D3.1 – Heuristics Approach for Environmental Impact Assessment of Technology Roadmaps and Technology Taxonomy & Mapping

Document Author(s)	Helen Szöke-Erös (DLR)
Document Contributor(s)	Patrick Ratei (DLR), Lukas Weber (DLR), Lukas Söffing (NLR), Mario Solazzo (CIRA)

Abstract

Aim of this deliverable is to propose a technology taxonomy categorizing them in terms of aerodynamics, structural, systems and propulsion technologies and their associated benefits. As well as to propose a suitable heuristic approach to collect, compare and analyse existing technology roadmaps on reducing environmental impact from government agencies or projects.

Both a technology and a roadmap database have been proposed and then derived in this work. Key findings, emerging trends and patterns are identified and presented. Additionally, the findings are summarized and an outlook is given on how technologies and roadmaps can be scouted, analysed and explored in future works.

This deliverable builds on parallelly on-going activities in the CLAIM project:

- Comprehensive literature review and analysis of the existing and publicly available advanced aircraft concepts and architectures
- Compiling an inventory of advanced purpose-built research facilities or test aircraft/demonstrators.

Keywords

Technology Roadmap, Technology Taxonomy, Technology Database

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Authoring & Approval

Prepared by		
Name & Organization	**Position and title**	**Date**
Helen Szöke-Erös (DLR)	WP3 Task Lead	2024-08-09

Reviewed by		
Name & Organization	**Position and title**	**Date**
Prajwal Shiva Prakasha (DLR)	Project Coordination Team	2024-08-30
Lukas Söffing (NLR)	WP3 Lead	2024-08-22
Mario Solazzo (CIRA)	WP3 Task Lead	2024-08-24
Patrick Ratei (DLR)	WP3 Task Lead	2024-08-30
Pascal Bertram (DLR)	WP3 Participant	2024-08-26
Lukas Weber (DLR)	WP3 Participant	2024-08-26

Approved for submission by		
Name & Organization	**Position and title**	**Date**
Prajwal Shiva Prakasha (DLR)	Project Coordination Team	2024-09-23

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Acronyms and Abbreviations

Acronym / Abbreviation	Description / Meaning
A*STAR	Agency for Science, Technology and Research of Singapore
ATAG	Air Transport Action Group
ATI	Aerospace Technology Institute
ATM	Air Traffic Management
DLR	German Aerospace Centre, German Aerospace Centre
EASA	European Union Aviation Safety Agency
ECAC	European Civil Aviation Conference
EIS	Entry Into Service
EUROCONTROL	European Organization for Safety of Air Navigation
GHG	Greenhouse gas
GLA	Gust Load Alleviation
HTP	Horizontal Tail Plane
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
JAA	Joint Aviation Authorities
JAXA	Japan Aerospace Exploration Agency
LCA	Life Cycle Analysis
LR	Long Range Aircraft
LR+	Ultra Long Range Aircraft
LTAG	Long-term Aspirational Goal, Long-term Aspirational Goal
MLA	Maneuver Load Alleviation
NLR	Netherlands Aerospace Centre
nVPM	Non-volatile particulate matter
SMR	Short and Medium Range Aircraft
TE	European Federation for Transport and Environment
TRL	Technology Readiness Level
UAV	Unmanned Air Vehicle
VTP	Vertical Tail Plane

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1. Introduction

Aim of this deliverable is to categorize these concepts in terms of aerodynamics, structural, systems and propulsion technologies and their associated benefits. This shall be linked to a technology mapping exercise according to an appropriate technology taxonomy and compared to the Clean Sky, Clean Sky 2 and Clean Aviation technology mapping. As well as to propose a suitable heuristic approach to collect, compare and analyse existing technology roadmaps on reducing environmental impact from government agencies or projects.

This deliverable builds on parallelly ongoing activities in the CLAIM project on:

- Comprehensive literature review and analysis of the existing advanced aircraft concepts and architectures publicly available, including their predicted performance improvements and greenhouse gas reduction potential versus a well-defined reference aircraft and compiling a list and short description of recent or ongoing research programmes related to those architectures worldwide, especially addressing hybrid-electric and hydrogen for aviation
- Compiling an inventory of advanced purpose-built research facilities or test aircraft/demonstrators, worldwide, especially addressing hydrogen for aviation as well as more electric aircraft or hybrid-electric technologies highlighting the criteria adopted.

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2. METHODOLOGY

This deliverable has been created in four methodological steps: first a scouting for technology roadmapping has been conducted, followed by the derivation of technology and roadmap taxonomies to be used in this project. Then, the technology and roadmap databases have been created, followed by the analysis and comparison of collected technology roadmaps.

As for the terminology of “Technology Roadmaps” the goal of this report is to obtain as much information on future and on-going research technologies as possible. Therefore, not only “classical” technology roadmaps regarding the definition of Bernal et al. 2009 (see Figure 1) have been included in this report but also aviation strategies, pathways and projections of in sector technologies into the future have been considered for this work. Also included are transition strategies towards sustainable aviation with aviation technology sections. One example are the technologies mentioned and aligned in the ATAG 2021 Waypoint 2050 (see Figure 2, technology section in blue). These strategies, pathways and projections have been considered in this report independent of a defined quantifiable goal in the future, see section 2.2.

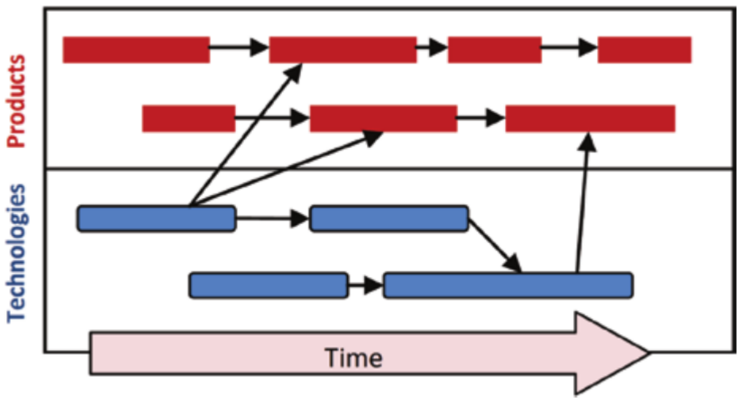

Figure 1: "Simple" technology roadmap (Bernal et al. 2009)

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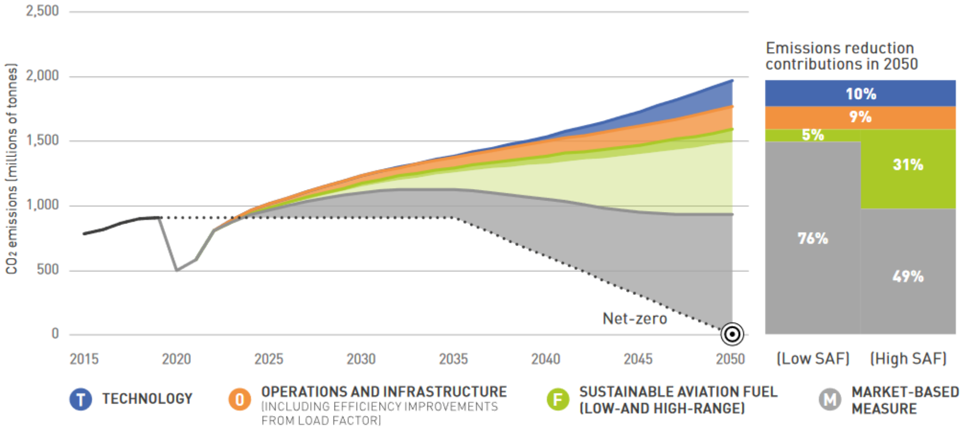

Figure 2: Example scenario from Waypoint 2050, scenario 0: baseline / continuation of current trends (ATAG 2021)

2.1. Scouting Approach for Technology Roadmaps

For the scouting of technology roadmaps, a literature review has been conducted including the search for:

- Aviation technology roadmaps
- Aviation technology (transition) strategies
- Aviation technology (future) pathways
- Aviation technology (future) projections

The considered international authorities are:

European Union Aviation Safety Agency (EASA), European Civil Aviation Conference (ECAC), European Organization for Safety of Air Navigation (EUROCONTROL), International Civil Aviation Organization (ICAO), Joint Aviation Authorities (JAA), FAA International Aviation, Civil Aviation Authorities (national), Agency for Science, Technology and Research (Singapore, A*STAR), Japan Aerospace Exploration Agency (JAXA).

The considered (non-governmental) Associations/ Councils/ Groups are:

International Air Transport Association (IATA), Air Transport Action Group (ATAG), International Council on Clean Transportation (ICCT).

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The search has also been carried out reviewing consortium internal sources as well as the literature databanks Scopus, Web of Science and The Lens.

2.2. Derivation of Taxonomies

This section describes how roadmaps and technologies will be classified and how their taxonomies are derived.

2.2.1. Derivation of Roadmap Taxonomy

In order to collect analyse and compare existing aviation technology roadmaps, strategies and pathways following classification criteria are used:

- **Name**
- **Author**
- **Date**
- **Literature Reference**
- **Theme(s)**

Many of the collected roadmaps/ strategies/ pathways do not only have technology sections but also touch on various climate impact mitigation measures such as alternative fuels, operational measures and marked based measures (as an example see Figure 2). For this work, it is documented whether the different roadmaps/ strategies/ pathways have multiple themes and which themes are considered. The strong focus for this report remains however on the technology sections.

- **Reference/ Forecast Scenario**

If used: Aviation traffic-, emission-, market-forecasts and carbon budgets.

