scenarios) or limitations in inflight services (Scenario C), are assumed to be in place by 2030 or even post-COVID. Industry players support some of these assumptions. For instance, SITA (2020) points out that air travel will change in the "new normal," post-COVID world. Technological advances might increase the passenger touchless journey experience along the air travel chain. Next to travel, McKinsey & Company (2020) show how COVID-19 might change consumers' overall preferences, e.g., regarding shopping, work, and entertainment. Further research is necessary to explore long-term preference changes and resulting long-lasting service attributes post-COVID. As Scenarios A and C show, after becoming voluntary, hygiene measures might also serve as an area of fragmentation in airline service offers. This is mainly due to different levels of priority passengers assign to such issues compared to the travel price. Higher-priced offers are more often seen to incorporate different hygiene packages for hygiene-sensitive passengers than, for example, LCC do in their range of products for rather price-sensitive passengers. The latter might still offer selected measures as additional ancillaries. Furthermore, as Bauer et al. (2020) show at the example of ultra long-haul flights, hygiene-related considerations might also help so far rare business models to gain in importance. In this case, this is achieved besides other factors owing to the independence from intermediate hub airports, effectively reducing the risk of infections and additional quarantine requirements.

Fig. 3. Timeline for hygiene measures for Scenarios A, B, and C (schematic illustration).

All scenarios are assumed to exhibit different expressions of a fast, V-shape economic recovery (Sharma et al., 2021). The long-term, post-COVID GDP growth rates vary between 3.2% p.a. (Scenario C) and 3.8% p.a. (Scenario A) (cf. Table 4). This slight disparity might be linked to the different times of the pandemic containment, recovery of other industry sectors outside aviation, but also the changing environmental awareness of consumers and the degree of political regulations and required actions from the industry side. There is a weaker correlation[6] between air traffic and economic growth as observed pre-crisis. This is due to pandemic effects (e.g., travel restrictions) still severely influencing air traffic while other sectors of

[5] Air traffic recovery levels were measured in the scenario process in revenue passenger kilometers (RPK).
[6] Based on the authors' observations only. Statistical testing, e.g., via a regression model, requires more data.

the economy are already on a growth path.

Post-COVID, the global climate crisis moves into focus, potentially rendering environmental issues more important for the success of airline business models than the current pandemic. Passenger and societal environmental awareness, and respective behavioral changes vary between the scenarios. In Scenario A, passengers return to pre-pandemic normal with only moderate awareness in both respects. Especially carbon-offsetting offers a welcome relief of conscience to continue flying. Environmental awareness is not translated into an actual behavior change. Conversely, passengers or consumers pressure the aviation industry to offer environmentally sustainable products, services, and operations in Scenario C. Here, passengers develop a strong environmental mindset, understanding that a pure carbon-offsetting scheme is insufficient for creating a sustainable aviation system. Thus, aviation stakeholders are under pressure to provide sustainable solutions, e.g., by investing in SAF and hydrogen technologies.

To achieve the described paradigm shift toward more environmentally friendly aviation, investments in innovations are indispensable, which can diminish airline revenue for a couple of years, underlining the interrelations between pandemic, societal and environmental topics. These potentially significant interactions are of indirect nature and could thus not be observed in the Consistency Matrix. They can result in lower economic growth rates short-term but yield a more sustainable business environment medium- to long-term. Destination 2050 (2021) details on subsequent key actions to reach net zero emissions by 2050. Most of those actions are discussed within the scenarios, and some are pushed by political regulations. As seen in the scenarios, such political regulations toward environmental targets can take different forms, significantly influencing airline business. During the COVID-19 crisis, governmental financial support tied European carriers toward governmental targets (Albers and Rundshagen, 2020). This is well depicted in Scenario B. The majority of states supported carriers and OEM and, at the same time, started to push investments from aviation into advancing sustainable energy sources and developing the respective infrastructure. However, short-term emission reductions are often the target of these rather undirected regulations. In contrast, in Scenario C, regulations are strictly connected with investments in green technologies as demanded by society, lacking incentives for technology development. As Ing and Nicolaï (2020) describe, this leads to a market financially weakened by a prolonged crisis and strict regulation, lacking the means for introducing eco-friendly solutions as expected by customers and society. Further air traffic growth in Scenario C consequently occurs in countries without such regulatory limitations, thus with current propulsion technologies, worsening aviation's climate impact. Investments in Scenario A focus on fast economic recovery instead of sustainability targets, not as bailout programs but as investment from private companies. This is in line with passengers wishing to return to the "old normal" rather than shifting environmental paradigms, thus considering "soft" measures such as carbon offsetting as sufficient.

