EREA
Association of
European Research Establishments in Aeronautics

EREA FUTURE OF AVIATION
The scenarios

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Summary

The "EREA Vision Study – The Future of Aviation in 2050" is the update of the previously released "EREA vision for the future –Towards the future generation of Air Transport System" published in 2010. This new study, describing EREA's own vision, has as objectives: (i) to share EREA's vision with external stakeholders to help enhance cooperation; (ii) to form the basis for EREA to support policy makers at national and European level; (iii) to motivate EREA and its members to work together to common and ambitious goals; and (iv) to engage with the general public, particularly on societal needs and sustainability for the aviation sector.

The outcome of the study is presented in two parts:

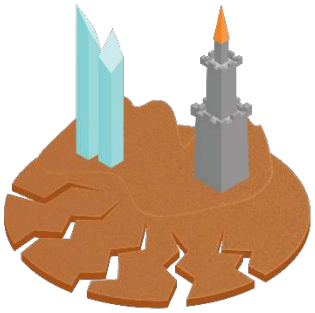
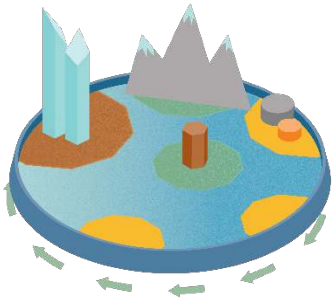
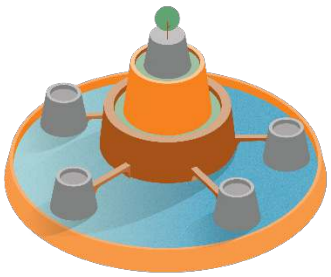
- a first document, which describes the current societal and aviation context and imagines four alternative future scenarios for 2050, exploring how aviation could contribute in each scenario;
- a second document, which provides the technical overview of the research and development (R&D) activities needed to realise EREA's vision for the Future of Aviation.

In the first document, four future, alternative scenarios are presented, built in a series of workshops by a range of EREA experts in the spring of 2020.

Although the four scenarios are all different, they result in common themes about the future of the air transport system:

- The integration of aviation into a broader, comprehensive, transport system. Transportation itself and all ancillary activities will be integrated, resulting in an interconnected, multi-modal transportation solution.
- Drones and urban air mobility vehicles, will become part of the everyday panorama. Their applications will vary greatly depending on specific societal conditions and will cover already-emerging markets, such as logistics and security, and others which have not yet been foreseen.
- An increase in the costs, and consequently in the price of aviation, both for producers and users. Whether it is driven by low demand, internalisation of external costs or by increases in the price of (customised) products, flying will become more expensive.
- An increase in alternative technologies to classic aviation and mobility. Whether out of security concerns or sustainability awareness, travelling and commuting will be reduced and be replaced by digital interaction or by different forms of transportation.
- An increased awareness and demand for security and safety and an increase in related challenges. Either caused by societal instability, by increased aversion to perceived risk or by increases in traffic, safety and security will be paramount aspects for aviation (and all transport modes).

The Scenarios for the Future of Aviation

	**Mad Max** ...aviation: a luxury for the few in a world of consumerism, challenges and conflict	*A world characterised by deglobalisation and fragmentation; extreme nationalism and populism; instability; protectionist economies; high levels of inequality; low sustainability; climate crisis; low levels of R&D.* *Aviation is an expensive, luxurious and highly desirable product but is unreliable due to climate change and different sources of instability. There are few industrial players with no innovation and limited R&D.*
	**Tech for You** ...aviation: side by side alternative technology in islands of choice, competition, and customisation	*A world characterised by multipolarity and competition; high-cost, low economy-of-scale production offset by widespread automation; market driven by consumer choice and desires; free market economies; high R&D with national and short-term focus; different approaches to and meaning of sustainability in different islands.* *Mobility is flexible with air transport part of the local, intermodal transport system. The overall approach is to strive for door-to-door mobility.*
	**Stripping Down** ...aviation: sustainability achieved by a world of centralised command and control	*A world characterised by political stability; command economies; centralised government; prescriptive regulation; slow but stable economic growth; standardisation and uniformity; prioritised and government-directed sustainability.* *There is limited and highly controlled mobility due to high prices, security threats, flight shaming and regulation. Sustainable intermodal generic solutions are enforced. There are few industrial players due to high cost and low demand.*
	**Optimising Together** ...aviation: unlimited freedom in a world of common purpose, collaboration and cohesion	*A world characterised by unification and harmony; global cooperation and collaboration; global legal and institutional frameworks; high stability and growth; sustainability; market-driven economies and liberalisation; high standardisation and confidence.* *Mobility is growing and is fully sustainable. Different aviation solutions are available for all journey segments from UAM through formation flying to sub-orbital flights.*

About this study

This study has created EREA's vision for the Future for Aviation in the year 2050. This Future is used to understand the potential impacts on aeronautical research and development (R&D) activities. The study was performed in the context provided by Flightpath 2050[1], describing Europe's vision for aviation alongside the more detailed strategic research and innovation agenda[2] (SRIA) developed by the Advisory Council for Aviation Research and Innovation in Europe (ACARE).

The complete study is presented in two documents:

- this report, which describes the current societal and aviation context and imagines four alternative scenarios for how the world could look in 2050;
- a second document, which provides the technical overview of the R&D activities needed to realise EREA's vision for the Future of Aviation.

Aviation is a vast subject that incorporates many different definitions often for the same terms; the definitions used in this document are those that align most closely with EREA's mission in civil aeronautics. In particular, throughout this study, **Aviation** means the **Civil Air Transport System**, encompassing the movement of civilian passengers and cargo in the Earth's atmosphere, from both private and commercial perspectives. Defence and/or space aspects are only touched upon when they are foreseen as having significant impact on the civil panorama and are not investigated in depth.

The outlook year selected for this study is 2050. Although several studies have already been produced which give a view on how aviation might evolve to be in 2050 or what aviation should aim at becoming in 2050, a number of significant changes in the political and societal landscape indicated the need to re-evaluate those studies and re-assess the potential range of Futures of Aviation in the light of new events.
The study is broad and non-specific in geographical scope. The scenarios can be applied to global, regional or national scales or to international blocs and could be mixed to allow for different development paths in different places.

This study is directed to connect and to engage all of the different stakeholders essential for a healthy R&D ecosystem.

First, and most important, the study aims to enthral and motivate **EREA** and its individual research establishments, as representatives of the European Research Community. The vision has been created by EREA experts for EREA experts, in order to connect all EREA members, at all levels, from the Board to the youngest of the researchers. The vision should be used to guide EREA through the decisions which will need to be made and to inspire the EREA members.

Second, this study enables the EREA vision to be presented to its **external stakeholders**. Several groups are active in Europe, with the common interest of maintaining European aviation's competitiveness, safety and security, whilst minimising negative environmental impacts and maximising positive socio-economic benefits. These groups include ACARE, the Clean Sky Joint Undertaking, the SESAR Joint Undertaking, the European Aeronautics Science Network (EASN) and oth-

[1] *Flightpath 2050, Europe's Vision for Aviation, Report of the High Level Group on Aviation Research, https://ec.europa.eu/transport/sites/transport/files/modes/air/doc/flightpath2050.pdf*

[2] *Strategic Research and Innovation Agenda, ACARE, https://www.acare4europe.org/sria*

ers. Even though there is a shared purpose, multiple voices with different emphases may hinder even the most robust of messages. By sharing its vision, EREA hopes to create a platform for dialogue to reach a single, communal vision and boost cooperation.

With a strong, coherent and common vision, EREA and its stakeholders can then approach **policy makers** at national and European level to support their decision-making process, as a credible, coherent, independent and trustworthy voice. Engaging policy makers and government bodies will ensure that R&D outcomes are not confined to laboratories and academic publications, but are used practically and effectively in a broad, multi-interest environment to maximise positive socio-economic and environmental impact.

Finally, this study wants to engage the **general public** by showing that EREA and its members have an ambitious vision which can ensure a thriving aviation industry without compromising on societal needs and sustainable goals[3]. The study means to show the public that their concerns are also EREA's, and that research choices will be made together, towards a common goal.

The scenarios described in this document are the outcome of a series of workshops performed in the spring of 2020 and attended by EREA members experienced in scenario thinking and future strategy. The context in which those workshops took place is given, together with a short description of the workshops themselves. Given the background of the participants in this study, this vision should be seen as the opinion of EREA R&D experts, from different technical and cultural backgrounds, all functioning at the interface of different spheres of influence: academia, industry and governments. No pretence of scientific validation has to be assumed.

[3] *https://sdgs.un.org/goals*

Setting the scene

...on Civil Aviation

Aviation as we know it, with airports and passenger flights, is a relatively young concept. Since its beginnings around a century ago, civil aviation has been steadily making the world smaller, more connected and accessible to its citizens. Currently, there is no other way of travelling quickly and efficiently over long distances around the world. Aviation is also by far the safest and most secure means of travel. Given the estimated worldwide air traffic in 2019 of about 39,000,000 flights, the accident rate is one fatal accident per almost two million flights[4].

Aviation is a strategically important industry to individual sovereign States, but it cannot fulfil its potential without a seamless, global, world network. A specialised United Nations agency, the International Civil Aviation Organization (ICAO) works with its 193 member states to manage the governance and administration of the global civil air transport system. The International Air Transport Association (IATA) is the global trade association for the world's airlines. ICAO and IATA promote interoperability and standardisation to support a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. In Europe, the European Commission (EC), the European Aviation Safety Agency (EASA) and EUROCONTROL, all have their roles in the operation of the European aviation single market, regulatory and technical harmonisation, compliance, and research and innovation and external relations.

Aviation's contribution to the global economy is undisputed. ICAO estimates[5] that in 2018, the direct contribution of aviation to the global economy supported 10.2 million jobs and contributed $704 billion to gross domestic product (GDP). If indirect, induced and catalytic effects are included these figures increase to 65.5 million jobs and $2.7 trillion. Within Europe[6], the aviation sector directly employs between 1.4 and 2.0 million people and contributes €110 billion to the European Union's gross domestic product (GDP). When multiplier effects are included these figures rise to 4.8 to 5.5 million jobs and €510 billion respectively.

Aviation also makes a significant contribution to social well-being. It enables citizen's mobility, connecting remote and peripheral regions as well as ensuring that these regions are accessible for the delivery of essential supplies, such as food and health care, especially in times of crisis. It also facilitates cultural links between communities distributed across the world, in the event of emigration or diaspora. Travel by air

[4] *https://news.aviation-safety.net/2020/01/01/aviation-safety-network-releases-2019-airliner-accident-statistics*

[5] *Aviation benefits report, Report of the Industry High Level Group, 2019*

[6] *An aviation strategy for Europe, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, SWD(2015) 261 final, 7 December 2015*

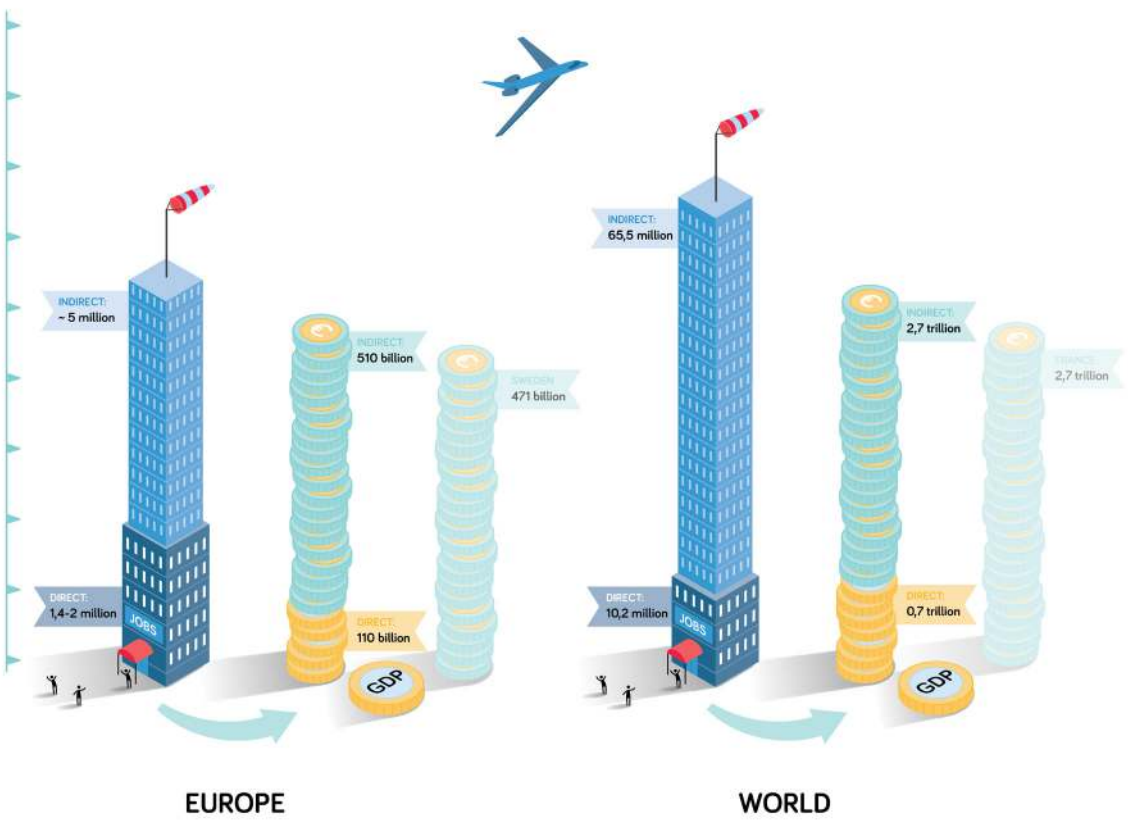


Figure 1: Comparison of aviation jobs and contribution to GDP for Europe and worldwide

is often essential for visiting distant friends and relatives, enabling a flexible and mobile workforce. Aviation is one of the critical enablers of tourism, allowing people to make best use of their leisure time and broadening experience and awareness of other cultures.