- **Goal**
- **Considered Time Horizon**
- **Viewpoint(s)**

As proposed by Phaal et al. 2009 a technology roadmap framework can capture a meta-view of different types of roadmaps. Roadmaps can therefore be considered from different

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viewpoints: commercial and strategic, design and development and production and technology research (see Figure 3).

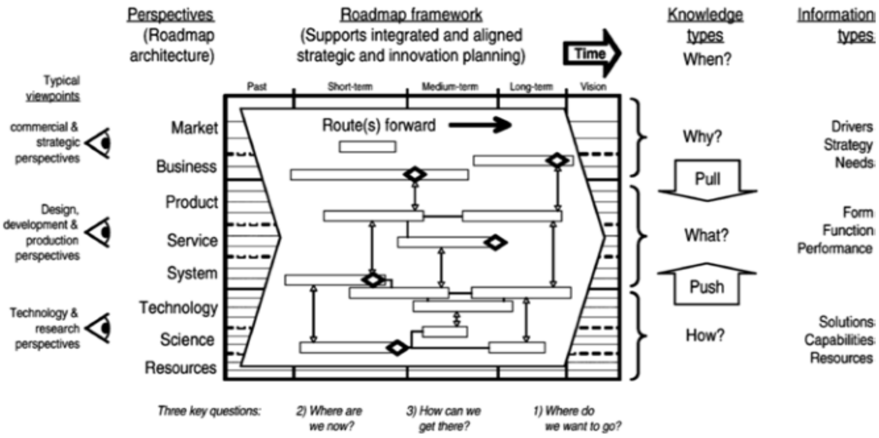

Figure 3: Potential framework to capture roadmapping viewpoints (Phaal et al. 2009)

- **Considered Technologies**
- **Technology Alignment/ Combination**
- **Monetary Cost-Effectiveness**
- **Alignment with Policies**
- **Emerging Trends**
- **Considered Emissions (CO_2 and/ or non- CO_2 emissions)**
- **Achievement of defined Goal**

The aim of the proposed technology roadmap taxonomy is to enable fast and relatively easy analysis and comparisons of various aviation technology roadmaps/ strategies/ pathways from different authors and different intentions.

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2.2.2. Derivation of Technology Taxonomy

In order to collect analyse and compare existing and future aircraft technologies, architectures and concepts following classification criteria are used:

- **Technology / Architecture / Concept Name**
- **Category**
  - **Aerodynamics**
  - **Propulsion**
  - **Systems**
  - **Structural**
  - **Architecture**

    Geometric arrangement and location of aircraft components such as fuselage, wings, HTP, VTP, landing gear, propulsion system
  - **Concept**

    A combination of technologies and possible architectures, usually combined to reach a certain (performance or emission) goal
  - **Air Traffic Management (ATM)**
  - **(Aero) Acoustics**
- **Short Description**
- **Entry into Service (EIS) conservative and progressive**
- **Lifetime**
- **Interdependencies (with other Technologies/ Architectures/ Concepts)**
- **Technology Readiness Level (TRL)**

  The TRL can vary from 0 where technology research has not yet started to 10 where the technology is available and in service.

- **Market Segment**

  Possible and usual market segments in civil aviation can be: Short and Medium Range Aircraft (SMR), Long Range Aircraft (LR), Ultra Long Range Aircraft (LR+), Supersonic aircraft, Unmanned Air Vehicle (UAV), (Sub-)Regional Jets, Business Jets.

- **Literature Reference**

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- **Technology Reference**

The technology references determine against which (already existing) technology/ architecture/ concept the new technology is being measured or compared with.

- **Estimated Market Penetration**
- **Considered Benefits**

  Possible climatological, environmental, social and economic benefits expressed in physical units can be:

  - Fuel burn or flow reductions and direct CO_2 emission reductions due to reduced drag, weight or improved lift characteristics, or increased efficiencies
  - Non-CO_2 emission reductions due to reduced fuel burn, or due to reductions in NO_x, particulate matter, water vapor emissions or reduced contrail formation. If given or used: Climate metrics for CO_2 equivalent estimations.
  - Noise reductions
  - Air quality, health and safety improvements
  - Connectivity, accessibility and effectiveness improvements
  - (Seat-) Capacity improvements
  - Propulsion improvements possible due to more fuel compatibilities, potential for new energy sources

  The focus for the CLAIM project remains on fuel burn and non-CO_2 emission reductions.

- **Uncertainties of considered Benefits**

  Quantification of the uncertainties of the possible considered benefits mentioned above.

- **Scope of considered Benefits**

  The scope of considered benefits in terms of Life Cycle Analysis (LCA): Tank to wake, well to wake.

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- **Development of considered Benefits**

  Evaluation of the benefit development during the scope and technology lifetime. Possibly dependencies of the considered benefits on local or temporal circumstances.

- **Location of Emission**

  Estimation of flight phases or location (longitude, latitude, altitude) of the emissions or where the benefit effects can be expected.

In order to estimate a technology's environmental impact, e.g. in terms of temperature change due to different aviation emissions emitted into the atmosphere, the amounts, location as well as atmospheric background concentrations, weather situations and interactions between weather and emissions need to be known. In this deliverable of the CLAIM project the scope includes only the very top level of Figure 4: the emission level. Work package 2 of CLAIM investigates aviation suitable climate metrics and the potential use of simplified metric approaches.

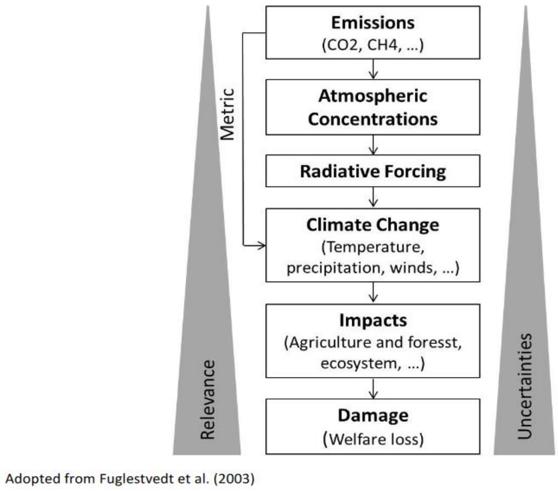

Figure 4: Schematic explanation of climate impacts and metrics (Niklaß et al. 2020)

This methodology for both roadmaps and technologies is meant to build towards future environmental technology and roadmap assessments. In the framework presented in Figure 5 the systematic collections and databases of technologies and roadmaps enable the analysis and comparison of different roadmaps (light blue box). From the left- to the right-side roadmaps are structured with their respective timelines and goals (according to section 2.2.1)

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and the technology database (see section 2.2.2) can serve as first input for the top to bottom technology assessments. Note that the timelines can differ for different roadmaps, Figure 5 is a schematic view only. In future works the framework can result in key findings and the identification of emerging trends from across various roadmaps including multiple technologies.

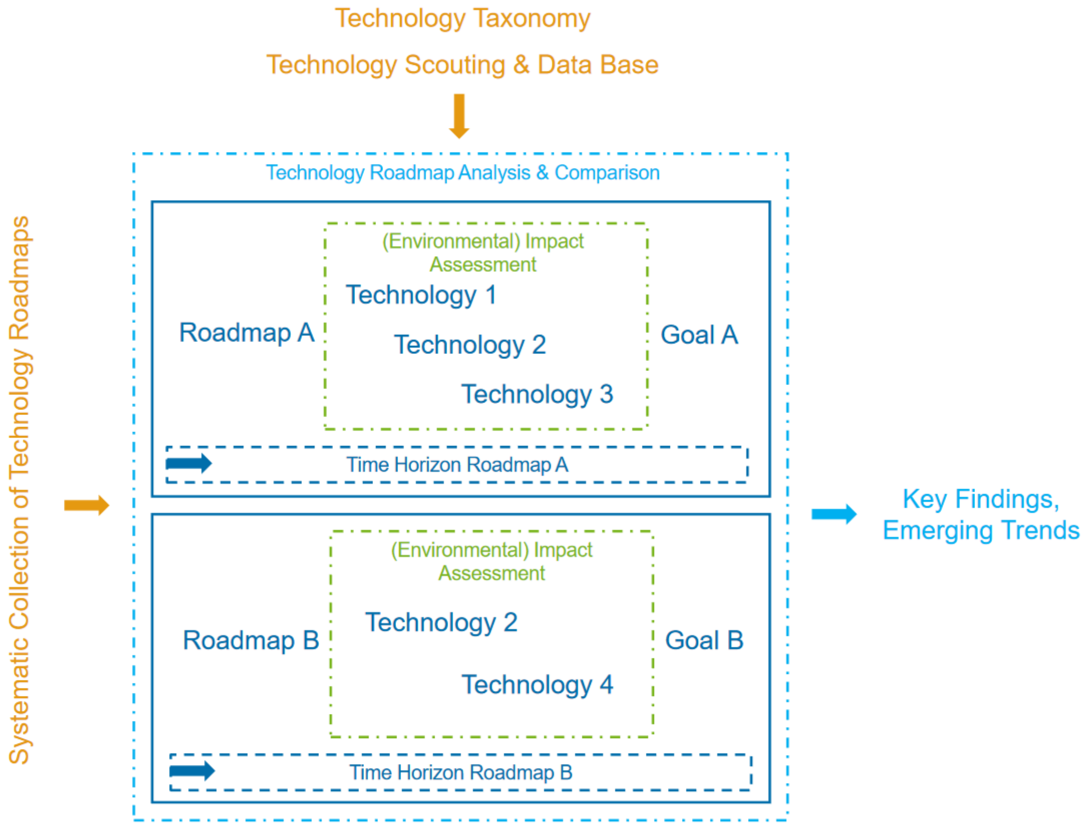

Figure 5: Framework for roadmap and technology analysis and comparison

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2.3. Derivation of Roadmap and Technology Databases

The technology roadmap database as well as the technology database have been created using Excel spreadsheets in order to collect and organize information mentioned in sections 2.2.1 and 2.2.2 for each technology and roadmap.