An essential driver to discuss is the level of digitization, which holds two sides of the coin. Within Scenarios A and B, high levels of digitization and automation enhance the passenger travel experience, provide personalized services, open new partnership opportunities, and thus boost passenger trust in air travel. Accordingly, in Scenario A tech companies enter the aviation market with low financial effort, take over struggling airlines and their fleets, and thereby enhance their product platform toward seamless travel chains and personalized offers. While in this scenario, classical airlines have to adapt rapidly to not lose market shares, in Scenario B, these classic market players push forward digitization by cooperating with tech companies.

Table 4
Overview of Scenarios A, B, and C along key parameters.

	Scenario A ***Post-COVID Digivation***	*Scenario B* ***Clean Restart***	*Scenario C* ***Green and Clean New Normal***
Macroeconomic development	V-shape global economic recovery *3.8% p.a.* GDP growth rates	*3.6% p.a.* GDP growth rates	*3.2% p.a.* GDP growth rates
Air traffic volume	Strong growth of *4.8% p.a*.	Moderate/ strong growth of *4.2% p.a.*	Small growth of *2.2% p.a.*
Impact of Covid-19	Medium, long-term impact	Predominantly short-term effects	Strong, long-term impact
Passenger hygiene awareness and measures	Varying hygiene awareness and long-term measures Globally harmonized hygiene rules	Low, long-term hygiene awareness Withdrawal of (most) measures after 2025	High, long-term hygiene awareness and measures Local, bilateral agreements
Environmental awareness and its influence on aviation	Moderate No influence on travel behavior	Moderate-High Influence on travel behavior	High Strong influence on travel behavior
Politics & regulations	No severe political commitment to the environment	Moderate political commitment to the environment	Strong political commitment to hygiene & environment
Level of digitization & automation	Significant increase along the complete travel chain Driven by new players	Increasing level of automation both on-ground and in-flight	Only evolutionary digitization due to poor financial situation
Share of business traveler	Same as pre-COVID	Decreasing share inter alia due to increasing mobile working	Strong decreasing share inter alia due to increasing mobile working

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5. Conclusions

5.1. Limitations and further research

A main limitation of this study is the date of the scenario development in late 2020. The pandemic and respective political regulations change unpredictably. It is not easy to stay up to date with the state of affairs and incorporate novelties in the scenarios while working scientifically and plausibly. The scenario development process uncovers the high need to conduct further, ongoing research, e.g., long-term effects on consumers' preference changes, changes within door-to-door air travel, and innovations with on-board hygiene measures. The authors would like to encourage other scholars to use the three scenarios as starting point for further research and adaptations based on pandemic-related developments. Accurate monitoring of the claims made in this paper could prove whether the interdependencies observed hold true. Hence, a better understanding of the air transport system and its influencing variables can be established. The path toward recovery from future crises for aviation and the one toward a sustainable air transport system can be substantiated.

Further, the authors acknowledge biases and limitations during the research process. Although the expert group has an international background, most researchers come from continental Europe with a high level of education and belong to Generations X (born in the 1960s and 1970s) and Y (born in the 1980s and 1990s). For instance, no elderly or impaired representatives were involved in the process. It is commonly acknowledged that one's personal and cultural background influences one's thinking, leading to biases and influences within scenario planning. Working with a more diverse scenario team can help tackle that limitation.

Another limitation is the scenario development method per se within forward-looking research. Based on a proven research approach, the technique can shed light on uncertainty and show possible future development paths and underlying trends and drivers. This technique can also support decision-makers and complement other sources. It cannot provide robust forecasts of, for instance, the growth rate of year-on-year air traffic volume until 2030. Additional sources and a combination with other methods have to be considered for a more precise picture. Further work with the presented scenarios may include their quantification to achieve scenario-specific annual air transport growth factors, i.e., annual RPK growth factors. This step would quantify the COVID-19 influence on air traffic, aircraft fleet structures, and aviation emission development using an evolutionary fleet development model and emission analysis. The individual results should be accompanied by the findings of other authors, who, for example, depict changes in aircraft retirement and fleet introduction behavior following the current crisis, as analyzed by Wenzel (2021). Another level of detail could be added to the issues discussed in the current paper, concretizing them toward specific technical questions while at the same time broadening the results into a long-term relevance that extends beyond the direct consequences of the COVID-19 pandemic.