In its beginnings and reflecting its strategic importance, civil aviation was heavily State controlled and governed by treaty-like agreements between States on a bilateral basis, under the global ICAO umbrella. From the early 1990s, the sector has been gradually evolving from State-controlled provider perspective to a more consumer-focused industry. This evolution started initially through the creation of competitive internal aviation markets within the US and Europe; the relaxation of bilateral agreements followed, with some constraints remaining, to govern the travel between some countries or blocs. This progressive liberalisation of the industry is not yet complete on a global scale and is accompanied by continued strict regulation to ensure safety, security and global interoperability.

Liberalisation, achieved in part through the application of competition law, has resulted in the replacement of restrictive bilateral air services agreements with open skies agreements, and the creation of multilateral common aviation areas, such as the European Common Aviation Area (ECAA). Competition on routes has emerged along with new business models, such as low cost carriers. This has reduced prices – the unit price of air travel has reduced by around 80% since 1950 – and increased access to air travel for the world population. What started as a luxury commodity for the rich has become highly accessible in both the developed and developing worlds. For example, World Bank data[7] shows that globally in 1975 there were approximately 432 million air trips with a world population of approximately 4.1 billion. In 2018, there were approximately 4.2 billion air trips with a population of

approximately 7.7 billion.

As people become more affluent, their desire to fly also increases. All other things being equal, the chart in Figure 2 shows that, following even small increases in wealth in a large population (indicated by bubble size), developing countries will lead to large increases in demand for air travel. It is also in these developing countries, such as India and China, that wealth is increasing the fastest, signalling a potential exponential growth of demand for air travel.

Traditionally therefore, aviation is a growth industry, albeit with some glitches caused by disruptive events, such as economic crises and the terrorist attack on 9/11. The growth to 2019 is shown in Figure 3. This situation, however, has been challenged by environmental groups and dramatically changed due to the COVID-19 pandemic.

... on Current Challenges

As would be expected in such competitive growth industry, there are direct challenges on capacity, efficiency, quality of service and resilience. As the sector strives to meet increasing demand, capacity constraints start to bite. When looking at airspace and airports, this increases congestion and delays, especially at key nodes in the network, resulting in

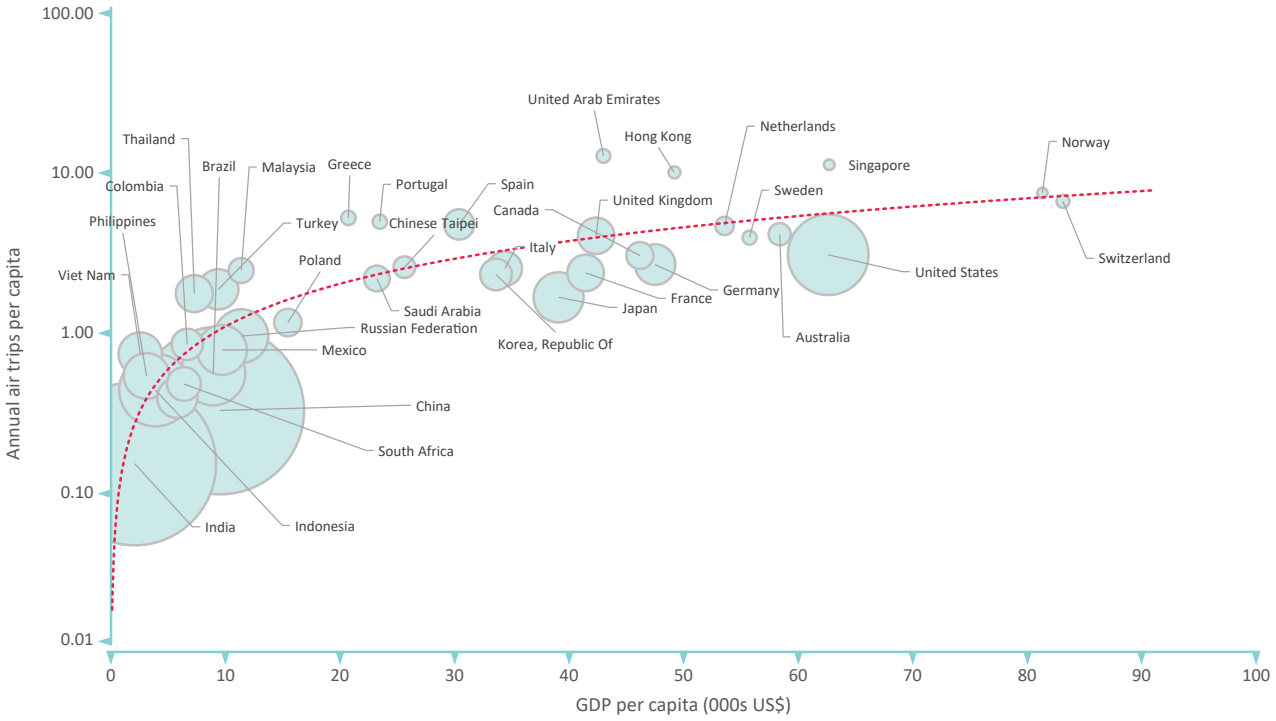


Figure 2: Correlation between increase in GDP and increase in annual air trips (Source: Taylor Airey analysis, using data from Airports Council International (ACI), the United Nations Conference on Trade and Development (UNCTAD) and the World Bank, 2019)

[7] *https://data.worldbank.org/indicator/IS.AIR.PSGR*

poor punctuality and increased costs to airlines and passengers alike. Strains on the aeronautical manufacturing industry and supply chain have resulted following the high production rates set up by aircraft OEMs[8,9]. As the system starts to operate near to its capacity, the impact of even small disruptions is amplified and resilience – the ability to mitigate and recover from disruption – becomes compromised. Air transport is a highly interconnected network, so disruptions can propagate quickly through the system. Much research has been and continues to be performed to improve the aviation's performance, resilience and flexibility to traffic fluctuations and disruptions.

Although aviation makes positive contributions to the economy and social well-being, the awareness about the aviation's negative impact on the environment, principally on climate change, local air quality and noise, has been steadily rising in the last years. This awareness generated from political activities, through the United Nations Sustainable Development Goals[10] (SDG) and, in Europe, through increasing awareness that led to the European Green Deal[11].

The key components of the Green Deal (Figure 4) for aviation include:

- the development of a circular economy action plan;
- legislation on batteries, taking into account the circular economy;
- development of a strategy for sustainable and smart mobility;
- options to boost the production and supply of sustainable alternative fuels.

Different European countries are developing different responses to the overarching European goal. Different industries are also reacting at different speeds to established policies and regulations.

Popular engagement to such political agendas has become apparent through movements such as Fridays for Future activities and the Flygskam (flight shaming in Swedish) and Global Climate Strike movement.

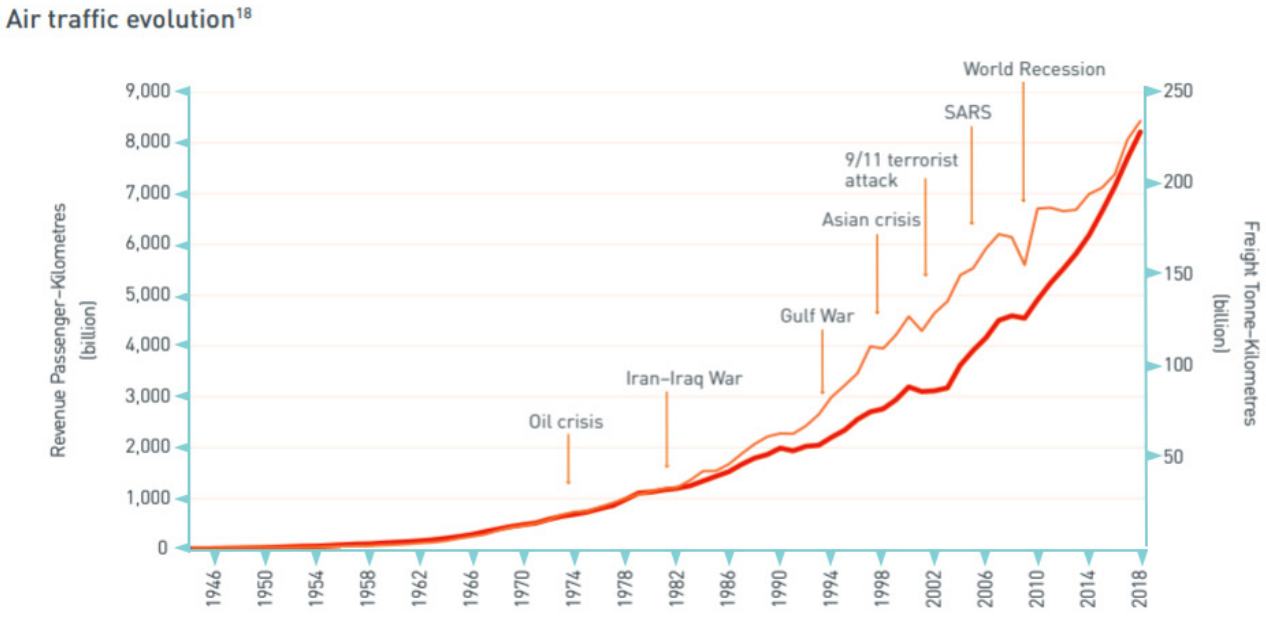


Figure 3: Growth of aviation industry until 2018 (source: ICAO)

[8] *Boeing Commercial Market Outlook 2019–2038,*

[9] *Airbus Global Market Forecast 2019-2038*

[10] *https://sdgs.un.org/goals*

[11] *The European Green Deal, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2019) 640 final, 11 December 2019*

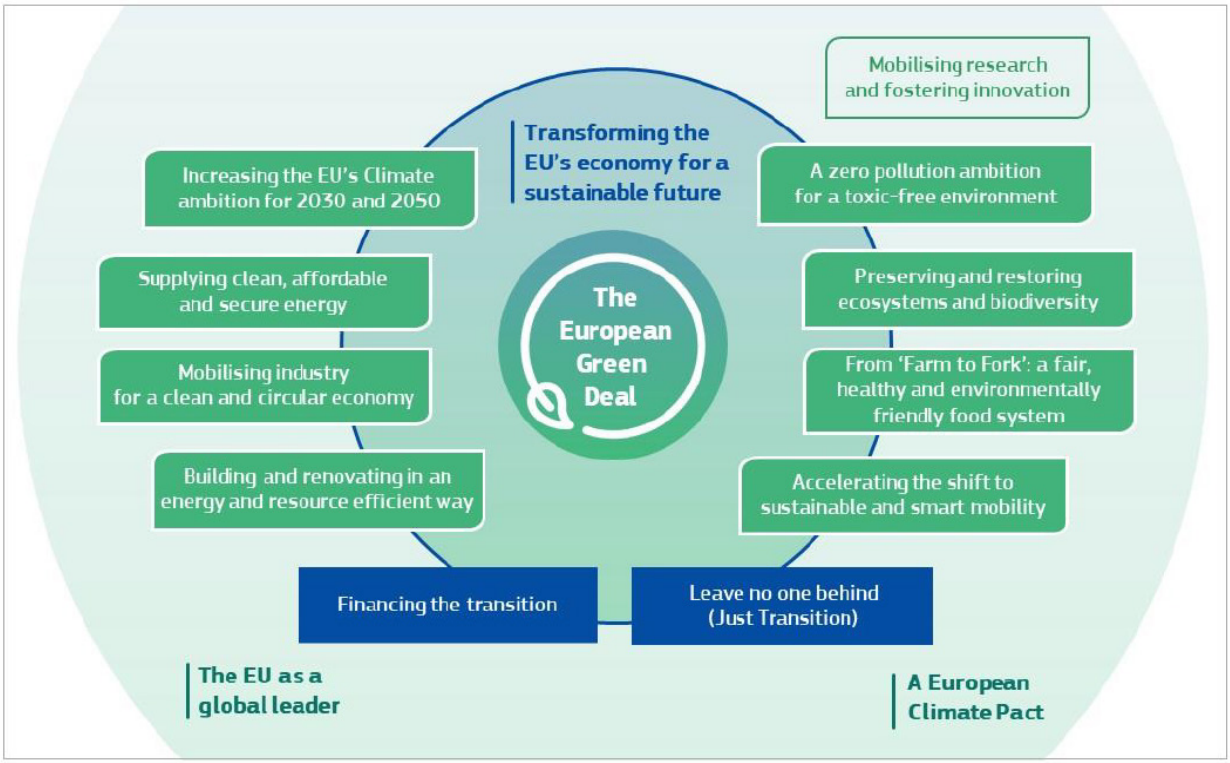


Figure 4: The European Green Deal[12]

The aviation industry responded promptly to the climate change challenge. In terms of climate impact, aviation currently emits[13] 2 to 3% of the world's CO_2 generated by human activities. In addition to CO_2, there is an impact on climate from its non-CO_2 emissions, such as NOx, water vapour, and particulates. Aviation can also impact global warming through contrails, which can have both warming and cooling effects, although the overall global mean response is considered to be warming. CO_2 effects are reasonably well understood but non-CO_2 effects have not been extensively researched to the same degree, resulting in large uncertainty about their impact on climate. Through the Clean Aviation Partnership[14] (Figure 5), the European aeronautics sector aims to work towards climate neutral aviation by 2050, building on the work of the Clean Sky and Clean Sky 2 programs.