2.4. Analysis & comparison of Roadmaps

In order to compare and analyse technology roadmaps heuristic analysis techniques are applied, for example pattern recognition or common themes across multiple roadmaps. The goal is to identify emerging technologies, trends, or strategies that are consistently mentioned to highlight promising approaches, generate insights and being able to suggest areas for further research and collaboration.

Note: Strategies/ pathways for modelling future aviation emissions have recently been analyzed by IATA in 2024 (Aviation Net-Zero CO2 Transition Pathways – Comparative Review). IATA's review gives more detailed information on modelling approaches, boundary conditions and assumptions taken in the models by various authors. This CLAIM report will focus on the technology collection and alignments from the sources listed in 3.1.1.

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3. Results

This chapter summarizes the results from the collection, comparison and analysis of technology roadmaps, as well as the results from the derivation of the technology database using the methodology described in chapter 2.

3.1. Technology Roadmaps & Data Base

According to the scouting approach described in section 2.1 a set of technology roadmaps/ strategies/ pathways have been collected and used as inputs for the Excel roadmap database. The main focus while collecting information from the roadmaps, in addition to basic information, were the considered technologies, their alignments, emerging trends and results.

3.1.1. List of collected Roadmaps

In total 17 aviation technology roadmaps/ strategies/ pathways starting from the year 2020 have been identified and selected for this work:

- United States of America: United States 2021 Aviation Climate Action Plan, 2021
- Netherlands Aerospace Centre (NLR): Destination 2050 – A Route to net zero European Aviation, February 2021
- Clean Sky 2 Joint Undertaking: Clean Sky 2 – Technology Evaluator First Global Assessment 2020 Technical Report, May 2021
- ATAG: Waypoint 2050, September 2021
- German Aerospace Centre (DLR): Towards emission free aviation - DLR Strategy for European Green Deal, December 2021
- Clean Aviation Joint Undertaking: Clean Aviation – Strategic Research and Innovation Agenda, December 2021
- EASA: European Aviation Environmental Report 2022, 2022
- ATI: Destination Zero - The Technology Journey to 2050, 2022
- ICCT: Vision 2050 – Aligning Aviation with the Paris Agreement, 2022

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- ICAO: Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO_2 emission reductions, March 2022
- European Federation for Transport and Environment AISBL: Roadmap to climate neutral aviation in Europe, March 2022
- Mission Possible Partnership (MPP): Making Net-Zero Aviation Possible – An industry-backed 1.5°C-aligned transition strategy, July 2022
- Roland Berger: Roadmap to True Zero – A path-breaking approach to bring down aviation's total climate impact, August 2022
- NLR: TRANSCEND D3.2: Novel propulsion and alternative fuels for aviation towards 2050, September 2022
- IATA: Aircraft Technology – Net Zero Roadmap, 2023
- House of Commons Environmental Audit Committee (United Kingdom): Net zero and the UK aviation sector, December 2023
- Aerospace Technology Institute (ATI): Non-CO_2 Technologies Roadmap, April 2024

This report will summarize key findings and emerging trends from all collected roadmaps and give insights on the process of gathering roadmap information.

3.1.2. Key findings from individual Roadmaps

- **United States of America: United States 2021 Aviation Climate Action Plan**, 2021

Goal: "This Aviation Climate Action Plan provides a whole-of-government approach and policy framework for the aviation sector to contribute to broader, economy-wide objectives." (USA 2021)

Key findings:

- Referring to BlueSky FAA office of Environment & Energy aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- No out of sector measures modelled, remaining emissions reduced through SAF uptake to reach net-zero by 2050
- Yearly technology improvements 2019-2030 modelled with 1.1%

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- “While developments in aircraft and engine technology require longer timescales than other measures to realize their environmental benefits, significant improvements in fuel efficiency through the introduction of new and improved technologies are needed to reduce aviation’s climate impact and make our limited supplies of SAF go further. To achieve this goal, the USG is pursuing a sustained major technology development initiative, the SFNP, under which NASA and the FAA will work with industry, to accelerate the maturation of aircraft and engine technologies that enable a step-change reduction in fuel burn and CO_2 emissions (i.e., 25-30% lower fuel burn) by 2030.” (USA 2021)

- **Netherlands Aerospace Centre (NLR): Destination 2050 – A Route to net zero European Aviation**, February 2021

Goal: “Assesses to what extent four groups of sustainability measures are able to reduce carbon emissions until 2050, strongly influenced by policies and actions.” (NLR 2021)

Key findings:

- Aviation future emission scenario modelled (non-CO_2 emissions are not included/ modelled)
- Large technology sections
- Yearly technology improvements 2018-2050 modelled with 1.2%
- With economic measures net-zero is reached in 2050.
- “The measures leading to net zero CO_2 emissions from European aviation need to be realised through collective global policies and actions by governments and industry. Industry should:

  Continue to substantially invest in decarbonisation

  Develop more fuel-efficient aircraft and bring these into operation through continued fleet renewal

  Develop hydrogen-powered and (hybrid-)electric aircraft and associated supporting (airport) infrastructure and bring these into the market

  Scale up drop-in SAF production and uptake

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Implement the latest innovations in ATM and flight planning

Compensate remaining CO_2 emissions by removing carbon dioxide from the atmosphere. Governments should

Support industry investments by direct stimuli or by reducing investment risk through a consistent and long-term policy framework

Stimulate further development and deployment of innovations by funding research programmes and promoting carbon removal technologies

Work with the energy sector to ensure sufficient availability of renewable energy at affordable cost

Support the development of the SAF industry

Contribute to optimising ATM, in particular by fully implementing the Single European Sky." (NLR 2021)

- **Clean Sky 2 Joint Undertaking: Clean Sky 2 – Technology Evaluator First Global Assessment 2020 Technical Report**, May 2021

Goal: "[…] Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness by delivering innovative solutions for the aviation sector. The Technology Evaluator, as a Transverse Activity, has been established as an independent Technology Evaluator for the entire duration of the Clean Sky 2 Joint Undertaking, i.e. until 31 December, 2024." Clean Sky 2 2021)

Key findings:

- Review of performances for various aircraft concepts at mission level compared to relevant reference aircraft from 2014 standards
- Technology alignments and their related benefits for advanced LR, ultra advanced LR, advanced & ultra advanced SMR, advanced turboprop concepts
- Large technology sections
- "[…] Substantial progress has already been achieved and that the programme is well on track. Most of the concepts achieve their target or even exceed it. However, this is a snapshot of the results at programme mid-term. In 2050, reductions of CO_2 emissions

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will amount to about 8-13.5% for the European airports considered, while the associated NOx reductions will be in the range 6.5-10.5%. At fleet level (Air Traffic System), according to the present forecast, approximately 75% of global available seat kilometres (ASK) will be operated with aircraft expected to carry CS2 technologies in 2050, while 25% of global ASKs will still be operated by aircraft with 2014 reference technologies, not yet retired. By applying the performance improvements of the SPD aircraft models, an overall reduction of CO_2 and NO_x emissions of about 15% and 31.0% per seat kilometre can be expected for the year 2050 high fleet scenario as compared to a 2050 global traffic scenario incorporating only 2014 reference technology. As for fleet evolution, in the case of mainliners, the model predicts a major shift towards larger aircraft (301-500 seats) mainly to be used to fly short range (<3000km).” (Clean Sky 2 2021)

- **ATAG: Waypoint 2050**, September 2021

Goal: “Exploring how the sector could meet a greater ambition of reaching net-zero carbon emissions globally by 2050” (ATAG 2021)

Key findings:

- Aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- Yearly technology improvements 2019-2050 modelled with 1.1%
- “Perhaps the single largest opportunity to meet and go beyond the industry’s 2050 goal is the rapid and worldwide scaling up of sustainable aviation fuel and new energy sources. Aviation will need to turn to carbon offsets in the near-term to stabilise CO_2 emissions as it works on long-term, permanent, in-sector reductions through the ramp-up in alternative energy and new technology.” (ATAG 2021)
- With carbon offsetting net-zero is reached in all three scenarios until 2050.

- **German Aerospace Centre (DLR): Towards emission free aviation - DLR Strategy for European Green Deal**, December 2021

Goal: Report on how the European Green Deal can be fulfilled within DLR.

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Key findings:

- Aviation future emission in percentual growth scenario modelled (non-CO_2 emissions are not included/ modelled)
- Technological potentials show climate neutral aviation by 2050 is possible, but all relevant areas need to be connected.
- SAF use can reduce emissions by 80%, technologies and operations can save additional 20%, H_2 is needed for the rest.
- Green Deal can be reached with technology improvements, SAF employment and market-based measures.

- **Clean Aviation Joint Undertaking: Clean Aviation – Strategic Research and Innovation Agenda**, December 2021

Goal: Research agenda, "Clean Aviation Joint Undertaking will contribute to the delivery of Europe's climate neutrality by 2050 by pioneering new solutions in the aeronautics disciplines, addressing the relevant EU policy priorities (e.g. the Green Deal) and supporting the sector-wide European Sustainable Aviation Roadmap. It will trigger a technology revolution that will target climate-neutral aviation in Europe by 2050." (Clean Aviation 2021)

Key findings:

- Technology alignments and their related benefits for regional, SMR, LR aircraft and disruptive technologies to enable hydrogen-powered aircraft (Similar to Clean Sky 2)
- Large technology sections
- "The Clean Aviation JU will develop disruptive new aircraft technologies to support the European Green Deal, and climate neutrality by 2050. These technologies will deliver net greenhouse gas (GHG) reductions of no less than 30%, compared to 2020 state-of-the-art. The technological and industrial readiness will allow the deployment of new aircraft with this performance no later than 2035, enabling 75% of the world's civil aviation fleet to be replaced by 2050. The aircraft developed will enable net CO2 reductions of up to 90% when combined with the effect of sustainable 'drop-in' fuels,

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or zero CO2 emissions in flight when using hydrogen as energy source." (Clean Aviation 2021)

- EASA: European Aviation Environmental Report 2022, 2022

Goal: Report every 3 years to summarize the European aviation environmental developments

Key findings:

- Aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- Wide range of aviation environmental impacts including noise, air quality, climate change and adapting aviation to a changing climate (Non-CO_2 emissions are explained and risks for the aviation sector due to climate change are given)
- Net CO_2 emissions could be halved by 2050 using sustainable aviation fuels, technology and operational improvements and introducing electric and hydrogen aircraft.
- With economic measures net-zero is reached in 2050.