5.2. Summary

This paper presents three scenarios for post-COVID aviation in a highly uncertain environment, including drivers and paths for recovery from the current crisis. A diverse group of postgraduate students under the supervision of aviation professionals prepared the scenarios. An expected result is the interrelation between the pandemic development and the recovery of the aviation sector. A long-term pandemic, as foreseen in Scenario C, implies the highest burdens for aviation's future development. Here, society's perception of health security and hygiene awareness plays an essential role. This is evidenced by the comparison of Scenarios A and B. While Scenario B shows the earliest and most complete containment of the pandemic, Scenario A experiences the highest air traffic growth, owing to a lower importance society assigns to the effects of COVID-19 and higher trust in the effectiveness of hygiene measures.

A further main observation is a possible decoupling between the economic and air traffic development following the pandemic. This unusual behavior is linked to a fast economic recovery (e.g., for Germany Ademmer et al. (2021)) in many sectors, while at the same time, aviation is among the sectors most severely affected by the pandemic and recovering only slowly. The validity of this observation should be closely followed during the recovery process. Considering historic correlations, a return of the coupling of growth in aviation and the general economy seems likely.

Our scenarios further indicate that dealing with the effects of the COVID-19 pandemic is highly intertwined with environmental considerations. We observed strong interrelations between the pandemic development, resulting in societal behaviors and ensuing political action. Rapidly adopting new, eco-friendly propulsion technologies within a healthy air transport market was only possible with determined financial state support for aviation coupled with strong environmental targets. If such directed state support is missing and the societal priority is on recovery from the current crisis, companies focus on economic recovery by finding new investors but with less rigid environmental commitment. Finally, a long-lasting pandemic leads to a decline in demand and, subsequently, the business of airlines and OEM due to limited financial means. Without state support, the introduction of environmentally sustainable technologies, although requested by society and customers, proves difficult. The dual strategy of providing financial support for troubled airlines and strong investment commitments in environmentally sustainable propulsion technologies, as implemented by some European countries, appears as a valid approach for establishing a strong and more environmentally friendly aviation industry. The development toward digitization in aviation is expected to remain, however, just as environmental sustainability, following mainly passenger expectations and the general financial ability of airlines for investments in new technology.

The presented scenarios reference the range of possible pandemic influences on aviation and pathways for its post-COVID recovery. They shed new light on the range of plausible developments in the interplay of the recovery from the pandemic and the path toward eco-friendly aviation. Constant tracking and comparison with actual developments help check the validity of the assumptions made and give indications for an improved assessment of future crises. The presented scenarios and their implications build the starting point for further studies quantifying the pandemic impact on air traffic.

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Appendix: Consistency Matrix

The consistency matrix uses the key scenario factors outlined in Table 3 with the projections shown in Table A.1.

Table A.1
Key scenario factors and projections

Factor	Projections
1 Passenger demand	A: Stagnation (average growth < 2.2% p.a.) B: Moderate growth (average growth 2.2-3.2% p.a.) C: Strong growth (average growth > 3.2% p.a.)
2 Environmentally friendly propulsion systems and fuels	A: Little usage of SAF / evolutionary development of propulsion systems B: Strong usage of SAF / evolutionary development of propulsion systems C: Little usage of SAF / revolutionary development of propulsion systems D: Strong usage of SAF / revolutionary development of propulsion systems
3 Operational intervention into air traffic	A: Keeping of existing processes B: Mostly regional, moderate interventions C: Global, drastic interventions
4 Environmentally aware traveling	A: Little change in travel habits B: Moderate change in travel habits C: Strong change in travel habits
5 Development of kerosene price	A: Rising (> +5% p.a.) B: Constant (±5% p.a.) C: Sinking (< -5% p.a.)
6 Teleworking / Mobile working	A: Strong increase B: Moderate increase C: No increase
7 Trade policy / Globalization	A: KOFecon.[7] < 55 B: KOFecon. = 55…65 C: KOFecon. > 65
8 COVID-19 travel regulations	A: Large discrepancies, isolationism through regulations B: Bilateral agreements, hygiene rules remain in the mid-term C: Harmonization successful, hygiene rules adopted D: Post-COVID: Rule withdrawal and plan for future pandemics
9 Economic development	A: Recession & recovery in L-form; long-term stagnation (ca. 1% p.a.) B: Recession & recovery in W-form; long-term low growth (ca. 2% p.a.) C: Recession & recovery in U-form; long-term moderate growth (2-3% p.a.) D: Recession & recovery in V-form; long-term strong growth (>3% p.a.)
10 Global pandemic development	A: Persistent or renewed threat by mutations / new pandemic B: Isolated regional outbreaks C: Global pandemic contained until 2025
11 Changes in airline customer service driven by COVID-19	A: Short-term change of customer service B: Permanent change of customer service with extra charge C: Permanent change of customer service as a new revenue source
12 Customer / Passenger Structures	A: Share of business travel increases, strong decline in leisure travel B: Share of business travel decreases, increase in leisure travel C: Distribution of shares like in 2019