Around airports, degradations in local air quality and noise impact negatively on local communities. Flightpath 2050[16] has set goals for 2050 related to these factors:

- a 75% reduction in CO_2 emissions per passenger kilometre;
- a 90% reduction in NO_x emissions;
- a 65% reduction in the perceived noise emission of flying aircraft;
- aircraft movements to be emission-free when taxiing.

Within the ambition of smart and sustainable mobility, a topic that is receiving considerable attention from research organisations and industry, is the development and use of drones for many purposes, including professional and leisure. There is also much work being performed to develop urban air mobility (UAM) solutions. Collectively drones and UAM are becoming known as advanced air mobility (AAM).

Other widely discussed topics are automation, robotics and big data. Automation and virtual and augmented reality technologies are already being deployed in manufacturing plants, maintenance hangars and air traffic control towers and pres-

[12] *ibid*

[13] *Source: EASA*

[14] *An ambitious vision for clean aviation, January 2020*

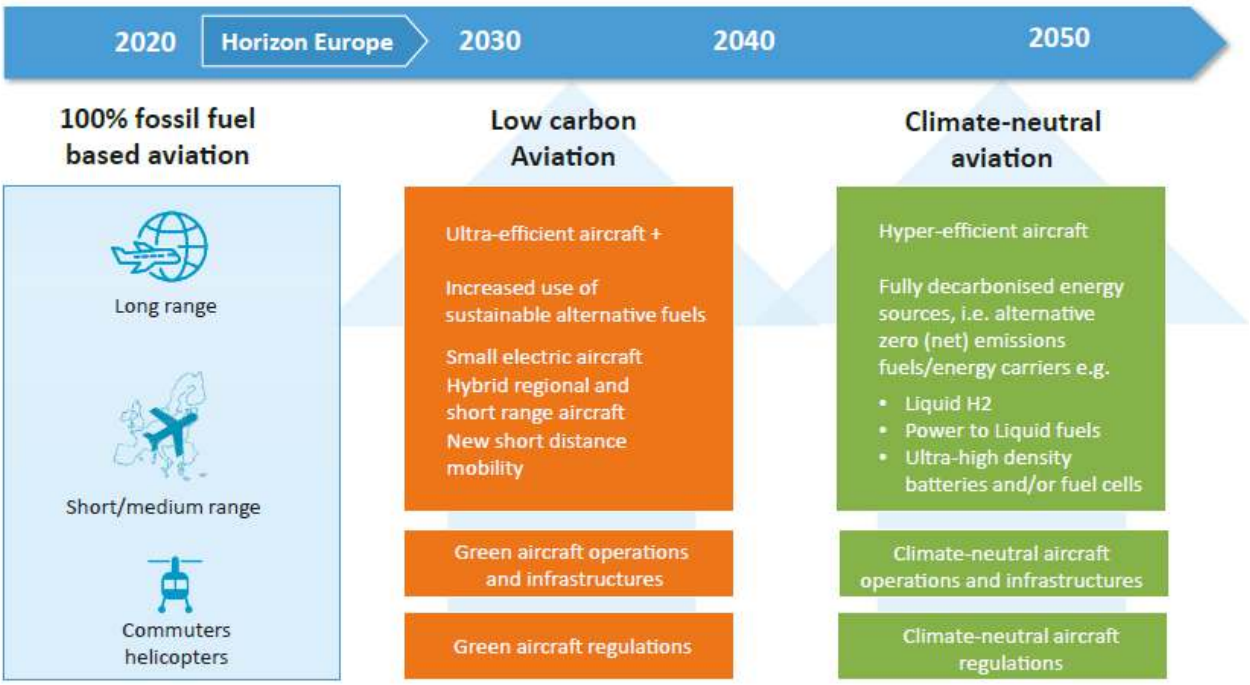


Figure 5: Clean Aviation Partnership[15]

ent many more opportunities within the sector alongside challenges of safety assurance, certification and human factors.

All those topics and many more have been part of numerous research activities aimed at contributing to the Flightpath 2050 goals, performed via EU research programs, such as Horizon2020 and the upcoming Horizon Europe, fostering collaboration between research institutes, academia and industrial partners. Despite this active and fruitful collaboration, the outcomes of innovation programs

and the deployment of disruptive technologies and business models present a challenge to the conventional aviation industry and system. Implementation has so far been limited.

... on COVID-19

Aviation's seemingly unlimited growth came to a sudden stop at the beginning of 2020. At the time of writing, October 2020, it is clear that the COVID-19 pandemic has resulted in possibly the largest challenge that the aviation sector has ever faced. Immediate effects included:

- the near closure of passenger air transport as various measures, including border and travel restrictions, were put in place to contain the virus;
- the massive contracting impact on world economies, resulting in companies being (near-) bankrupt, staff being furloughed or made redundant;
- aircraft fleets being reduced in size with, mainly, old aircraft being retired and cancellation of aircraft orders, with knock-on effects up the supply chain.

Acknowledging the strategic importance of air transport, many governments have created financial support packages for their home industries, including manufacturing, airlines, airports and air traffic control. In several cases, but not all, these packages come with " sustainability" conditions to man-

[15] *An ambitious vision for clean aviation, January 2020*

[16] *https://www.acare4europe.org/sria/flightpath-2050-goals*

age future environmental impacts – for example short-haul, domestic journeys must be made by train, not plane, or push for fully electric short-range aviation – that may shape future demand for flying.

There are also likely to be longer-term, lasting impacts of the virus. For example, health may be elevated to a similar level of concern as safety and security, requiring health passports, health screening at airports and on aircraft, so that the aviation system detects and provides alerts on diseases. Additional systems to ensure healthy air circulation in aircraft cabins and other enclosed spaces may become mandatory. The attitude of people towards flying may also change permanently. When the severity of the pandemic became clear, several measures were rapidly put in place to ensure the minimum continuity of daily activities. One of the most impactful of these measures, home-working, has become common practice and is embraced by both workers and their employers. A full return to past habits seems unlikely when people can interact worldwide from the comfort of their living rooms. In addition to the now proven convenience of alternatives to travelling, the uncertainty on possible new contagions may

Figure 6: Consequences of COVID-19, from top left clock-wise: grounding of aviation; from commuting to office to home-working; request of "environmental conditions" in economic aids; fragmented response to the crisis.

act as a deterrent to travel, when not strictly necessary. This trend builds upon attitudes towards flying that were starting to change before the virus struck, thanks to a new awareness of the impact of flying on the environment, publicly vocalised by environmental and Flygskam groups. Even before the virus, there were indications that travellers were already using the train instead of the airplane for domestic journeys and relying more on video conferencing technology. Therefore, in the future it is likely that different people will have very different attitudes to travel generally and flying in particular.

There is much uncertainty about when the aviation sector will recover from the impacts of COVID-19, depending, not least, when the virus is brought properly under control, possibly requiring effective vaccines. However, there will undoubtedly be a recovery. From several sides, there is a desire or request to return to "business as usual" or "back to normal" as fast as possible. Others see the current disruption as an opportunity to evaluate what the aviation sector could or should look like in the future.

At the time of writing, forecasts vary greatly and, at times, are even contradictory. The only common characteristic is uncertainty, and that is fully represented in the scenarios presented in this study.

… on General Trends emerging across the world

This section describes the common, underlying features and characteristics of the world in which the potential future scenarios will develop. Beyond specific aviation trends and situations, there are also demographic, socio-economic and political aspects to consider.

Population

There is broad consensus that the world population will continue to increase from around 7.8 billion in 2020 to around 9.8 billion in 2050, although with reduced growth rates. Thereafter, forecasts diverge with some sources[17] predicting further growth to a population of around 11 billion by 2100 albeit also at reduced growth rates. Other forecasts[18] predict a population contraction between 2050 and 2100, to around 8.8 billion in 2100.

Independent of the exact figures, it is evident that the population growth across the world is not uniform. Africa's population will increase, while Europe's population is forecast to decrease. Half of the world's population growth between now and 2050 is expected to be concentrated in nine countries: Democratic Republic of the Congo, Egypt, Ethiopia, India, Indonesia, Nigeria, Pakistan, the United Republic of Tanzania, and the United States of America. Disparate population growth rates among the world's largest countries will re-order their ranking by size: for example, India is projected to surpass China as the world's most populous country by around 2027 and Nigeria will have replaced the United States as the world's third most populous country by 2050. China and India are forecast to remain the two most populous countries by 2050.

Age distribution is also expected to change[19]. Life expectancy at birth for the world's population reached 72.6 years in 2019, an increase of more than 8 years since 1990. The average length of life globally is expected to reach around 77.1 years in 2050. The number of people aged over 65 is expected to double by 2050, to approximately 1.5 billion. In Europe and North America, the proportion of people aged over 65 is predicted to increase from 18% in 2018 to around 25% in 2050. The number of people aged over 80 is predicted to increase threefold by 2050 and by seven times by 2100.

At present 55% of the world's population live in cities[20, 21]. This is expected to increase to 70% by 2050. Urbanisation is expected to increase in all regions. The highly urbanised regions of Latin America and the Caribbean, and Northern America already have around 80% of their population living in cities, with this projected to rise to nearly 90% by 2050. Europe had 75% of its population living in urban areas in 2018: this is expected to reach nearly 85% by 2050. Africa, in contrast, remains mostly rural, with just over 40% of its population living in urban areas in 2018, while Asia is now at approximately

[17] World Population Prospects, United Nations, Population Division, Department of Economic and Social Affairs, 2019

[18] Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. The Lancet, 14 July 2020

50%. The proportions of city-dwellers for Africa and Asia are projected to reach 59% and 66% per cent urban by 2050 respectively. Mega-cities, with populations of more than 10 million, are currently located in only 20 countries: Asia currently has 20 mega-cities, followed by Latin America and the Caribbean with six, and two or three in each of the other regions. By 2030, the number of mega-cities is projected to have increased to 43.

Income

In terms of income levels, on average across the Organisation for Economic Cooperation and Development (OECD) countries[22], the share of people in middle-income households, defined as households earning between 75% and 200% of the median national income, fell from 64% to 61% between the mid-1980s and mid-2010s. However, in contrast to this and driven by increases in wealth in the developing world, the global middle-class is expected to grow[23] and reach 5.3 billion by 2030 with 88% of the additional middle-class population living in Asia. China and India will represent over 43.3% of the global middle-class by 2030. Global middle-classes are splitting: a retreating developed-country middle-class, and a fast-growing emerging-economy middle-class. These highly and increasingly populated emerging economy countries will be the principal drivers for the largest increases in demand for aviation.

International cooperation

From the second-half of the twentieth century onwards, there has been a trend for increasing international cooperation from the creation of the United Nations in 1945 through the creation, evolution and expansion of the European Union to looser groupings, such as the Association of South East Asian Nations (ASEAN). This period has also seen the break-up of some blocs, such as the Council for Mutual Economic Assistance (Comecon).

Overall the current trend appears to be for increasing cooperation although there are situations of individual countries rejecting the cooperative approach in favour of more national-based arrangements, such as the UK's withdrawal from the EU and the USA's confirmed withdrawal of funding from the World Health Organization, the Paris' Agreement and its questioning of its contributions to the UN and NATO.

Education

Quality education is the focus of one of the UN SDG. Amongst its objectives are that by 2030 all have access to free, equitable and quality primary education, as well as to affordable and quality technical, vocational and tertiary education, including university. The proportion of people with appropriate technical and vocational skills to ensure employment, decent jobs and entrepreneurship should be increased substantially by 2030.

Other developments in education are likely to include increased cooperation between higher education and industry to ensure a pool of graduates with work-force ready, specific but transferable skills, including, for example, in data analytics and enhanced communication. As the world is changing rapidly, this cooperation will be very important to anticipate the requirements for future jobs that have not yet been created and technologies that have not yet been invented. This will not only likely require dynamic curricula reflecting the competences anticipated for when the students graduate but will also need adaptation of teaching and learning systems to develop knowledge, skills, attitudes and values effectively.

The approach to education will also have to adapt to changing demographics with, in many areas, the proportion of young people in the population becoming lower than today and adults or elderly also driven towards (late) education, either for necessity or interest.

R&D

Comparatively, R&D funding in EU countries is on a par with that in the developed world but behind that of the leading countries, most notably Israel and the Republic of Korea and also below the overall EU target. In terms of the growth in R&D funding again EU countries compare well with potential competitors but again with the Republic of Korea, Israel and,

[19] *World Population Prospects, United Nations, Population Division, Department of Economic and Social Affairs, 2019*

[20] *World Bank, April 2020*

[21] *World Urbanization Prospects, United Nations, Population Division, Department of Economic and Social Affairs, 2019*

[22] *Under Pressure: the squeezed middle class, OECD, 2019*

[23] *https://ec.europa.eu/knowledge4policy/growing-consumerism_en*

in this case, China, increasing their focus on R&D.