- **ATI: Destination Zero - The Technology Journey to 2050**, 2022

Goal: Guidance - The technological developments required and the potential timeframes to bring aviation closer to Net Zero emissions by 2050. 90% NO_x reduction, 65% reduced perceived noise by 2050 vs 2000.

Key findings:

- Aviation future emission scenario modelled (non-CO_2 emissions are not included/ modelled)
- Detailed technology roadmaps with EIS for "Zero-carbon emission aircraft technologies", "ultra-efficient aircraft technologies" and "cross-cutting enabling technologies"
- Large technology sections
- "Zero-carbon emission aircraft technologies have the largest potential for reducing carbon emissions at the tailpipe for the future. It should remain a top priority to

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accelerate the adoption of zero-carbon aircraft to have the greatest impact by 2050 and ensure the UK is a leader in their development for a greater economic benefit.
Ultra-efficient aircraft technologies considerably reduce the in-flight energy consumption of aircraft. Many will also enable energy savings on zero-carbon platforms.
Sustainable Aviation Fuels have a vital part to play in net CO_2 reductions to 2050. Current and ultra-efficient technology require SAF for net-zero. To have the required impact SAF scale-up needs to happen now, along with mechanisms which close the price gap between these fuels and kerosene.
Cross-cutting technologies could accelerate the introduction of novel aircraft platforms and establish the UK as the global leader for future sustainable aircraft. They will enable zero-carbon, and ultra-efficient technology development, validation, manufacture and adoption" (ATI 2022)

- With synthetic SAF and carbon offsetting net-zero can possibly be reached.

- **ICCT: Vision 2050 – Aligning Aviation with the Paris Agreement**, 2022

Goal: "[…] Present ICCT's scenarios for aviation technology and operations (defined from ICCT's own research) and evaluate the emission impacts of these scenarios using a new global aviation emissions model. Our goal is to assess the extent to which measures can reduce cumulative carbon dioxide (CO_2) emissions from global aviation in line with 1.5 °C, 1.75 °C, and 2 °C targets." (ICCT 2022)

Key findings:

- Aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- Scenario for fulfilling 2°C goal possible but not reaching net-zero by 2050, using different traffic forecasts, aircraft technical efficiencies, payload effects, traffic efficiencies, zero emission aircraft, SAFs and modal change and pricing methods (no out of sector measures).
- Yearly technology improvements 2019-2034 modelled with 1.1% and 2035-2050 2.2%

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- “In the three roadmaps discussed in depth (ICCT, ATAG, and ICAO), the most ambitious scenarios are consistent with a 1.75°C future in which aviation doesn’t increase its share of a global carbon budget.
  CO_2 emissions from aircraft need to peak by 2030 at the latest, and as soon as 2025, to align aviation with the Paris Agreement.
  Cumulative targets, rather than an absolute emissions goal for a given year, would provide greater certainty that aviation contributes fairly to the Paris Agreement.
  Significant investments, driven and rewarded by public policies, will be needed to put aviation on a path to contribute to the Paris Agreement.
  To get to 1.5°C, out-of-sector action and/or significant direct curbs to traffic growth would be needed.” (ICCT 2022)

- **ICAO: Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO_2 emission reductions**, March 2022

Goal: “Explore the feasibility of a long-term global aspirational goal (LTAG) for international civil aviation through conducting detailed studies assessing the attainability and impacts of any goals proposed” (ICAO 2022)

Key findings:

- Aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- In sector measures only (technologies, operations and alternative fuels, no carbon offsetting)
- None of the scenarios reach zero CO_2 emissions by 2050
- Annual technology improvements are modelled with factors of 2018-2050 0.2% to 0.9%.
- The overall traffic growth rate has an important impact.
- Drop-in fuels have the largest mitigation impact on residual CO_2 emissions.

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- **European Federation for Transport and Environment (TE) AISBL: Roadmap to climate neutral aviation in Europe**, March 2022

Goal: "What the sector needs is an urgent and effective suite of measures to arrest its alarming growth in emissions, and to ensure the deployment of new fuels and technologies to put it on the path towards zero climate impact by 2050 at the latest. This report details what these measures should be, and makes the case for their urgent adoption." (TE 2022)

Key findings:

- Aviation future emission scenario modelled (non-CO_2 emissions are not included/ modelled)
- Net zero CO_2 emissions are reached with fuel efficiency improvements, carbon pricing asks, business travel reduction, advanced bio fuels, E-kerosene, hydrogen and electric aircraft and leisure travel management.
- Large cost effectiveness and policy sections
- "To advance towards decarbonisation, we found that flight demand management is essential for several reasons. Firstly, cumulative emissions are what counts for global warming and the aviation sector cannot wait for the alternative fuels supply scale-up in the 2030s and 2040s to start reducing its emissions. We calculated that if aviation traffic keeps growing as expected, there will be 1 Gt CO_2 more in the atmosphere compared to a scenario where demand is managed, even if decarbonisation is reached by 2050.

  Secondly, achieving decarbonisation with only technology improvements and sustainable fuels would require more than one fifth of the EU's projected domestic renewable electricity supply.

  Thirdly, over-reliance on e-kerosene to decarbonise the sector is a risky strategy given that the scale and speed at which this technology will be developed is still uncertain. Finally, cutting flights is the only way to mitigate aviation's total climate impact, something sustainable alternative fuels cannot achieve.

  Clearly, clean fuels will be needed to decarbonise the sector completely. Having the highest efficiency and no emissions, the electric aircraft is a great technological innovation, but will likely have a limited impact due to its physical constraints. Hydrogen propulsion has more potential, but the industry's 20-year long stall in developing the

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technology will likely prevent it from saving more than 10% of emissions by 2050. The project is worth pursuing however, and we have shown that CO_2 savings could be tripled if industry players work urgently to get all the elements right, including the economics. This will be conditional on adequate government regulation and support, and regulation to close the price gap between cheap kerosene and green hydrogen. Policymakers should be motivated by the fact that hydrogen has less non-CO_2 impact than other fuels, that it is simpler to produce than e-kerosene, and that it will require less renewable electricity. For the part of the fleet not running on electricity or hydrogen, sustainable biofuels and e-kerosene will be necessary. Biofuels won't achieve more than 9% CO_2 savings as their feedstocks are limited and hardly scalable. E-kerosene production will thus have to ramp up to supply at least two thirds of the fuel demand by 2050 and achieve one third of CO_2 emissions savings. This would require 650 TWh of renewable electricity, or one eighth of the EU's domestic supply." (TE 2022)

- **Mission Possible Partnership (MPP): Making Net-Zero Aviation Possible – An industry-backed 1.5°C-aligned transition strategy**, July 2022

Goal: "MPP has developed an industry-backed Sector Transition Strategy that outlines how the global aviation sector can reach net-zero GHG emissions by 2050 while also complying with a 1.5°C target." (MPP 2022)

Key findings:

- Aviation future emission scenarios modelled (non-CO_2 emissions are not included/ modelled)
- Net-zero CO_2 emissions reached through fuel efficiency improvements, battery electric, hydrogen power-to-liquid, other bio fuels, HEFA and carbon dioxide removals
- Yearly technology improvements 2019-2030 modelled with 1.5% and 2030-2050 2%
- Large policy section
- "Bringing global aviation on a 1.5°C-aligned path to net zero is possible. It will require substantial annual investments in the order of $175 billion, of which about 95% would be in renewable fuel production, and entail large-scale implications for the energy system. Aviation demand could represent up to 10% of the expected global electricity demand and up to 30% of the expected global green hydrogen demand by 2050.

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Policymakers, financial institutions, and industry leaders need to collaborate to set the course towards 1.5°C and net zero. Early action in this decade is required to unlock technological innovation and economies of scale and to enable large-scale GHG emissions reductions in the 2030s and 2040s. In a joint effort by actors across the value chain, we can make this mission possible." (MPP 2022)

- **Roland Berger: Roadmap to True Zero – A path-breaking approach to bring down aviation's total climate impact**, August 2022

Goal: "Our study demonstrates that it is possible for the aerospace and aviation industry to continue growing, whilst still bringing its total climate impact down." (Roland Berger 2022)

Key findings:

- Aviation future emissions scenario modelled (in CO_2 equivalent emissions, including non-CO_2 emissions)
- Carbon removals are needed to reach net-zero by 2050.
- "By 2030 aviation can reduce its total impact by about 30%. By 2050 by about 75-85%. The industry should agree that non-CO_2 emissions are a major part of aviation's climate footprint. The industry should focus on achieving Coordinated Skies by 2030 through no-regret operational improvements and contrail mitigation. The incremental benefit of a fleet revolution in addition to a fuel revolution — or vice versa — is marginal (~10% CO_2e by 2050). Doing both may not be the optimal solution for society. → The industry should either:
  — Let the "invisible hand of the market" reign, or

  — Discuss benefits of collectively selecting a strategy — fuel, fleet, or both.