The resulting Consistency Matrix is depicted in Fig. A.1 on the following page. The consistency is expressed by values on a scale ranging from 1 (total inconsistency) to 5 (strong mutual support), with a value of 3 depicting independent factors.

[7] KOF Index of Globalization

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Consistency Matrix	Key Scenario Factors	1			2				3			4			5			6			7			8				9				10			11		
Key Scenario Factors	**Projections**	A	B	C	A	B	C	D	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	D	A	B	C	D	A	B	C	A	B	C
2	A	3	3	3																																	
	B	3	4	3																																	
	C	3	4	3																																	
	D	2	4	4																																	
3	A	3	3	3	4	3	2	2																													
	B	3	3	3	3	3	3	3																													
	C	3	3	3	2	4	4	4																													
4	A	3	4	4	3	3	2	2	5	4	1																										
	B	3	3	3	2	3	3	4	4	5	2																										
	C	4	2	1	2	4	4	5	1	2	5																										
5	A	4	3	2	3	4	3	4	2	3	5	3	2	3																							
	B	3	3	3	3	3	3	3	3	3	3	3	3	3																							
	C	2	3	4	4	2	2	2	4	3	1	3	4	3																							
6	A	4	3	3	3	3	3	3	3	3	3	2	3	5	5	3	1																				
	B	3	3	3	3	3	3	3	3	3	3	3	4	3	4	3	2																				
	C	3	3	3	3	3	3	3	3	3	3	4	3	1	1	3	5																				
7	A	5	2	2	3	3	3	3	4	2	1	2	3	4	5	2	5	3	3	3																	
	B	2	4	4	3	3	3	3	3	4	2	4	3	3	2	3	2	3	3	3																	
	C	1	4	5	3	3	3	3	2	2	5	4	3	1	5	2	5	3	3	3																	
8	A	5	2	1	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	2	5	2	1														
	B	4	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3														
	C	2	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	4	5														
	D	1	4	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3														
9	A	5	2	1	5	2	2	1	5	2	1	5	2	1	1	1	5	3	3	3	3	3	3	5	3	2	2										
	B	4	3	2	4	3	3	3	4	3	2	4	3	2	2	2	4	3	3	3	3	3	3	4	3	3	3										
	C	2	3	4	3	3	3	3	2	3	4	2	3	4	4	4	2	3	3	3	3	3	3	2	3	3	3										
	D	1	4	5	2	3	4	4	1	4	5	1	4	5	5	4	1	3	3	3	3	3	3	1	3	4	4										
10	A	5	2	1	4	3	2	2	4	3	2	4	3	2	1	2	5	5	4	2	4	3	2	4	4	3	1	5	3	2	1						
	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	4	4	2	1	4	3	3	3						
	C	1	4	5	2	3	4	4	2	3	4	2	3	4	4	4	1	3	3	3	2	3	3	1	1	4	5	3	3	3	4						
11	A	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	5			
	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4			
	C	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	4	3			
12	A	5	2	1	3	3	3	3	2	3	4	2	3	5	4	2	1	2	2	3	2	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	B	4	3	2	3	3	3	3	4	3	2	3	3	3	2	3	4	4	4	2	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	C	3	3	3	3	3	3	3	4	3	2	5	3	2	2	4	2	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Fig. A.1. Consistency Matrix.

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HIGHLIGHTS

- Aviation scenarios for 2030 support decision-making in the face of uncertainty
- Holistic system view based on pandemic-related, environmental, and societal factors
- Pre-crisis traffic levels assumed to be reached in 2023 earliest and by 2026 latest
- COVID-19 hygiene measures in place by at least 2024, some measures become permanent
- In all scenarios, high environmental consciousness requires a sustainability push

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