The scale of a country's R&D can be measured by R&D intensity, the ratio of R&D investment in that country to its GDP. Figure 7 shows the R&D intensity (for all sectors, not only aviation) for those countries that invest more than 1% of their GDP in R&D. The overall EU target is 3%.

Other than EU countries and Norway, the largest investors in R&D are Israel, the Republic of Korea, Japan, the USA, China, the UK and Canada. Of those countries that have an R&D intensity greater than 1%, Figure 8 shows the average annual rate of increase. For all other countries (notably Japan and the USA, as large-scale investors), R&D intensity has not increased over the last ten years.

Of the 14 countries with increasing R&D intensity, 11 comprise EU members and Norway. The remaining countries with increasing R&D intensity are the Republic of Korea, China and Israel.

...on the Background of this Study

In 2010 EREA published "EREA vision for the future –Towards the future generation of Air Transport System"[24] . In that document, four 2050 aviation scenarios were investigated describing the associated technology challenges.

The four scenarios were: Unlimited Skies, Regulatory Push & Pull, Down to Earth, and Fractured World.

- The scenario "Unlimited Skies" represented a world in which aviation undergoes explosive growth, with the development of many different types of aircraft.
- The scenario "Regulatory Push & Pull" placed emphasis on the public interest through a series of constraints and regulations.
- The scenario "Down to Earth" presented a radical situation, reflecting a political commitment to eliminate fossil fuels usage.
- The scenario "Fractured World" offered a divided world, following major political and economic crises.

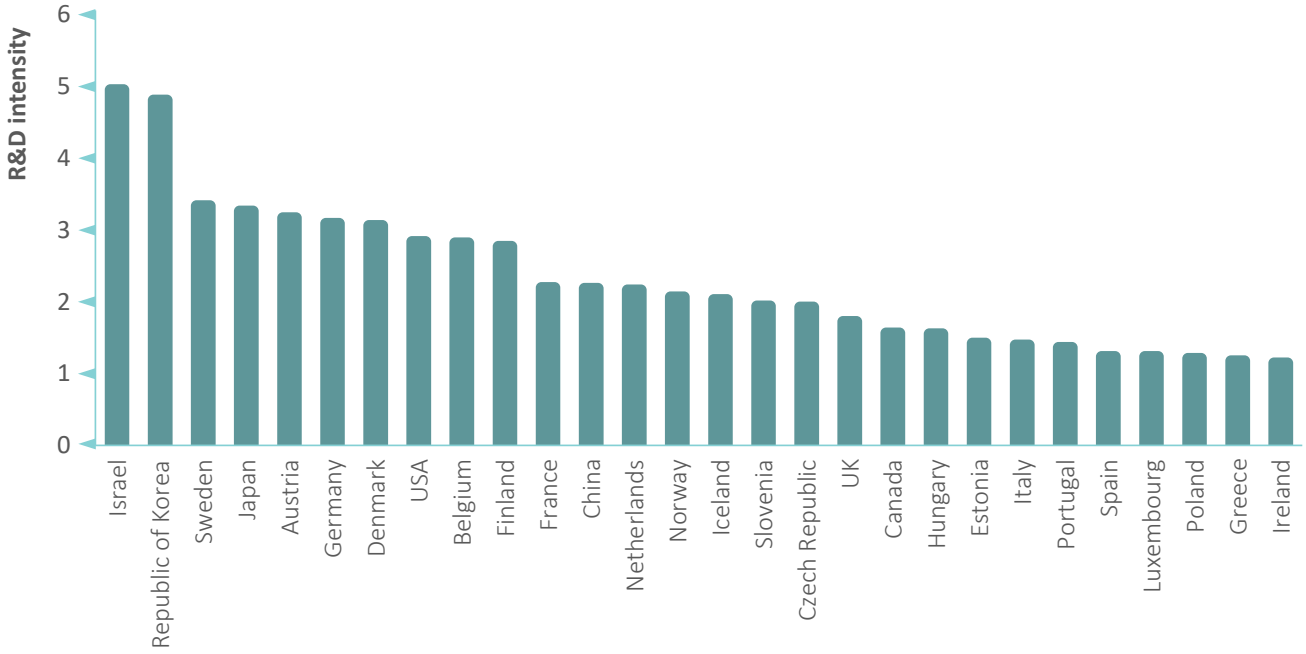


Figure 7: R&D intensity [Source: UNESCO institute for Statistics]

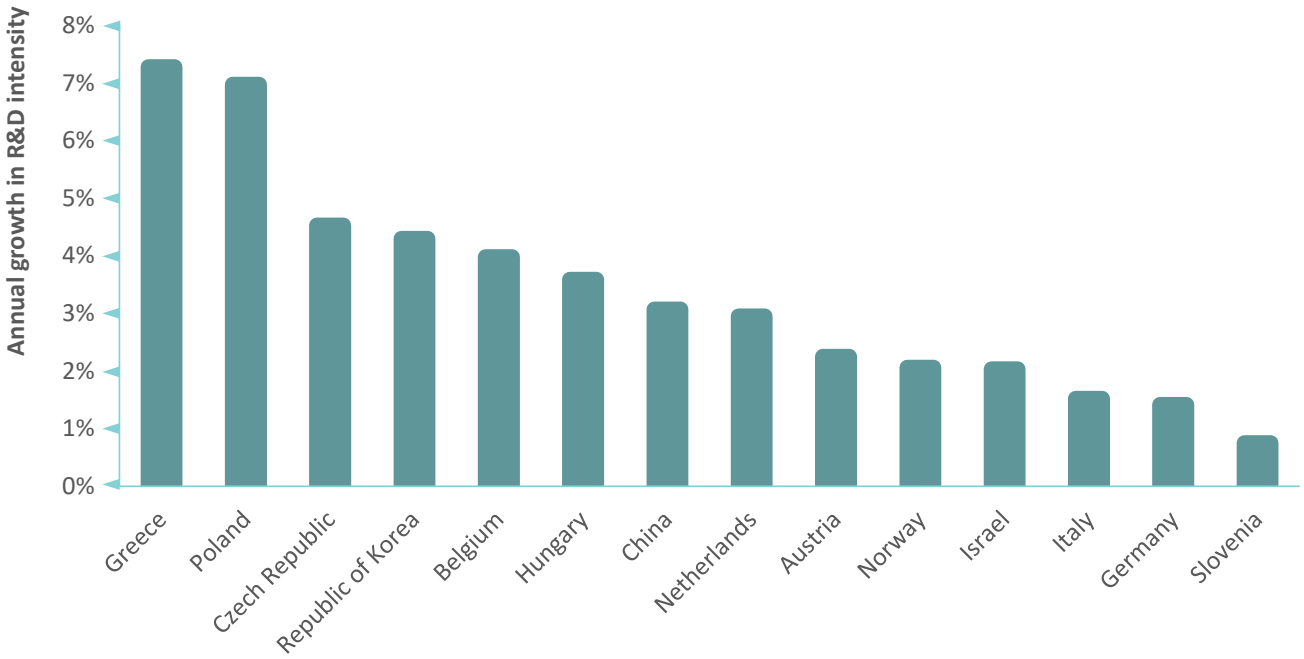


Figure 8: Annual growth in R&D intensity [Source: UNESCO institute for Statistics]

Over the last decade, those scenarios have been used to guide and orient the research and development choices and recommendations, which EREA presented in several industrial and institutional workgroups.

An evaluation of the validity of the 2010 scenarios was performed in the spring of 2020. This evaluation was based purely on the opinion of a group of EREA experts.

The outcome of the evaluation was that, though in general terms the scenarios might have still been valid, the changes in the societal and the aviation scenes during the intervening 10 years were so profound that a new study was required to develop new scenarios. Those new scenarios could include elements of the previous 2010 scenarios, but, more importantly, they should include the changes and factors which were not included in the 2010 study (e.g. the COVID-19 crisis and the strengthening of environmental concerns).

Development of scenarios

This study builds on the current context and the indicated trends, described above, to imagine four alternative future worlds and the contribution that aviation could have in those worlds. None of the scenarios are designed to be absolutely realistic, but they are the vehicle for exploring options and ideas. No value judgements have been implied or made, so no one scenario shall be perceived as "better" than any other in absolute terms, although the reader will obviously have a personal preference.

The scenarios were developed in a series of online workshops, which took place in the spring of 2020.
As a start, "driving forces" were identified, defined as big shifts in society, economics, technology and politics, etc., that are considered having an effect aviation in the time frame up to 2050. Out of all listed "driving forces", "key uncertainties" were identified. A "key uncertainty" can be highlighted by

[24] *https://www.erea.org/sites/default/files/pdf/EREA_2010_WEB.pdf*

answering two questions:

1. Does a change in the selected driving force generate uncertainty in how the world will look like?
2. Does a change in the selected driving force represent a fundamental shift within a specific area (in this case aviation)?

A number of "key uncertainties" were identified, which can be classified in one of the following categories:

- Threats (political instability, health risks, conflicts, terrorism, etc.);
- Sustainability (availability of alternative fuels, societal awareness, etc.);
- Availability of products (alternatives to travel, customisation of products, etc.);
- Policies and regulations (travel restrictions, environmental-orientated policies, health measures, etc.).

The "key uncertainties" were paired in a matrix and, for each combination, two questions were asked:

1. What sort of world would result when the given combination of "key uncertainties" occur?
2. What would the given combination of "key uncertainties" mean for aviation?

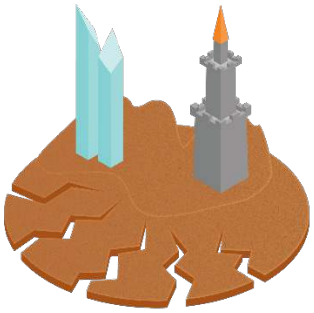
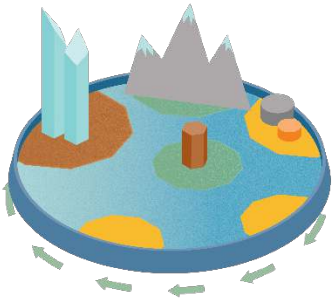
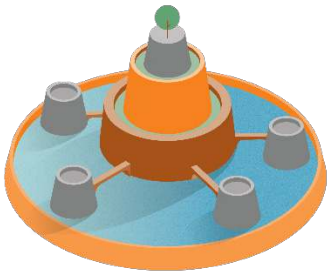
Within those matrices, scenarios were generated. As similar scenarios were generated by different combinations of "key uncertainties", overlaps were identified and discussed and, eventually, scenarios merged. The process resulted in the four scenarios which are detailed in this document.
Finally, the scenarios were evaluated and compared to each other based on five parameters:

1. Sustainability;
2. R&D in aviation;
3. Customisation;
4. Replacement of aviation;
5. Uncertainty.

For each scenario, signposts are given. In scenario analysis, a signpost is a signal on how a key characteristic of a scenario is developing as an early indicator of whether the scenario is crystallising. Signposts can be used to evaluate how future developments or events can be pointing towards one of the scenarios.

These scenarios will be used as the basis for EREA to chart its own up-coming technological, policies and infrastructure roadmaps, allowing to consider a wide range of potential future eventualities.

The Scenarios for the Future of Aviation

	**Mad Max** ...aviation: a luxury for the few in a world of consumerism, challenges and conflict	*A world characterised by deglobalisation and fragmentation; extreme nationalism and populism; instability; protectionist economies; high levels of inequality; low sustainability; climate crisis; low levels of R&D.* *Aviation is an expensive, luxurious and highly desirable product but is unreliable due to climate change and different sources of instability. There are few industrial players with no innovation and limited R&D.*
	**Tech for You** ...aviation: side by side alternative technology in islands of choice, competition, and customisation	*A world characterised by multipolarity and competition; high-cost, low economy-of-scale production offset by widespread automation; market driven by consumer choice and desires; free market economies; high R&D with national and short-term focus; different approaches to and meaning of sustainability in different islands.* *Mobility is flexible with air transport part of the local, intermodal transport system. The overall approach is to strive for door-to-door mobility.*
	**Stripping Down** ...aviation: sustainability achieved by a world of centralised command and control	*A world characterised by political stability; command economies; centralised government; prescriptive regulation; slow but stable economic growth; standardisation and uniformity; prioritised and government-directed sustainability.* *There is limited and highly controlled mobility due to high prices, security threats, flight shaming and regulation. Sustainable intermodal generic solutions are enforced. There are few industrial players due to high cost and low demand.*
	**Optimising Together** ...aviation: unlimited freedom in a world of common purpose, collaboration and cohesion	*A world characterised by unification and harmony; global cooperation and collaboration; global legal and institutional frameworks; high stability and growth; sustainability; market-driven economies and liberalisation; high standardisation and confidence.* *Mobility is growing and is fully sustainable. Different aviation solutions are available for all journey segments from UAM through formation flying to sub-orbital flights.*