  We must act now: our sensitivity analysis demonstrates that the above recommendations do not change regardless of the scientific uncertainty." (Roland Berger 2022)

- **NLR: TRANSCEND D3.2: Novel propulsion and alternative fuels for aviation towards 2050**, September 2022

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Goal: “The TRANSCEND project, within the Clean Sky 2 (CS2) Technology Evaluator, has investigated both novel propulsion technologies and alternative fuels for aviation as potential key technological contributors to climate neutral aviation towards 2050. The strategic recommendations in this report can be taken up by the public and private parties.” (NLR 2022)

Key findings:

- Aviation future CO_2 and H_2O emission scenarios modelled
- Detailed European roadmap for hydrogen-powered propulsion given
- “SAF-powered gas turbine-based propulsion technologies from CS2 and three hydrogen-powered propulsion concepts were selected. These technologies were evaluated with four promising production routes for bio- and waste-based SAFs and two promising production routes for synthetic SAF and green hydrogen. Gross CO_2 emissions reduce up to 20% in 2050 due to the introduction of hydrogen-powered aircraft.” (NLR 2022)

- **IATA: Aircraft Technology – Net Zero Roadmap**, 2023

Goal: Net Zero by 2050 – “This roadmap complements the Waypoint 2050 analysis undertaken by the industry where pathways to meet net zero carbon by 2050 were identified. It provides a more granular analysis of the technology and infrastructure steps needed to meet the global pathways identified in Waypoint 2050 and should be seen as a companion report, alongside the Fuelling Net Zero analysis of SAF deployment.” (IATA 2023)

Key findings:

- Detailed technology roadmaps with EIS on “reducing in-flight energy”, “SAF & hydrogen aircraft” and “Batteries & hybrid aircraft”, no modelling of emission scenarios
- Large technology sections
- “Even in an aggressive hydrogen scenario, only a small fraction of the active fleet by 2050 would be powered by this zero-carbon energy carrier that is hydrogen. From now until then, and for a few decades after, aviation will continue to rely on drop-in hydrocarbon fuels such as SAF. SAF is the only way to curb emissions of the existing

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and near-future fleet of aircraft which amounted to ~30,000 aircraft in 2019, and could reach ~65,000 aircraft in 2050. The scale-up of SAF, and the exploitation of new advanced feedstock pathways, is an absolute necessity for air transport to achieve net zero CO_2 emissions by 2050.

While this roadmap will be revised along the way to 2050 in step with developments and evolving scenarios, it is highly likely that the critical advancements identified here will need to happen. For this to become a reality, the roadmaps pertaining to infrastructure, operations, policy, and finance will also need to advance accordingly, as they are all interdependent. Reaching net zero CO_2 emissions in air transport by 2050 is achievable, and depends on all industry partners and stakeholders being united in this ambition." (IATA 2023)

- **House of Commons Environmental Audit Committee (United Kingdom): Net zero and the UK aviation sector**, December 2023

Goal: "In this report we examine the overall challenges that face the aviation sector as it moves to decarbonise. We make recommendations to Ministers on the steps that need to be taken to ensure that the UK Government can reliably meet its own targets for the contribution of the aviation sector to net zero." (House of Commons 2023)

Key findings:

- Usage of aviation future emission scenario modelled by the Climate Change Committee in CO_2 equivalent emissions
- Future equivalent emissions can be reduced by roughly 50% by managing demand, introducing more efficiencies and hybrid aircraft and SAF.
- Large policy sections
- Recommendations: Active research in total environmental effects of aviation, define emissions and emission sources aviation and shipping, work together with Climate change committee and sustainable aviation on comparative analysis of models underpinning projections for UK AC emissions, improve SAF standards, include non-CO_2 strategies, changes in EU ETS to no free fuel allocations.

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- **Aerospace Technology Institute (ATI): Non-CO_2 Technologies Roadmap**, April 2024

Goal: Give Technology Roadmap until 2050 for: 90% NO_x reduction against year 2000 engines, consensus and short- and long-term goals for SO_x, water vapour and contrails, 90% reduction non-volatile particulate matter (nvPM) mass and number and consensus for other particulates

Key findings:

- Detailed technology roadmap with EIS given as well as roadmaps for fuel characteristics and knowledge & operations
- Large technology sections
- No information whether net-zero is reached. Net-zero is targeted, no emission modelling.

3.1.3. Comparison of Roadmaps

The collected sources can generally be grouped into two different types:

- Emission Scenario models
  (MPP 2021, USA 2021, ICCT 2022, TE 2022, NLR 2021, NLR 2022, ATI 2022, EASA 2022, ICAO 2022, ATAG 2021, DLR 2021, House of Commons 2023, Roland Berger 2022)
- Technology Roadmaps
  (IATA 2023, ATI 2024, ATI 2022)

Following 16 key trends across roadmaps have been identified:

1. Goal to explore pathways or show scenarios for aviation towards net-zero emissions or meeting Paris Agreement
   (ICAO 2022, ATAG 2021, Roland Berger 2022, EASA 2022, ATI 2022, DLR 2021, TE 2022, House of Commons 2023, ICCT 2023, NLR 2022, USA 2021, MPP 2022)
2. Goal to make a Technology Roadmap for net-zero aviation
   (ATI 2024, IATA 2023)

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3. Goal to drive research towards net zero
   (Clean Sky 2 2021, Clean Aviation 2021)
4. SAF employment named as one of the largest potentials for climate effect mitigation
   (ICAO 2022, ATAG 2021, IATA 2023, USA 2021, NLR 2022)
5. In aviation sector net-zero is usually not achieved by 2050
   (House of Commons 2023, ICCT 2022, ICAO 2022)
6. Carbon offsetting is usually needed to reach net zero by 2050
   (ATAG 2021, Roland Berger 2022, EASA 2022, NLR 2022, TE 22, MPP 2022)
7. Fulfilling 2°C goal is still possible
   (CO_2 emissions only: ICCT 2022, Equivalents also: House of Commons 2023)
8. Stressing demand management importance
   (TE 2022, ICCT 2022)
9. Stressing costs of alternative fuels & importance of energy demand management
   (TE 2022, MPP 2022, ATI 2022, ICAO 2022)
10. Technological improvements yearly modelled with values between 0.2% and 2.2%
    (MPP 2022, ICAO 2022, NLR 2021, ICCT 2022, ATAG 2021, USA 2021)
11. Scenario model for CO_2 emissions only
    (MPP2021, USA 2021, ICCT 2022, TE 2022, NLR 2021, ATI 2022, EASA 2022, ICAO 2022, ATAG 2021, DLR 2021)
12. Scenario model for CO_2 equivalent emissions
    (House of Commons 2023, Roland Berger 2022) (NLR 2022 CO_2 and H_2O emissions)
13. Larger sections on cost effectiveness and policy alignment
    (House of Commons 2023, MPP 2022, TE 2022)
14. Larger technology and their alignment sections
    (Clean Sky 2 2021, Clean Aviation 2021, NLR 2021, ATI 2024, ATI 2022, IATA 2023)
15. "Act now" or "accelerate" developments across multiple mitigation measures
    (Roland Berger 2022, TE 2022, ICCT 2022, USA 2021, ATI 2022, Clean Sky 2021, Clean Aviation 2021, DLR 2021)
16. Time Horizon 2050
    (all)

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Table 1: Technology Roadmap Trends

Trend no.	ICAO 2022	ATAG 2021	Roland Berger 2022	EASA 2022	ATI 2024	ATI 2022	DLR 2021	IATA 2023	NLR 2021	TE 2022	House of Commons 2023	ICCT 2022	Clean Sky 2 021	NLR 2022	Clean Aviation 2021	USA 2021	MPP 2022
16	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
15			×			×	×			×		×	×		×	×	
14					×	×		×	×				×		×		
13										×	×						×
12			×								×			×			
11	×	×		×		×	×		×	×		×				×	×
10	×	×							×			×				×	×
9	×					×				×							×
8										×		×					
7											×	×					
6		×	×	×						×				×			×
5	×										×	×					
4	×	×						×						×		×	
3													×		×		
2					×			×									
1	×	×	×	×		×	×			×	×	×		×		×	×

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3.1.4. Discussion & Recommendations

Overall a roadmap database has been created according to the methodology given in section 2.2.1. Key findings from each roadmap are given and from comparing the collected roadmaps 16 trends have been identified and listed. In general, it can be said that all roadmaps/ pathways/ strategies recognize current challenges in aviation with the overall goal to decouple future growth from emissions and their resulting climate effects.

While specific goals, assumptions and reference scenarios can differ across the roadmaps, the main levers are commonly identified as: SAF employment, demand management, technology advances (both fuel efficiency increase and the shift towards zero carbon technologies) and operational measures. In the roadmap modelling, net zero emissions (often CO_2 emissions only) are usually not reached within the sector by 2050. Incorporating non-CO_2 emissions is commonly recognized as a future goal, resulting in the need for even further accelerations of mitigation measures to potentially reach net zero by 2050 with the additional non-CO_2 emissions. Some roadmaps stress the urgency to act now (regardless of the current scientific uncertainties) and have aviation emissions peak before 2030 (ideally even 2025), such as Roland Berger 2022 and ICCT 2022.

Some authors already incorporate non-CO_2 emissions in their future scenarios (Roland Berger 2022 and House of Commons 2023). Due to currently ongoing research activities especially regarding the understanding and quantification of non-CO_2 emissions the number of publications in the upcoming years including these effects in their scenarios is expected to increase.

The technologies and their alignments collected from the roadmaps are used in the derivation of a technology database, see section 3.2.

As an outlook, including, updating and maintaining the generated roadmap database will be beneficial to give a holistic overview, recognize upcoming trend developments as well as to extend and update the on-going technology advances.

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3.2. Aircraft Technology Data Base

According to the proposed technology taxonomy in section 2.2.2, the technologies and their alignments from each roadmap/pathway (see section 3.1.1.) have been collected into a database. After including information from the roadmaps in chapter 3 the database has been compared to-, and extended with information from consortium internal technology databases. Lastly the created technology database has been extended with information gathered in CLAIM task 3.1 (Existing advanced/disruptive aircraft concepts/architectures and related recent and ongoing research projects) and task 3.2 (Advanced and purpose-built research facilities or test aircraft/demonstrators, and aeronautical advanced research activities and technology areas).

3.2.1. Technology Database

In total a number of 117 technologies/ architectures/ concepts have been collected in the technology database. The technologies are grouped into 18 aerodynamic, 36 propulsion, 30 systems, 13 structural, 6 architectures, 7 concepts and 8 ATM and 6 aero acoustics technologies (some technologies are applicable to more than one category, which is why the sum is larger than 117. Given entry-into-service (EIS) vary from today already available technologies to technologies expected in 2050, accordingly TRLs vary from 1 to 10. There are technologies applicable to single market segments and technologies that can be applied across various types of aircraft. The technology references (if given) also vary from technologies from the year 2000 and technologies about to enter service or currently in service. Commonly expected technology benefits cover CO_2 effects due to a reduction in fuel burn, weight, drag or an increase of lift characteristics, noise benefits as well as alternative fuel/ energy compatibility.

This report summarizes key findings and emerging trends from all collected technologies and gives insights on the process of gathering technology information.

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3.2.2. Key Findings

While collecting the technologies and their information it appeared that there are more easily available information categories in the sources than others. They can be grouped into:

More easily available information:

Information such as the technology category, a short description and for which market segment they are being developed could be noted for almost all technologies. For 99 technologies out of the 117 at least one EIS (progressive or conservative) could be collected from the sources. For 54 technologies quantifications for (some of) the benefits could be collected (mainly fuel burn, weight, noise and drag reductions, lift increase or more alternative fuel compatibilities). For 50 technologies TRLs (current and aimed for) were collected. For 30 technologies their respective technology reference was noted. And for 37 technologies interdependencies with other technologies were collected.

Less easily available information:

Quantifications for non-CO_2 benefits (mainly NO_x reductions) could be collected for 9 technologies. For 4 technologies estimated market penetrations were noted. A benefit development until 2050 was collected for one technology only.

Technology uncertainties, the scope of the benefits as well as the location of the emissions and the technology lifetimes could not be collected from the sources.

Progressive technology EIS

Additionally, it can be noted that some sources were more progressive than others in their technology alignment in terms of EIS. It should be noted however that EIS taken from technology roadmaps do not always specify if the EIS is meant to resemble a TRL of 10 or potentially less for the beginning of the market uptake. Following sources were usually introducing technologies (especially aircraft concepts) 5 to 10 years earlier than other sources: NLR 2021, IATA 2023, ICCT 2022, ATI 2022.

Key Concepts

It can also be said that all sources seem to agree on the future aircraft concepts until 2050 as the collected concepts can for all sources be grouped into:

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- Sub-Regional zero-carbon electric aircraft (EIS 2029-2030)
- Regional hybrid electric aircraft (EIS 2029-2040)
- Regional zero-carbon aircraft (EIS 2036-2040)
- Ultra-efficient narrow body aircraft (2033-2040)
- Narrow body zero-carbon aircraft (EIS 2042-2050)
- Ultra-efficient wide body aircraft (EIS 2042-2050)
- Wide body zero-carbon aircraft (EIS 2050)

Key Technology Groups

The collected technologies and in addition to their categories (aerodynamic, structural, etc.) also be grouped into fulfilling following technology goals:

- Hybridisation & Electrification (key technologies, enabling technologies, testing and validation strategies)
- SAF upscaling technologies (infrastructure, research, testing and validation strategies)
- (Liquid) Hydrogen aircraft enabling technologies (both direct combustion and fuel cell propulsion, integration, infrastructure, research, testing and validation strategies)
- ATM and operational technologies (key technologies, enabling technologies, research, testing and validation strategies)
- Knowledge and research needs (research agenda, aimed for TRLs, especially for non-CO_2 research, fuel characteristics and operations)

Frequently mentioned technologies

Throughout the collected roadmaps and according to results from tasks 3.1 and 3.2 from CLAIM, as well as using consortium internal data, following technologies have frequently been mentioned:

Ultra-high bypass ratio engine, composite structures (wings & fuselage), riblets & shark skin paint, active load alleviation, laminar flow control (natural & hybrid), open rotor propulsion, (hybrid-) electric propulsion (including required systems and enablers), hydrogen combustion propulsion (including required systems and enablers), fuel cell propulsion (including required systems and enablers), blended wing body (and hybrid wing body), strut/ truss-braced wing, emission & environmental management instrumentation and systems, water vapour release controls, distributed propulsion, high aspect ratio wing (highly flexible wing, increased span),

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dry wing, advanced turboprop engine, advanced wing tip devices & advanced winglets & morphing flaps, more electric aircraft (including required systems and enablers), advanced systems & ATM.

Resulting Technology Roadmaps according to categories and concepts

In order to visualize some of the collected technology information according to the taxonomy proposed in section 2.2.2. in the following pages technology roadmaps have been derived. In the top section of each roadmap the collected aircraft concepts are visualized with their respective EIS (progressive and conservative) in different colours. Below, a selection of the collected technologies from one category are given with their EIS across the time horizon. Additionally, the coloured dots indicate on which concepts the respective technologies can be integrated.

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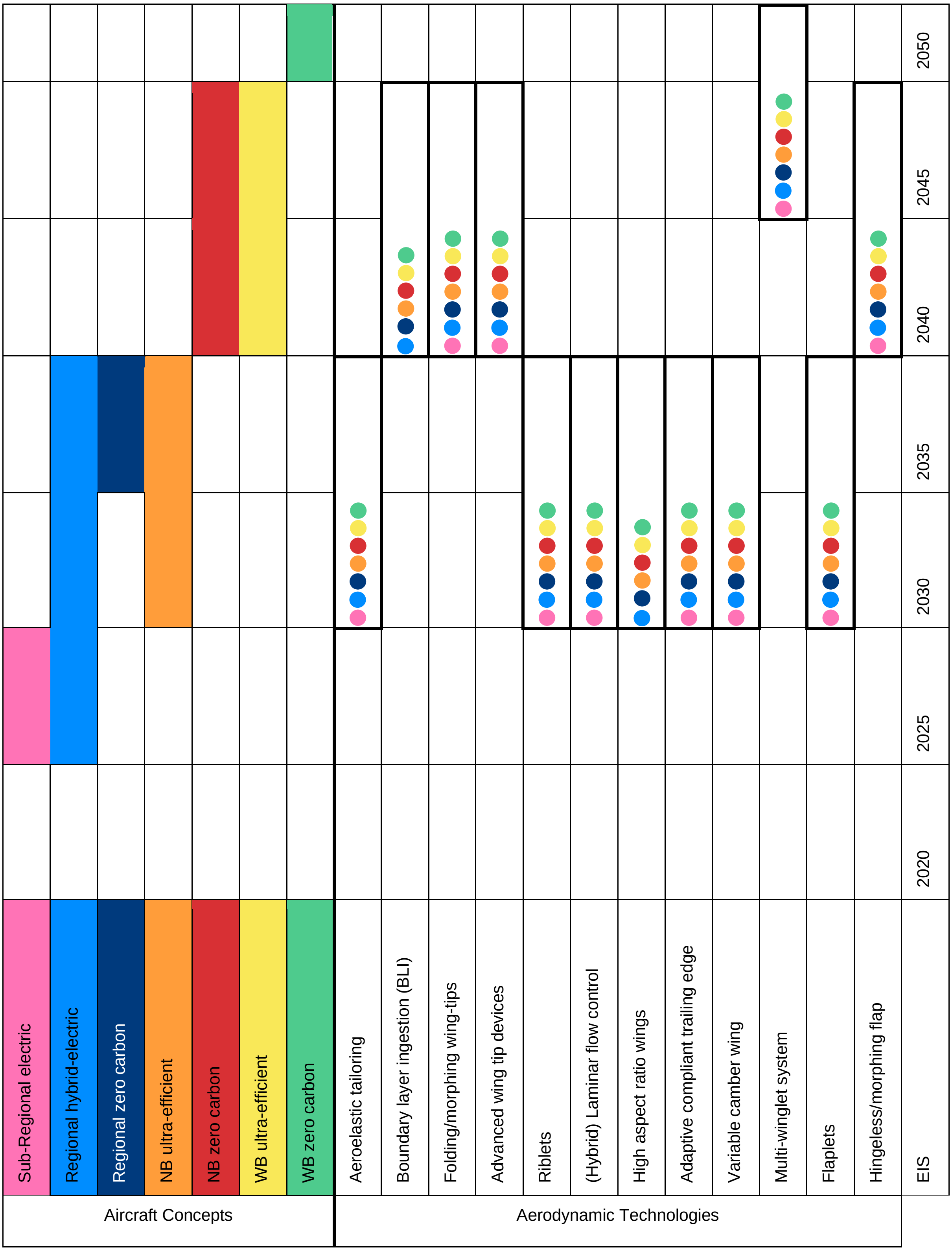