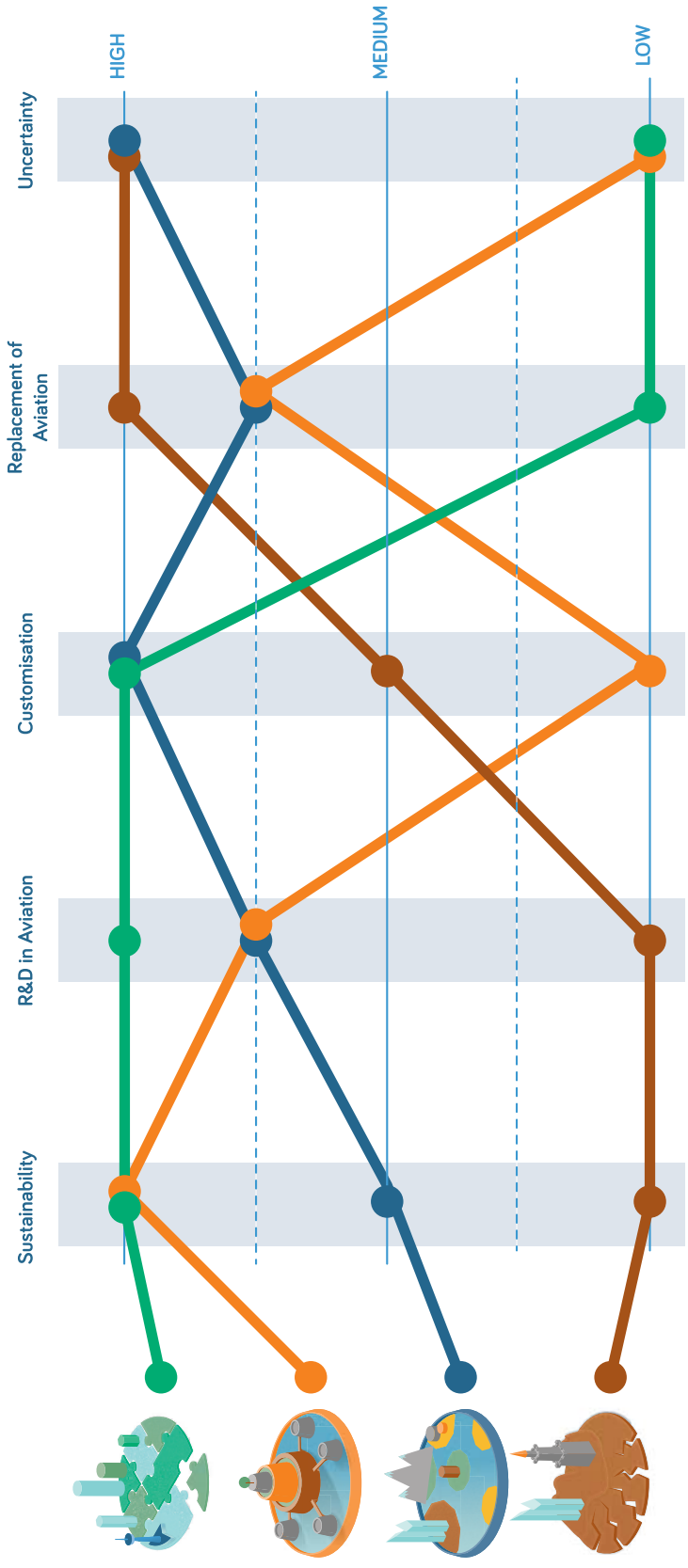


Figure 9: Comparison of the scenarios with regard to the five parameters identified in the study

Scenario 1: Mad Max

...aviation: a luxury for the few in a world of consumerism, challenges and conflict

A world characterised by deglobalisation and fragmentation; extreme nationalism and populism; instability; protectionist economies; high levels of inequality; low sustainability; climate crisis; low levels of R&D.

Aviation is an expensive, luxurious and highly desirable product but is unreliable due to climate change and different sources of instability. There are few industrial players with no innovation and limited R&D.

Politics

Since 2020 the world has deglobalised, has become extremely fragmented and is structured along national lines. Intergovernmental organisations (IGOs) have failed to resolve conflicting interests and needs at national, regional and personal levels; the result is that nation states have gradually withdrawn from IGOs over time, starting with the countries that perceive themselves as the richest and most powerful. The associated loss of funding means that the IGOs have become unsustainable so that the structures that support international laws and cooperation have collapsed. Power is centred in a few wealthy countries that, amongst other things, control access to valuable natural resources.

Countries act in their own local self-interest with disregard to global concerns. Each country has its own perspectives on and approaches to the main policy areas such as sustainability, energy, transport, trade, industry, health and social welfare. These are all addressed at national level and have different, and constantly changing, priorities in different places. Policies, in the main, are short-term and reactive.

Tensions between countries, the risk of conflict and terrorist threat are all consistently high because of global fragmentation, perceived and real economic exploitation and ever-widening cultural differences between and within regions and countries.

Economics

There is significant, and constantly growing, gap between wealthy countries and under-developed areas. Nations and governments that control access to fossil fuels and other, limited or scarce, natural resources consistently promote their use, maintain high prices by controlling supply and become rich and powerful in a self-sustaining cycle. This means that the consumption of expensive natural resources is kept high and their rich owners tend to get richer and the poor poorer, continuously increasing the disparity between affluent and deprived regions. This results in an extremely polarised world. However, even for wealthy countries economic growth can be very volatile, oscillating between very high growth, and recession or depression. The net result is that overall average global economic growth is low. The centre of gravity of global power fluctuates depending on where countries are in their economic cycles.

Wealthy powers exert strong influence over impoverished countries overtly using investment and aid programs as a lever to ensure that the donor country and its industry are in a preferential position in terms of, for example, trade, market access, political control and security.

In principle, economies are liberalised and completely driven by market forces with very little state control or regulation. Governments only intervene in the economy at time of crisis with packages to protect jobs and to safeguard the perception that the country is still rich and powerful, for example by maintaining production rates when there is limited demand, or by funding non-productive activities.

People have a strong preference for national goods and services so that locally produced goods and services are strongly favoured above imports. This means that in rich countries local markets are strong, vibrant and self-sustaining: there is significant consumer choice, quality is high but prices are also high. Goods and services exported from poor to rich countries must overcome national preference, meaning that there must be strong differentiation on, for example, very cheap price and/or very high quality. Therefore, export markets from poor to rich countries are constrained, suppressing economic development. Access to export markets from rich to poor countries is often required as part of aid programs and often involves second-hand or inferior goods, or the dumping of excess goods resulting from over-production.

Industry is dominated by a few large industrial players that strive to become increasingly efficient and agile to optimise use of scarce resources and to react to rapid and sudden changes in demand. Automation and robotics are applied to design and manufacture, in order to improve efficiency and production rates. Overproduction is not seen as being negative, even though resources are scarce, because active industry is perceived as being an indicator of a country's strength. Accumulating possessions accentuates the image of being

rich for individuals. Major production facilities are based in low-cost economies where environmental and health conditions are not monitored and human resources are cheap. This off-shoring is hidden from the consumer, who believes that big-name brands are produced locally and are, therefore, preferred. There are (real or perceived) safety, security and reliability risks for products produced in these low-cost economies due to the lack or differences of standardisation, variation in certification and quality control, low skill levels and poor working conditions. Irrespective of whether these risks are realised, the public perceives imports as lower quality than domestic goods and services. Only the rich can afford high quality, luxury goods and services whereas others are limited to the lower quality, functional and essential. This increases resentment and tension within society.

Society

Social values are based on freedom of opportunity for the individual with minimum state control. Free enterprise, the pursuit of profit and personal wealth are highly valued. Countries and individuals like to be perceived as being rich and powerful. Social welfare policy is centred principally on individual responsibility with little government intervention. Taxes are minimised and have been replaced by altruism and voluntary donations to state funds and charities by individuals and corporations. Social divides between rich and poor, incentivise people to strive to become rich but also stoke resentment, instability, crime and security threats.

Cultural differences between regions and countries have also been accentuated and nationalism has risen. International and global information and news are not widely accessed as people are inward-looking. However, individuals have access to local information and news to enable them to understand their local and national situation, mostly at the personal level. Although it is mostly reliable, the provision of public information and news is dependent on funding from, for example, advertising and sponsorship, and is sometimes manipulated by governments and corporations to influence choice for their own political and commercial gains.

People select their education and training trajectory either based on the desire to access the highest paid jobs, which are in sports, social media and IT, as well as traditional sectors such as finance, law, medicine, and military, or they end up with no education. Compared to these sectors, aeronautics is viewed as an undesirable career path so the number of suitably qualified and highly-skilled candidates is low. In addition, poor pay makes knowledge retention in aeronautics difficult. There is also low job security, as the need to be agile to cope with high demand volatility is addressed by the industry through automation. Only the really passionate choose a career in aeronautics.

Legal

Each country develops and applies its own individual legal frameworks, with very light-touch regulation. There are different standards on safety, security, sustainability and health in different places. Certification is not applied uniformly and the same products are approved to different standards depending on where they are designed and manufactured. Each country favours its own standards, and is distrustful of others' standards. Certification is often used as a tool to restrict foreign access to markets. Political, trade, legal and transport agreements are now managed bilaterally between sovereign states.

Environment

Sustainability is of very low priority and concern everywhere. There are no global agreements on sustainability. The consequence is that climate change is accelerating.

Rich and powerful countries control access to and supply of fossil fuels and use this control to maintain their dominance. Development of alternative fuels is, therefore, not in the interest of those with the capacity to fund the necessary research and development. Other countries that are sometimes interested in sustainability, have conflicting, and often higher, short-term but urgent priorities such as health, unemployment and social unrest. In addition, public perception of environmental issues has become jaded: the rich use their

wealth to protect themselves from the poor environment while the poor are preoccupied with overcoming short-term, personal challenges than thinking about long-term social responsibility. There is understanding and consensus that sustainability needs to be addressed to mitigate the severe environmental threats. However, the general view is that *"I have more severe and urgent challenges to address"* with the result that no-one is willing to be the first mover in proposing and developing solutions.

Climate change has caused unstable weather conditions, including very high and low rainfall resulting in floods and droughts, severe storms, with very strong wind, hail, thunder, sand and snow, and other hazardous events, such as micro-bursts and wind-shear. Other negative environmental impacts include high levels of waste, general pollution and poor air quality. Uncontrolled housing, infrastructure, agricultural and industrial developments and activities, including mining, quarrying and fracking, reduce biodiversity, lead to land erosion, earthquakes and sinkholes.

Technology

Technological innovation is limited by low economic growth, and it is linked to a short-term agenda, typically limited to politicians' tenure, and addresses today's problems rather than having strategic objectives. There is little international R&D collaboration because of tensions and mistrust, and the perception that local solutions are best. Intellectual property (IP) is viewed as a valuable asset; therefore, governments tend to protect their own national-generated IP fiercely and tend to overlook when national industries engage in industrial espionage against foreign companies. This results in little knowledge-sharing between companies or countries and in a general feeling of mistrust. The difference in education between average citizens and academics is an obstacle to scientific democracy.

Automation, information and communication technologies (ICT), and virtual and augmented reality applications are available. There are significant concerns about the vulnerability of ICT systems to data theft and hacking, especially as the cyber threat is very high. Personal data is only protected at national level and is owned by the country or company to which it has been provided. Use of personal data is commonplace for many purposes including political research and campaigning, market research, and general marketing and advertising. Spam and phishing are common.

Countries without access to fossil fuels focus R&D on alternative energy sources and multi-fuel systems, but, because these countries are poor, funding is limited and progress is slow. More generally, the perceived high risk of technology investment constrains private financing, e.g. venture capital, and funding for long-term projects.

Aviation topography

In general, flying becomes more expensive and is often restricted to the rich. Therefore overall, global demand decreases. Wealth inequality and the risk of conflict mean that travel between some places is in more demand than others and varies from time-to-time.

Although it competes with virtual technologies and alternative modes of transport, aviation is seen as a desirable lifestyle choice for the rich. The priorities of the seamless, door-to-door journey are speed, comfort, convenience and quality of service.

Passengers and their luggage are collected at their home by a personalised vehicle, which transports them, often using either piloted or autonomous urban air mobility (UAM) technology, directly to the aircraft. For longer feeder journeys, there may be an intermediate segment by a different transport mode, such as rail or hyperloop. Invisible security and border checks are performed en-route in the passenger's personalised vehicle, which has all the facilities needed for the comfort of the passenger. Therefore, the airport has the minimum infrastructure required for operation of the aircraft and the passenger spends only a small amount of time at the airport.

The aircraft cabin is fully connected and designed for luxury and relaxation. The journey is fast, smooth and free from external noise, vibration, turbulence and other severe weather impacts. The in-flight experience is personalised and customised, and the majority of the investment in R&D is directed to this segment as it is also the most profitable for the aviation industry.

In addition to being a mode of transport, aviation has become an integral part of the leisure industry, providing experiences as diverse as cruises in airships, pleasure flights, parachute jumping and space tourism. Advanced air mobility solutions (flying cars) are used as toys. Locally produced and operated drones are commonplace and have many applications including in integrated logistics chains. Some drones are fully autonomous. Other drone uses include surveillance and data collection in applications such as counter-terrorism and crime prevention.

Jobs in the air transport sector have become predominantly customer-service focused to ensure high quality, luxury experience for passengers. Previous research and innovation meant that many highly skilled jobs, such as pilot, engineer and air traffic controller, have at least been partially automated.