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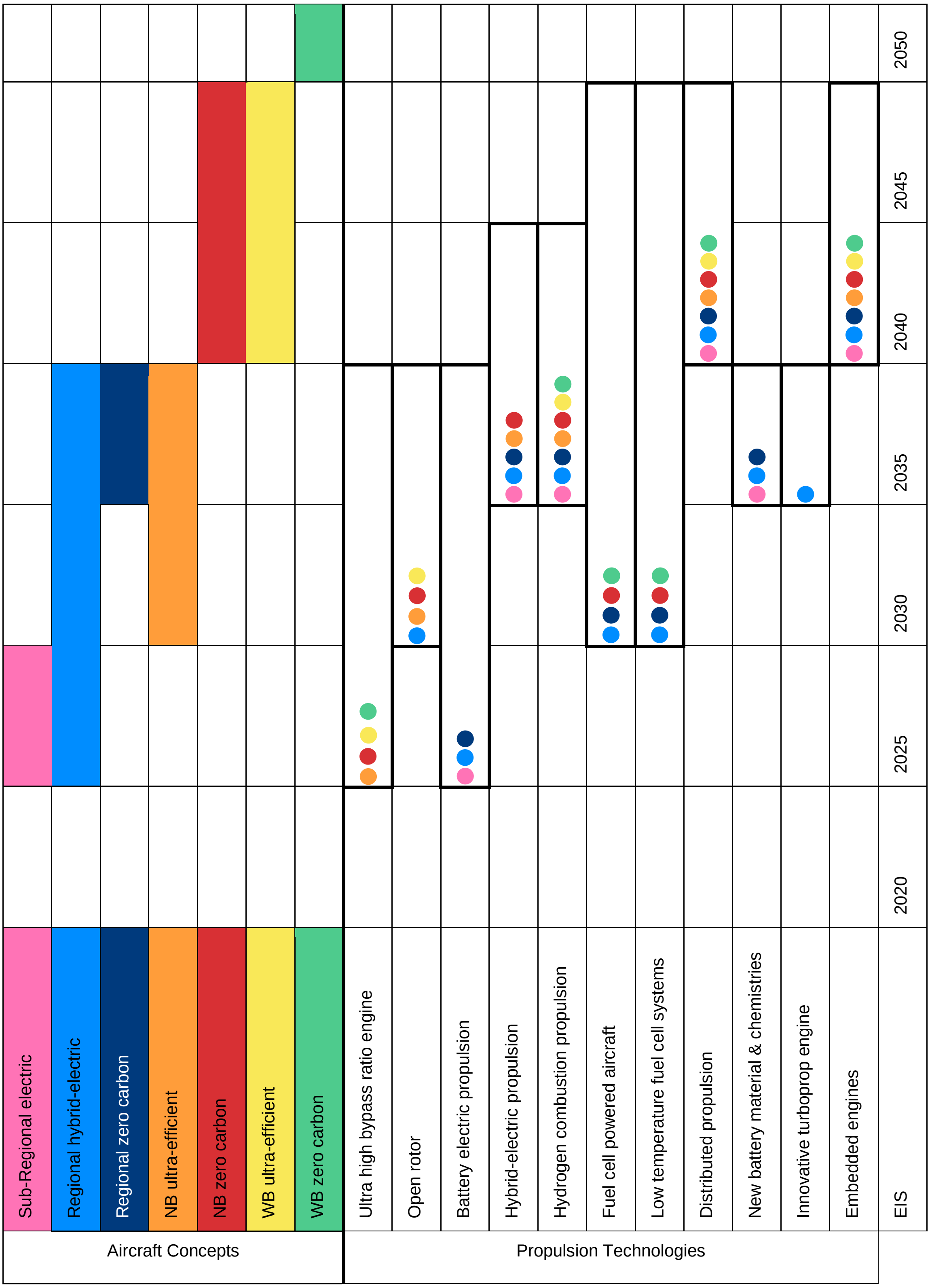

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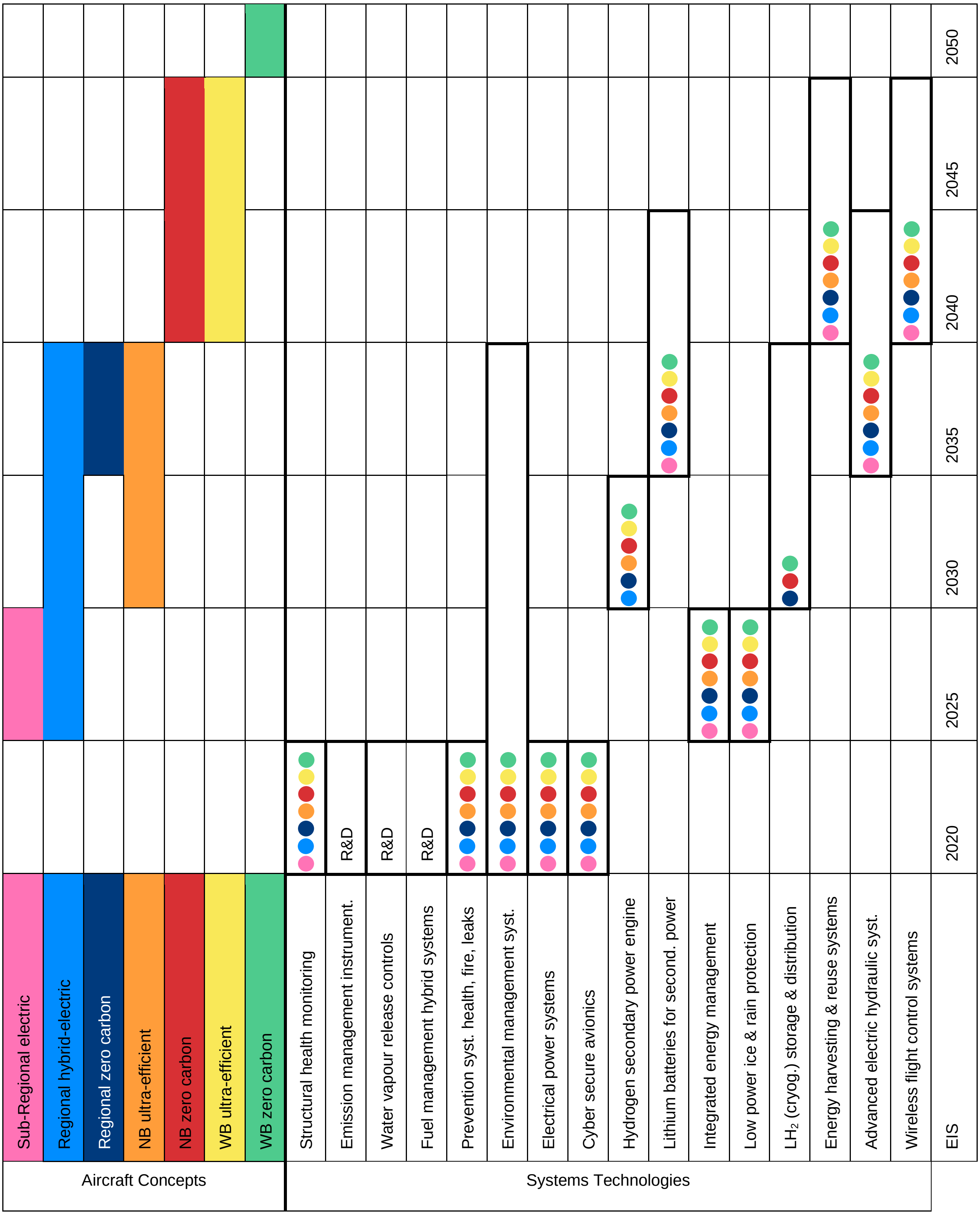

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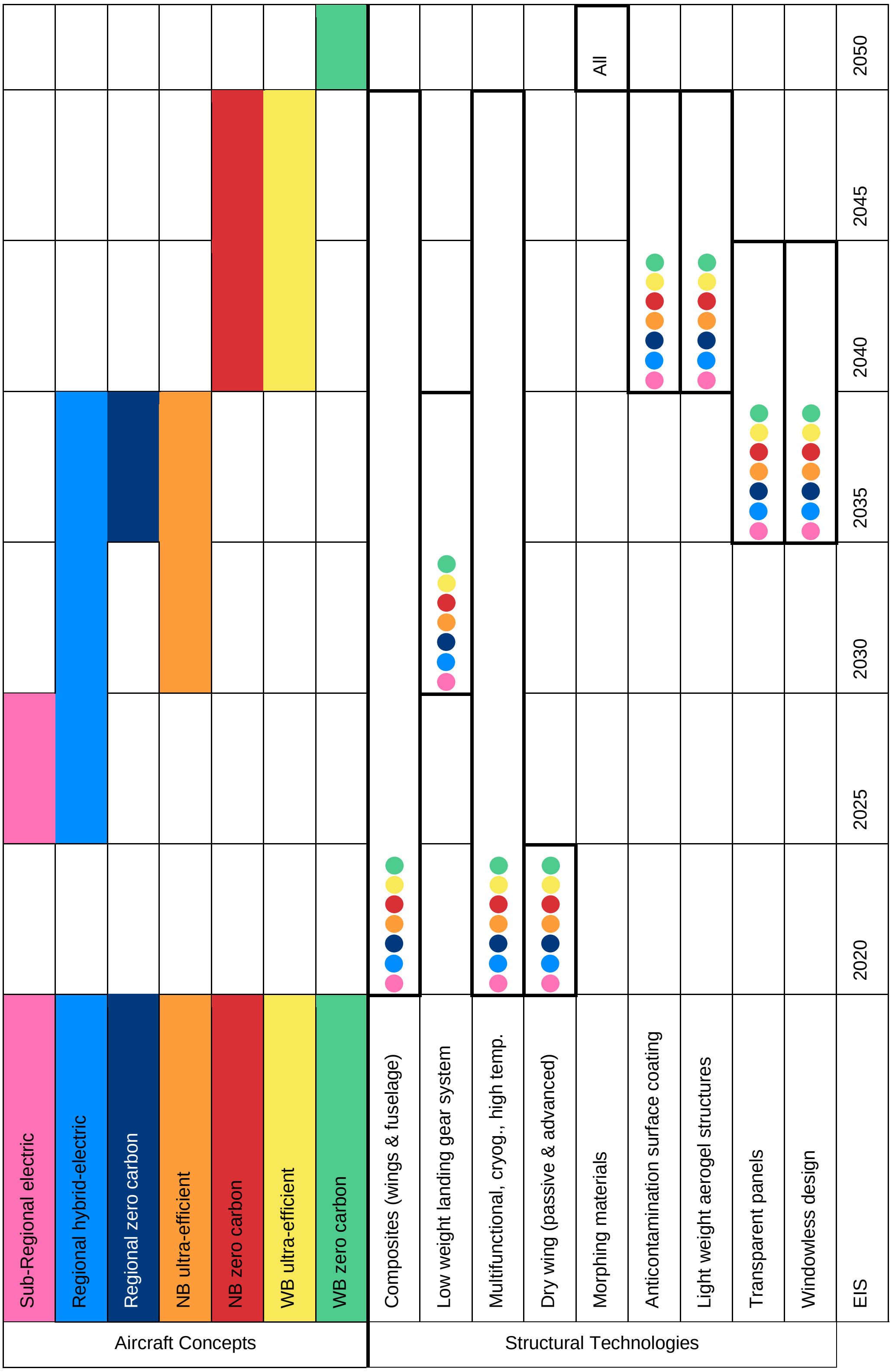