Oil-rich countries continue to use their fossil fuels as the sole source of energy for flying. In these countries the price of flying is relatively lower than average, whereas in other countries the price increases manifold. Other countries buy expensive fuel from the oil-rich or use alternative hydro-carbon-based fuels (because of the lack of alternative propulsion for aircraft). These alternative fuels are a combination of bio-fuel and fuels derived from waste, whose production have either negative environmental impact in terms of land usage or limited availability/efficiency due to the chemical process used. Other sources of propulsion, such as hydrogen, electricity and nuclear are considered from time-to-time, but little progress is made because of the short-term nature of and budgets for R&D.

International air transport is governed by liberalised bilateral air services agreements to simulate a free market between the origin and destination countries. The freedom to fly, therefore, depends on the places being connected and fluctuates according to volatile political relations between countries and variations in aviation safety and security requirements at each end of the journey.

States have sovereign control of their airspace. Some countries view their airspace, from the ground up to sub-orbital levels, as a national asset and charge royalties for overflights whereas others allow free access, along the lines of the old International Civil Aviation Organisation (ICAO) first freedom of the air principle, and only apply air navigation service charges.

There is a very strong preference for local regulation, certification, design and production. Countries favour the use of aircraft that are designed, produced, certified, operated and maintained locally against local requirements and standards. Therefore, restrictions may also apply to aircraft type and associated supply chains on a route-by-route basis.

In this fragmented world, tolerance to aviation's environmental impact and licence to operate vary from country-to-country but, in general, there are no environmental restrictions on flights.

Flight routes are planned and re-planned dynamically during the journey to avoid any very severe weather that has become more common because of climate change. Sub-orbital and supersonic flights are also considered when needed. R&D has produced sophisticated tools for weather forecasting, and dynamic flight planning and control. Research has enabled vehicles to be designed to be robust against severe weather and other hazards and to safeguard passenger comfort.

The need for locally produced aircraft means that wealthy countries have their own, relatively small, aeronautics industries. Aircraft manufacture is highly automated, requiring pro-

gramming and management skills that are in demand in other, well-paying industries, so that the required skills are in short supply. Production costs, scarce resources and lack of economies of scale means that aircraft are very expensive. It is not possible to export new aircraft – those that can afford the price prefer to make their own and those that do not make their own aircraft cannot afford the price. There is, however, a market for cheaper, second-hand aircraft, which is fuelled by the desire of the very rich to own the latest models as soon as they become available. The market conditions result in oversupply and aircraft that cannot be sold on second-hand markets are dumped, adding to pollution and pirating of components that can be extracted from the dumping grounds, with potential risks regarding flight safety.

To maximise useful life, maintenance, repair and overhaul (MRO) of second-hand aircraft is a priority activity and this has been facilitated by the necessary R&D.

Deregulation in the market-driven world and the preference for local standards and certification means that aviation safety has decreased. Despite this, aviation remains the safest way to travel.

The tension between and within countries mean that high profile activities, such as aviation (and other transport) modes have persistently high security threat levels. Therefore, passenger security checks are strict but necessarily un-intrusive. The increasing reliance on automation and autonomy has increased the risk of virtual hijacking of aircraft, drones and other assets by terrorists or criminals. Robust cyber security is, therefore, increasingly important and is continuously addressed as a priority in national R&D programs.

Signposts

The following table summarises the main trends and associated signposts that will indicate that the world is moving in the direction of the Mad Max scenario.

Trend	Signposts
Deglobalisation	• Countries withdraw from international structures • International agreements replaced by national rules • Increased nationalism • Reduced safety and security • Increased tensions
Polarised world	• Increasing disparity between rich and poor • Very high prices for scarce natural resources • Increased offshoring of low skilled jobs • Increased linking of aid and trade • Increased tensions • Increased crime • Increased social unrest
Sustainability is a low priority	• Higher global temperatures • More extreme weather • Increased noise and pollution • Increased waste
Free market principles	• Increased automation and digitalisation • Reduced taxes • Reduced social safety nets • Skills shortages
Aviation as a desirable luxury	• Price increases • Narrowing of services to the luxury and bespoke • Aviation emerges as entertainment • Aircraft as toys
Focused R&D	• Reduction in long-term R&D • No international collaboration • Local focus on R&D topics - security - luxury solutions - alternative fuels - maintenance

Scenario 2: Tech for You

...aviation: side by side with alternative technology in islands of choice, competition, and customisation

A world characterised by multipolarity and competition; high-cost, low economy-of-scale production offset by widespread automation; market driven by consumer choice and desires; free market economies; high R&D with national and short-term focus; different approaches to and meaning of sustainability in different islands.

Mobility is flexible with air transport part of the local, intermodal transport system. The overall approach is to strive for door-to-door mobility.

Politics

Since 2020, the world has deglobalised, has become more fragmented and is structured into many discrete sovereign entities, mainly along national lines or as small blocs, such as the remnants of the European Union. Although the world has fragmented with a focus on local rather than global priorities, cooperation between countries is facilitated, but not driven nor enforced by, intergovernmental organisations (IGOs) similar to, but weaker than, those in place in 2020. These international bodies provide guidance and advice rather than rules and regulations. This guidance, which is welcomed by most individual nation states, is based on sophisticated simulation tools used to understand the impact of local actions and bilateral agreements on the global scale. Cooperation between countries is voluntary, not mandatory, and driven by common purpose/economic interest. This cooperation only happens when the circumstances are stable enough to enable it. Decisions by countries whether or not and how to cooperate are based on rational assessments of the benefits and value-added of cooperation. These decisions are taken on an issue-by-issue basis and are reviewed, and possibly revised, from time-to-time.

Multilateral political alliances, large economic blocs and free-trade areas have broken up since 2020. Countries and the remaining small blocs now act mainly in their own local concerns, particularly driven by the influence of their local industries, rather than being driven by overarching global concerns. These concerns include a range of themes such sustainability, social welfare and health, albeit these are all addressed at local level. Each country sets its own objectives and strives to be self-sufficient rather than working with others to a common goal, or pooling or sharing resources. The relative importance of each theme depends on the nation/bloc, and sometimes changes gradually over time. Although, sustainability is potentially a single, global, high priority thread, it is interpreted and addressed in different ways in different places.

Economics

Economies are consumer-focused, liberalised, and are driven by market forces and provision of choice to meet individual and local needs. The consumer has become the main driving force in the market and individuals expect and are provided with personalised, bespoke products and services, which range from the purely functional to luxury. Although sustainability has become one of the main considerations in consumer choice, it is sometimes overridden by other preferences. Other important consumer considerations include, in no particular order: ethical production, quality, reliability and, of course, price.

The consumer's influence has also permeated into politics where, in search of votes, governments devise policies, laws and regulations designed to meet consumer interests. In response to the major concern on sustainability, government regulation requires that the full impact of the production of products and the provision of services is included in the price (all external costs are internalised), and labels based on life cycle assessments and cradle-to-cradle approaches are mandated. These labels are not necessarily consistent from place-to-place. Producers, therefore, need to deliver goods and services that are tuned to the consumers' other demands and meet sustainability regulations which vary from country to country.

Each local market has its own specific characteristics, requiring its own bespoke solutions, goods, products and services but when possible or necessary local solutions in one market are exported to other markets with similar characteristics. There are, therefore, only a few large, international industrial players, who exert global influence, with production facilities centred in low cost economies to compensate for the need to produce low economy-of-scale, bespoke goods and services that must meet the diverse regulations and standards local to their target markets. To overcome distrust in imported products and services, as well meeting consumer demand for ethical and sustainable production and high product and service reliability, recognised strict local oversight and certification of production facilities can be a competitive advantage to producers. This can be an incentive for industry when selecting locations for their production facilities. Wealthy powers and large corporations exert influence over poorer countries using investment and aid programs that have conditions to

ensure that the donor country and its industry are in a preferential position in terms of, for example, trade, market access, political control and security.

To complement the few, large multinational industry players, there are a large number of highly-specialised, highly-innovative small companies, focused on local markets. Creativity is highly valued trait, and innovation in all fields and areas is supported by government policies and funding. However, fragmentation and the need to provide local, non-standard solutions mean that the potential for exports is low and the scale of production is small. Companies operate using customised business models in an artisan-like economy.

The local decision whether to import or make products and services is a balance between the costs and benefits of self-sufficiency compared to international trade. This varies from place-to-place depending on local circumstances.

Although international cooperation is possible, it is complex to organise because of lack of harmonisation in local regulation and funding, and local protectionism, including on intellectual property. Combined with the high demand for customisation, this results in high prices for products. In response, to reduce prices to access larger markets, companies have invested heavily in efficiency, including the application of automation and virtual technologies to design and manufacture (right-first-time). Prices are also heavily influenced by the cost of the resources and energy used to manufacture the products and to deliver the services, and by the cost of high-skilled human resources needed to enable such a high degree of automation.

Highly specialised skills and knowledge are a scarce resource: people with in-demand abilities and characteristics have a lot of opportunities and command high salaries. The demand for highly-valued highly skilled workers is addressed in two ways. Locally, it incentivises the creation of local education and training programs to upskill local workers, in competition to the inward relocation of skilled workers from elsewhere. On an international level, as production is highly automated and supported by sophisticated technology solutions, the need for workers to commute to centralised working locations is reduced and home-working is increased using information and communication technologies (ICT). This gives companies access to extensive human capital within their national catchment.

Society

The principal, common social value is caution concerning risks and the unknown. In some places this caution is managed through the application of sustainability principles, including circularity to create an environment the enables flexible responses to mitigate and recover from adverse situations. Other places take different approaches, including insularity. This societal concern and the responses to it have reduced the population's desire to travel. Other than these common social values, there are wide cultural differences between regions, countries and often within countries. However, there is a high degree of tolerance to these differences.

The interest in international and global information is limited to understanding the impact of global events on local and personal situations. News is only accessed from an introspective view as people are generally inward-looking. However, citizens have access to, mostly reliable, information and news to enable them to understand their local, national and international situation at personal, social, economic and political levels.

In some nations innovation and citizens' initiatives are supported, and entrepreneurship is encouraged, while in others they are restricted, limited or not encouraged. Given the local character of society, citizens trust in and rely on their neighbours and local communities. This encourages the flourishing of social and citizens' initiatives and of co-creation spaces, such as living labs. In these co-creation spaces, citizens and experts work together as equal partners to develop, implement and operate mutually-valued solutions collaboratively. Within the co-creation space, all voices are given equal weight without recourse to hierarchy based on, for example, technical expertise, wealth or political standing. Solutions for local problems are developed that match the specific circumstanc-

es and constraints of the local community. Local solutions often have the potential for expansion to different contexts with similar circumstances. However, the uncertainty of making connections beyond the local community is a barrier to both identifying the opportunity for and achieving this expansion. When this barrier is overcome, trust is generated in the scientific and academic communities who, in turn, truly appreciate social factors and the importance of non-technical skills in solving technical problems. This extends the concept of sustainability beyond the environment to encompass the sustainable development goals defined in 2015.

Within the constraints of local laws, for example on work permits and taxes, the increase in technology-enabled home-working gives workers more freedom to live where they want to rather than having to travel to their place of work every day. This also means that citizens and people outside the job market can collaborate with local developments and create social support networks.

People select their education and training trajectory on their personal preferences rather than as a means to access the highest paid jobs. This means that people are equally likely to be highly educated in arts, humanities and social sciences as in science or technology. To overcome the risk of shortage of qualified people in specific areas, governments adjust priorities in education and training in specific subjects depending on needs/circumstances.

Legal

Each bloc or country employs its own individual legal framework, with regulations and standards developed, applied and enforced locally. The general view is that self-sufficiency is preferred, local regulation is best and there is distrust of imported products and services, and of the foreign standards to which they are certified. To overcome this distrust and facilitate global markets, there is a centralised, voluntary framework as a bridge for verification and recognition of compliance with local regulations and standards. Even with this bridge in place, the local nature of solutions and lack of global standardisation means international goods and data exchange has become difficult.

Political, trade, legal and transport agreements are now managed bilaterally between sovereign states or blocs. Regulation focuses on sustainability, security, safety, health, data protection competition, markets and consumer protection, although these are interpreted differently in different places. Constraints imposed to limit the impact of travel on the environment and due to security concerns mean that the international traffic volumes are limited but are provided on a smooth, seamless door-to-door basis. International air transport is governed by restrictive bilateral agreements due to the political fragmentation.

Local ICT solutions and applications are highly-trusted and widely accepted. They are used by the (local) public for business and leisure purposes. However, the threat of data breaches from hacking is significant. The high level of reliance on ICT and associated applications means that consequences of security breaches are potentially very severe so that cyber security is a very high priority.

Environment

Sustainability is an underlying high common priority but is generally defined and addressed at national level. Individual blocs/countries develop and apply their own technological, economic and regulatory solutions to green issues with no single common approach. Some governments impose local sustainability regulations across all walks of life with the aim of reducing or achieving zero ecological footprint, whereas others do not. Those that strive for sustainability are supported by tools that assess environmental impact reliably according to locally varying standards. The general principle of lifecycle management is applied across the world, but is often interpreted differently. International data exchange for lifecycle analysis is facilitated by guidelines and voluntary standards produced at international level.

Each country applies its own principles with the objective to create local resilient, flexible economies with the result that the world is made up of discrete islands. Some of them apply circular economy principles at various degrees of slightly different interpretations of circularity. Most, but not all, countries prohibit the extraction of naturally occurring minerals

and non-renewable fuels and there has been extensive research in and application of recycle and reuse, next to the extraction of natural resources if needed. Recycling can include the extraction of useful elements of previous waste from old landfill sites and by urban mining. Some governments apply bespoke, local mechanisms to ensure that the price of scarce new natural resources is kept very high, especially for fossil fuels, to discourage their use. There are locally-defined recycling processes for all materials, and re-use and re-sale of used items is mandatory. However, different countries have different solutions, both influenced by and influencing local sustainability choices. The fragmentation of the circular economy into a series of islands and constraints on or lack of trade between them means that access to recycled natural resources can sometimes be difficult.