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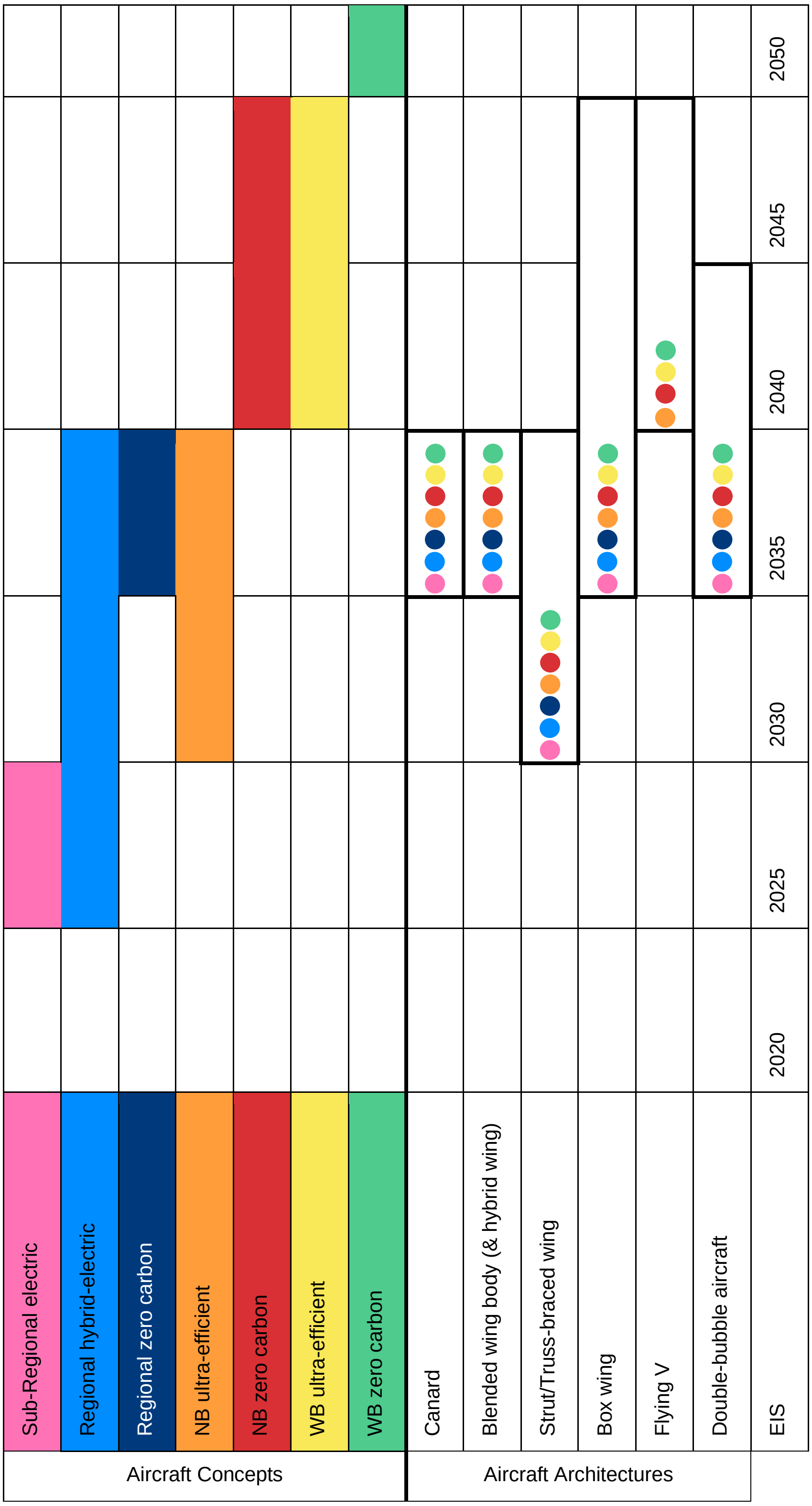

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3.2.3. Discussion & Recommendations

In conclusion, an aviation technology database has been created, using the technologies collected from the roadmap database (see section 3.1) and consortium internal information, including current information from tasks 3.1 and 3.2 of CLAIM. The technologies have been grouped in their respective categories aerodynamics, structural, systems, propulsion technologies, etc., as proposed in the methodology described in section 2.2.2.

From the created database key findings and patterns are recognized and given in this report, including the difficulty to encounter specific information types, identifying more progressive or conservative sources, key technologies and concepts, as well as reoccurring technology groups. Finally, a selection of technologies from the created databank is used to create six technology roadmaps from 2020 until 2050 with respect to the technology categories and potential aircraft concepts the technologies could be implemented in.

The EIS represented in the roadmaps are literature based, as described in chapter 2. It should be mentioned that the EIS window for a technology (e.g. composite structures) can be very large, due to the collection of several sub-technologies (different composite materials) under on technology entry. For other technologies the EIS can vary drastically due to their mention in both more progressive and more conservative sources. Especially the earlier sources (early 2020s or before) and the progressive sources mentioned in section 3.2.2. result in pushing the EIS windows represented in the roadmaps towards years as 2025 and 2030, even 2023, resulting in questionable early EIS from a viewpoint of today. Generally, sources from 2023 and later are more conservative for the upcoming years 2025-2035.

The selected technologies in aerodynamics are mostly expected to enter service beginning with 2030. For the selected propulsion technologies, the EIS vary more in the considered sources, most of the technologies are expected to have entered service by the mid-2030s. Some of the selected systems technologies are already in (or currently prepared to enter) service before 2030, most of them are expected to have entered service by 2040. Similar distributions can be observed for the selected structural technologies, some of them are expected to enter service until 2025 while others have a large EIS range due to different assumptions in sources and a multitude of single technologies and materials collected under one technology entrance. Most selected aircraft architectures are expected to start entering

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service by 2035 or 2040 starting with (sub-) regional, then SMR and LR aircraft are the last to enter the market. Similarly, most of the selected ATM technologies are expected to enter service by 2035.

As an outlook it is suggested to update and maintain the created technology database in parallel to the roadmap database (see 3.1). Thereby, it would also be beneficial to remove unrealistic EIS from older sources with increasing state of the art knowledge and developments in the ongoing and upcoming years. This would enable a more holistic dataset for the technologies and could enable the identification of future trends and patterns.

Lastly, in order to access, explore and use the stored data in future research activities and projects, the export of this database from Microsoft Excel to an interactive and potentially graphically visualization enabling database format is suggested.

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4. Summary & Conclusions

In summary, for both the technology and the roadmap database the methodologies have been proposed in chapter 2 and have then been applied in chapter 3. Both databases have successfully been derived and analysed, giving key findings for each individual roadmap and key findings and emerging trends from their comparison. From the created technology database key findings are given, including information availability, key technology concepts and groups as well as the identification of more and less progressive sources. The technologies can generally be grouped into technologies enabling hybridisation and electrification, hydrogen aircraft, SAF upscaling, and ATM & operations. Finally, a selected set of the technology database is visually represented in technology roadmaps towards 2050 with respect to the technology applicability in key concepts. Here a majority of the selected technologies is expected to enter service during the 2030s, while some others are expected earlier and others later during the 2040s and 2050s.

In conclusion, the aim of this work to categorize technologies and concepts in terms of aerodynamics, structural, systems and propulsion technologies and their associated benefits, as well as to propose a suitable heuristic approach to collect, compare and analyse existing technology roadmaps from government agencies or projects on the topic of environmental impact reduction, has been achieved. Main levers commonly identified in roadmaps are: SAF deployment, demand management, technology advances (both fuel efficiency increase and the shift towards zero carbon technologies) and operational measures. Incorporating non-CO_2 emissions in the roadmaps is commonly recognized as a future goal, therefore the number of publications in the upcoming years including non-CO_2 emissions and effects in the scenarios is expected to increase.

Regarding the project roadmap of CLAIM, it should be mentioned that the technology database will be updated in parallel to the work finalization from tasks 3.1 and 3.2. The current version of this work and the technology database are based on current work statuses from tasks 3.1 and 3.2, that are yet to be completed. Finally, it is suggested to store the generated databases in a non-Excel format. More interactive formats could allow for an easier data exploration, analysis, maintenance and visualisation as well as potentially enable more collaborative features.

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