Similarly, sustainability for essential international transport tends to be based on circular technologies agreed at international/bilateral level but sustainable solutions for domestic travel are applied individually, country-by-country. Diverse societies across the world have the common characteristic of very low tolerance to pollution and noise.

Technology

To maintain competitiveness in a world with rapid technological development, national spending on research and development (R&D) is high and rewards for researchers are high. Political and societal fragmentation means that different countries often have different priorities and specialisations that result in different technology solutions, which are sometimes not fully compatible. Although most R&D is, therefore, generally small-scale and there are limited economies of scale, competition and rivalries between states increase R&D productivity and promote high levels of innovation. Technological progress has, therefore, been rapid, in part driven by the desire of researchers to find the best place to work both in terms of opportunity to innovate, the rewards generated and the scope to learn and develop.

To facilitate competitive advantage, education and training in technology are organised nationally and given high priority to ensure that skilled human resources are available to maintain the high pace of technological advance. Highly educated and skilled people are of very high value and command high salaries to keep them in their own country or to tempt them to work in other countries. To safeguard their own innovation, countries or blocs apply strict security controls on intellectual property to overcome the lack of substantive international agreements on international property rights (IPR) and patents.

Sustainability and achieving competitive advantage are the two common themes for R&D globally. Sometimes these themes are complementary and at other times they conflict with each other. Although there are differences of opinion and approach, researchers strive to collaborate internationally and there are some large-scale sustainability research programs.

Social media enabled by widely accepted and reliable information and communications technology (ICT), and augmented and virtual reality applications are ubiquitous. These often replace physical interactions for political and business connections and home working, as well as leisure activities, such as sports and cultural events and virtual vacations. Technologies and applications are provided as customised, local solutions with limited or irregular/inconsistent international standardisation.

The 2020 concerns over the reliability, safety, security and privacy issues associated with these technologies have been investigated and addressed by local regulations and standards. There are also voluntary regulations and standards to facilitate their use globally. However, personal data is only protected at national level and is owned by the person that it describes. Use of personal data requires permission from the owner and can be used for many purposes including targeted advertising. Spam and phishing from other countries is high risk if data breaches occur, but the risk is perceived as low by individuals, who trust the security standards so that applications are widely used.

Aviation topography

All aspects of travel are purely market-driven and are subject to consumer choice based on a range of personal criteria. Factors that influence the passenger's choice are price, safety,

security, health and sustainability. The combination of those factors and the precise current circumstances drive the traveller's choice on whether-or-not to make the journey, and which combination of transport modes to use.

Customisation means that all possible customer needs can be met. Luxury solutions that optimise the passenger experience are provided at high price, whereas competition on customisation means that very low prices can also be used to attract travellers to different range of services. This need for customisation means that diverse aircraft types and classes of travel are developed based on the needs of the market, cultural preferences and available national resources.

International travel is managed by bilateral agreements between the governments concerned. These bilateral agreements are often restrictive due to the political fragmentation. In some places, sustainability requirements can also limit the volume of traffic, the vehicles that can be used and the routes that can be flown. International travel has decreased because of deglobalisation, social disapproval, the successful reduction of the need to travel by the use of ICT and virtual technologies for both business and leisure purposes, and the availability of alternative transport mechanisms for all but intercontinental journeys. In parallel, the cost of international flying has increased because of this reduced demand, the lack of global standardisation, the need for multiple certifications for aircraft and equipment, and the requirements that aircraft and systems must meet multiple, different sustainability, safety and security requirements. This increased cost has further reduced demand for international aviation in a vicious circle.

Long-haul air services have become less convenient because of global fragmentation and the restrictive bilateral, rather than liberalised multilateral, nature of international aviation agreements. The prevalence of bilateral agreements means that technological developments can often proceed rapidly and customised solutions are possible but both are constrained to the specific market being addressed with the risk that requirements vary from market-to-market. These constraints might include restrictions on propulsion and fuel types as well as other aircraft characteristics such as noise footprint, depending on the countries involved.

There is still high demand for short- and medium-journeys, and the market demands door-to-door solutions. These journeys are made in different ways depending on location and personal preference. Air journeys can be combined with other modes of transport to provide a seamless, customised door-to-door service. In some places, journeys are served mainly by non-aviation modes of transport such as high speed rail or hyperloop. In prosperous places, short-haul flights using highly-customised, personalised conventional aircraft and/or urban air mobility concepts, are available to the very rich and VIPs. In other places, short- and medium-journeys are still made using conventional but sustainable aircraft. In others, UAM is fully developed and implemented. Personal air mobility (PAM) solutions provide very convenient travel solutions for journeys within national boundaries, minimising the number of inter-connections for door-to-door travel. PAM solutions can be available for domestic journeys, covering intra-urban, inter-urban, rural and regional travel. In all cases, door-to-door journeys are customised and seamlessly integrated irrespective of transport mode.

Drones are commonplace and have limitless applications. The most widespread application is within fully integrated logistics chains. Other drone uses include surveillance and data collection in applications such as traffic management, crime prevention, air quality monitoring, waste management and emergency services. Drones are also used in agriculture for crop and herd monitoring, mapping, pest control, planting, irrigation, crop spraying and harvesting. In addition, high altitude platform systems (HAPS) are used to support communications, navigation and mapping, surveillance and monitoring, and earth observation.

Concerns about the negative impacts of aviation means that aircraft are designed keeping some level of sustainability in mind. Whether it is propulsion or to be fully re-usable and the materials used are locally sourced and constantly recycled. This does not have a negative impact on aviation safety, as

recycled and bio-based materials, and the processes to produce them, have been fully certified for high-tech, high-specification, operationally-critical applications. Although sustainable fuels and propulsion covering all lengths of journey from intra-urban to inter-continental and all aircraft types, from advanced air mobility through to long-range aircraft, are available, their availability depends on local circumstances, so they are not always used. To adapt to the diversity of market requirements, aircraft have been developed to be modular, scalable and multi-purpose.

The aviation R&D ecosystem is local, multidisciplinary and based on co-creation principles. Solutions developed in different industries are constantly evaluated for application in the aviation domain. This generates a R&D situation in which communication skills are essential, and technical jargon is simplified, so that it is easy for experts form different domains to interact. Citizens are fully integrated in the development of solutions for aviation challenges which relate directly to society, such as noise and passenger experience.

There are airports here and there, depending on the island, for long-haul travel. The majority of transport is door-to-door, so the need for nodes of interexchange is limited, but they do exist in some areas relying more on traditional transportation or physical infrastructures. Passenger experience is as smooth as possible for everyone.

Signposts

The following table summarises the main trends and associated signposts that will indicate that the world is moving in the direction of the Tech for You scenario.

Trend	Signposts
Deglobalisation	• Vocal dissatisfaction with international structures • Increasing non-compliance with international requirements • International agreements replaced by national rules • Federal arrangements replaced by free trade areas
Sustainability	• Increasing consensus on sustainability issues • Increasing intolerance of noise and pollution • Emergence of voluntary global cooperation mechanisms
Consumer choice	• Economies tend to free market principles • Large numbers of customised competing products and services • Increase in start-up initiatives and SMEs • Decreasing international trade, focus on local markets • Price increases
Reluctance to fly	• Vocal opposition to flying • Increase in substitute travel solutions • Increases in virtual and augmented reality alternatives to travel • Increase in price

Scenario 3: Stripping Down

...aviation: sustainability achieved in a stable, coordinated and harmonised world

A world characterised by political stability; a few continental-sized democratic blocs; global harmonisation between blocs; limited consumer choice; markets organised around incentive-based regulation; planned, slow but stable economic growth; prioritised and government-directed sustainability.

Sustainable intermodal generic solutions adopted to reduce environmental impact and achieve sustainability policy objectives. There is limited and highly controlled mobility due to sustainability objectives and incentives.

Politics

Since 2020 the world has unified and is organised harmoniously on universally agreed common principles. Politics is led by elected governments that are trusted to set and inspire people to work collectively, towards a commonly-accepted set of objectives. These objectives cover all aspects of the sustainable development goals and other societal concerns, including poverty, employment, education, economics, climate change, terrorism and health. These objectives are defined and underpinned by clear, compulsory rules and regulations.

Internationalism has replaced nationalism and the world is organised into a few large, continental-sized, federal blocs. Each bloc has pooled sovereignty, centralised institutions and a common legal framework. Global power is centred on these blocs, which work together cooperatively through multilateral political agreements and strong institutions developed from the United Nations model. Amongst other things, these agreements cover the sharing and safeguarding of scarce resources, including fossil fuels and critical materials. These arrangements are stable, tensions are low, and there is very low risk of conflict and little or no security threat. Despite this stability, but based on past experience and history, there is still concern about the perceived risks that can potentially threaten human existence, including climate change, war, terrorism and adverse health events, even though the actual risk is very low.

Economics

The world economy is overseen communally by the governments of the large federal blocs and is based on mandatory principles to ensure compliance, fairness and a level playing-field. Individual governments work together to ensure that local economies are synchronised. Economic growth is planned to be neither too high nor too low, with the objective of ensuring stability and predictability. Wealth is distributed equitably with the result that there is no large variation between rich and poor, nor between different regions of the world.

The market for goods and services operates globally. Sustainability impacts all aspects of life. Governments provide recommendations and guidelines on sustainability. Minimum sustainability standards are mandated for every product and service. Standardised solutions and products are replaced only when a more sustainable alternative is identified and developed. Consumer choice is not a significant driving force and consumers are satisfied by high quality, but generic, goods and services with little variety or differentiation to choose between them.

Industry develops slowly but consistently, and is dominated by a few large, international industrial players, operating as near-monopolies under regulatory incentives to grow and improve efficiency. Government policy promotes strong industrial clusters to drive economic growth. Centralised transport policy ensures good inter-connectivity between clusters.

The profit motive has been replaced by corporate social responsibility and companies take a stakeholder rather than a shareholder view. This ethical approach, reinforced by government regulation, means that the full impact of the production of products and the provision of services is included in the price (all external costs are internalised), as based on life cycle assessments and cradle-to-cradle approaches. Combined with the lack of proper market competition, this means that prices are relatively high.

Workers are highly skilled and highly specialised. Working conditions are good. Job security is high because the workplace only changes slowly. In addition, government investment has created a strong education and training system enabling workers to develop new specialisations when needed.

Society

Social and cultural diversity across the world remains, but has converged on a set of common social values, based on maximising the established common good. This common good covers factors such as sustainability, equal wealth, economic stability, peace and health. Individuals have become out-

ward-looking, but are accepting of rules imposed by their elected governments. These governments provide citizens with reliable information and news, local and global, to enable them to understand the world at personal, social, economic and political levels.

Social policy ensures that all citizens have access to adequate salary, job opportunities, education and training, healthcare, cultural and leisure opportunities and social welfare. Implementation of this social policy means that populations are centred on large mega-cities, where these benefits are most easily delivered, and because governments strictly control the spread of populations into the countryside to ensure the safeguarding of wildlife and biodiversity. Centralised transport policy ensures good inter-connectivity between mega-cities. Regulations, systems and restrictions are in place to control congestion and pollution within the mega-cities.
Depending on their particular aptitudes, people are encouraged along a specific education and training trajectory by government to meet forecast future skills needs. This results in people becoming highly specialised and narrow in focus, limiting innovative, out-of-the box thought and inhibiting the flow of radical new ideas. Re-education and re-training are required as the need for old skills is superseded.

Legal

The major federal blocs work within a global, legal framework defined by universally agreed regulations and standards developed, applied and enforced at international level. There are common, mandatory standards on sustainability, safety, security, health, and data protection. These are applied and enforced uniformly across the world. Sustainability is a very high priority all across the world and strict environmental regulations are in place.

Safety assurance is applied on a zero tolerance basis; there is no room for uncertainty, by aiming at a no-accident performance requirement from demonstrators through to full operations. Certification is achieved efficiently to a very high global standard through mutual recognition.

Political, trade, legal and transport agreements are now managed through multilateral agreements and overseen by global institutions. Borders are open for sustainable and responsible travel. International travel requires health, security and immigration checks, which are organised to be minimally intrusive and are based on citizen databases that are shared between governments.

Environment

Common technological, economic and regulatory solutions are mandated and applied to environmental issues globally. Extraction of naturally occurring minerals, raw materials and non-renewable fuels by mining, drilling and fracking is prohibited by law except in exceptional circumstances. However, useful elements of previous waste are extracted and recycled from old landfill sites and by urban mining.
Life cycle assessments are mandatory, applied uniformly across the world and cover the entire life cycle of products and services. Strict laws apply to the end-of-life management and disposal of all vehicles, electronics, materials, batteries, etc. Re-use and recycling are mandated and the global economy is fully circular following common principles and definitions. This fully circular economy means that recycled natural resources are plentiful. There is almost no need for further exploitation of untapped natural resources. Although the general population is highly aware of, sensitive to and supportive of environmental and health issues, laws are in place to ensure compliance.

Technology

Technological progress occurs mainly as a result of government incentives rather than market pull or technology push. R&D requirements are defined by government to meet their specific objectives. Government-funded solutions are developed collectively across the world, often through shared, large-scale program, often with highly specialised research organisations focusing on their own (narrow) specialisms but working closely with others to provide a complete solution. The directive nature of R&D means the solutions focus on known-problems and are very successful, but innovation is slow. Change is evolutionary and incremental, rather than revolutionary and disruptive.

There is a risk that access to skilled human resources can sometimes be problematic, especially in the light of unforeseen events or developments. This is due to workers having highly specialised and non-transferable skills. This risk is managed by governments' forward planning in education and training to ensure that the required mix of skills is available to meet future demand as it is envisaged.

Globally standardised information and communication technologies (ICT), and virtual and augmented reality applications are ubiquitous. These have arisen from government directives to develop applications to reduce travel to improve sustainability and health. The 2020 concerns over the reliability, security and privacy issues associated with these technologies have been overcome so that they are generic, globally standardised, widely accepted and used by the public for business and leisure purposes. Large-scale data is collected by government and is used for the benefit of society to analyse and improve performance and understand behaviours. Personal data is protected, is fully-owned by the government and can only be used for societal benefit.

Aviation topography

Aviation is no longer a competitive market, but is driven by government guidelines that advise the traveller according to commonly accepted principles rather than providing or allowing full freedom of choice.

Unless it is proven to be the most sustainable mean of transportation, flying is strongly discouraged. This approach is a huge incentive for original equipment manufacturers (OEMs) to develop the most sustainable solutions not only within aviation but also compared to other transport modes – extensive research has been undertaken to optimise the sustainability of air vehicles.

Governments have agreed globally to allow flights for long-haul journeys where there is no alternative. For other journeys, government encourages the mode of transport to be used, in order to control congestion and pollution and to assure safety and security. Research has produced tools to manage mobility and mitigate congestion. A common safety and security management system has been developed and applied further improving aviation's safety record. Government strongly promotes the use of public rather than private transport. Virtual and augmented reality technologies are also promoted as an alternative to travel for both business and leisure. When flights are allowed, skies are fully open, but subject to strict aircraft performance (pollution, noise), market access and non-discrimination rules.

The public is aware of the negative impacts of travel in general and of flying specifically. People also have strong memories of the risks associated with terrorism and pandemic and try to avoid travel as much as possible. Social pressures not to travel, including flight-shaming, are widespread.

The combination of government discouragement of flying and the public reluctance to fly means that aviation demand is very low; consequently the market for conventional aircraft is small, and the few industrial players produce only low numbers of aircraft. There is strong focus on alternative transport modes for short- and medium-journeys. These alternative modes include rail, metro, bus, autonomous vehicles and urban air mobility (UAM) public transport solutions, and drones for logistics.

Low volume, long-haul services are provided from a small number of hub airports using small conventional aircraft operated point-to-point by airlines. New business models have been developed to enable operators to remain profitable with few passengers and low economies of scale.

Sustainability is the key concern in planning and operating flights and takes precedence over journey time, flight frequency and convenience. Schedules are optimised using demand forecasts and might not provide direct routes, requiring intermediate stops, aircraft changes and layovers to ensure that aircraft are full. Operationally, minimum load factors have to be reached, otherwise government measures incentivise the cancellation of flights to minimise adverse impacts. Flights follow environmentally optimised flight paths, considering factors such as distance and weather conditions, and utilise new operational models, such as formation flying.

The full environmental cost of the flight must be paid in the ticket price: coupled with government intervention, this means that long-haul travel is very expensive, further suppressing demand and mainly restricting air travel to the few people. Essential journeys, with no alternative to flying, are subsidised within the constraints of strict international guidelines.

Social principles, reinforced by laws, require that shorter journeys be made by the most environmentally friendly means, defined using widely-accepted performance indicators by reliable and impartial government agencies. Connections to the few, geographically sparse, large hub airports are provided from strategic locations within the mega-city transport network using sustainable aircraft, high speed train or hyperloop-like solutions, which are also used to replace air transport for short- and medium-journeys. Within the mega-cities themselves, local connectivity is optimised at multiple, small intermodal nodes to provide time-efficiency, affordability and convenience using sustainable vehicles, including train, bus, metro, connected autonomous vehicles and public urban air mobility solutions.

Drones are only used when they meet fully the environmental goals set by government. When they are used, they must be fully sustainable. Their applications are integral part of the functioning of the mega-cities, providing a number of services within the city limits.

Signposts

The following table summarises the main trends and associated signposts that will indicate that the world is moving in the direction of the Stripping Down scenario.

Trend	Signposts
Federalisation	• Reduced tensions between neighbouring countries • Strengthening & integration of free trade areas • Expansion of existing federal structures • Strengthening of global institutions
Sustainability	• Global consensus on the need for sustainability • Agreement priority areas for sustainability • Unaffordable prices for fossil fuels • Increased research into alternative energy sources
Controlled markets	• Incentive-based regulation • Internalisation of external costs • Stakeholder based governance • Increased free trade agreements based on regulatory convergence
Opposition to aviation	• Increased anti-aviation social media campaigns, including flight shaming • Direct action/demonstrations against aviation • Reduced tolerance to noise and pollution • Government guidelines on modal preference and promotion of public transport, including UAM as a service • Reduced demand for flying
Alternatives to travel	• Development of cheap, ultra-fast, reliable, high bandwidth communications • Emergence of new virtual and augmented reality apps • Increased confidence in cyber security
Focused R&D	• Increase in government-defined, international R&D programs focused on a few specific topics • Reduction in more general blue sky research and innovation • Reduction in national and industry R&D • Increased R&D specialisation in research institutes • Short-term focus on research into battery and nuclear technology, and quantum and optical computing

Scenario 4: Optimising Together

...aviation: unlimited freedom in a world of common purpose, collaboration and cohesion

A world characterised by unification and harmony; global cooperation and collaboration; global legal and institutional frameworks; high stability and growth; sustainability; market-driven economies and liberalisation; high standardisation and confidence.

Mobility is growing and is fully sustainable. Different aviation solutions are available for all journey segments from UAM through formation flying to sub-orbital flights.

Politics

Since 2020 the world has unified and is organised harmoniously on common views, widely-held principles, tolerance and understanding.

Politics is based on international cooperation working towards universal goals within a globally agreed and stable framework. Internationalism has replaced nationalism and the world is structured as a combination of large federal blocs and sovereign states.

Countries work together cooperatively through multilateral political agreements, governed by institutions developed from the United Nations model. Amongst other things, these agreements cover the sharing and safeguarding of scarce resources, including fossil fuels, minerals and other raw materials. The global agreements and institutions ensure that countries and regions can retain their heritage, culture, customs and characteristics. Diversity is celebrated and contributes to different perspectives and ideas. This promotes tolerance and understanding needed to avoid tension and conflict and to manage uncertainty and risk.

Economics

Economies are market-driven, liberalised and self-sustaining with minimum government intervention. Economic growth is high and stable. Wealth increases and is distributed evenly with the result that there is no large variation between rich and poor nor between different regions of the world.

The market for goods and services operates globally. Consumer choice is a significant driving force and consumers demand sustainable, high quality goods and services. There is great demand for sustainable energy, mobility, and goods and other services that have real or perceived high social-value.

Industry develops very quickly, is fully globalised and operates under well-defined frameworks that support cooperation between businesses, improving supply chain efficiency. Industry operations have very high productivity, are agile and can quickly adjust supply to match demand. Large-scale, specialised systems with short production runs and low volumes are only produced on a near-monopoly basis with optimised regulatory frameworks ensuring that this position of market power cannot be abused. There are highly competitive markets for mass-produced consumer items. Efficiency is optimised through automation of design and production.

The profit motive remains, but at the same time companies have highly developed policies for corporate social responsibility and taking stakeholder views into account. Companies account for the full impact of the production of products and the provision of services in their approach to pricing using life cycle assessments and cradle-to-cradle approaches (all external costs are internalised). The competitive, market-based economy and continuous efficiency improvements mean that prices are moderate.

Workers have high and transferable skills, are flexible, and are able and willing to work in different jobs and locations. However, the availability of home-working ICT applications means that there is little need for employee mobility or commuting and gives employers access to the global skills base. Working conditions are good and there is a strong education and training system enabling workers to adapt to changing requirements and to ensure job security in a rapidly developing workplace.

Society

Sustainability is a major societal goal all across the world. The general population is highly aware of, and sensitive to environmental issues and committed to sustainability. In addition to sustainability, social policy has many other objectives including ensuring equality of opportunity, overcoming poverty and improving health. In particular, health monitoring is an un-intrusive, routine part of daily life and is used to predict and prevent outbreaks of infectious, congenital and lifestyle related diseases.

Empathy is also a major societal goal. Celebration of different cultures enhances diversity in a virtuous circle of tolerance and understanding. This diversity equips society with the confidence and strength to manage uncertainty, risks and threats

without undue disruption. Individuals have become outward-looking and are genuinely interested in understanding others. Citizens have free and open access to reliable sources of information and news, local and global, to enable them to make informed decisions at personal, social, economic and political levels.

Given the empathetic nature of society, citizens trust in and rely on their fellow-citizens globally. Social and citizens' networks, and global and local co-creation spaces abound unfettered by geography and distance. In these co-creation spaces, citizens and experts work together as equal partners to develop, implement and operate mutually-valued solutions collaboratively. Within the co-creation space, all voices are given equal weight without recourse to hierarchy based on, for example, technical expertise, wealth or political standing. Solutions for global and local problems are developed that match the specific circumstances and constraints of the communities involved. Solutions are scalable to different contexts with similar circumstances. Trust is generated in the scientific and academic communities who, in turn, truly appreciate social factors and the importance of non-technical skills in solving technical problems. This extends the concept of sustainability beyond the environment to encompass the sustainable development goals defined in 2020.

People select their education and training trajectory on their personal preferences and aptitudes. Personal preferences vary and can range from enabling access to the highest paid jobs to making contributions to society for the general good. This means that people are highly educated across the entire range of subjects including science, technology, engineering and mathematics, and arts, humanities and social sciences. Investment and training in education and training are balanced between the state, industry and the individual.

Legal

Political, trade, legal and transport agreements are now managed through multilateral agreements and overseen by the global institutions. Borders are open and international travel only requires the minimum checking and scrutiny.

All countries work within a global, legal framework defined by universally agreed regulations and standards developed, applied and enforced, light-touch, at international level. There is a uniform global regulatory framework covering safety, security, sustainability, data protection and health standards. Minimal national variations are allowed but are harmonised. Standardisation and certification use virtual tools and are flexible and agile enough to facilitate new technology development and advanced operational concepts. Efficient certification is achieved to a very high global standard using mutual recognition.

Safety and security assurance are applied on a continuous improvement basis, with the ultimate goal no-incident performance requirement for demonstrators that flows through to full operations.

Environment

Challenging, common sustainability goals are agreed and applied consistently across the world. Countries and blocs work in concert to meet these goals by working together to produce common, global technological, economic and regulatory solutions, but also by developing harmonised local solutions where this is more appropriate. These solutions are proved before application using reliable simulation tools and models.

Full lifecycle management and analysis is applied to all products and services. End-of-life management of all vehicles, electronics, materials, batteries, etc., follows fully sustainable principles everywhere. There is strong social pressure to avoid waste and pollution, so everything is re-used or recycled on a spontaneous basis. Zero-emission fuels, fully electric vehicles and other sustainable solutions are available and applied everywhere. Sustainable development goals are met. Clean energy is readily available from renewable sources. The global economy is fully circular following common principles and definitions. The fully circular economy means that recycled natural resources are plentifully available. There is almost no need for further exploitation of untapped natural resources.

Technology

R&D investment is high. Activities are balanced between international collaboration and national investments, large- and small-scale programs and short- and long-term objectives. R&D is characterised by distributed, virtually supported, programs with contributors addressing their own specific areas of specialism in an integrated and coherent way from any location in the world. This is supported by a global framework for international multi-disciplinary cooperation in R&D, including optimised knowledge sharing and access to publications.

Access to human resources is optimised. This is due to a combination of highly flexible skills within the workforce, the capability and desire of workers to re-locate if required, as well as the widespread application of automation and access to extensive human capital using ICT-enabled remote working.

Technological innovation is rapid. Automation, information and communication technologies (ICT), artificial intelligence (AI), quantum computing and virtual and augmented reality applications are ubiquitous, standardised globally and fully interoperable using seamless and transparent data exchange. The past concerns over the reliability, security and privacy issues associated with these technologies have been overcome so that they are widely accepted and used by the public for business and leisure purposes. Large amount of data is collected throughout the full range of daily activities, including transportation, and is used for the benefit of society to analyse and improve performance and understand behaviours. Personal data is protected, fully-owned by the person that it describes and can only be used for the benefit of society and/or of its owner with its owner's permission.

There is widespread trust in politicians and scientists. Citizens are actively involved and engaged in policy decisions and product development. Because of this, R&D has extensive social involvement following co-creation principles that result in very high positive societal impact and economic benefits.

Aviation topography

Demand for travel is high, driven by increases in wealth, the open, stable and outward-looking nature of global society, the high confidence of the average traveller, and the achievement of highly sustainable transport systems. All concerns related to pollution, noise and unsustainable practices linked to aviation have been solved or are being addressed using inclusive, collaborative mechanisms in cooperation with citizens and passengers. The very low negative impact and positive public view of aviation means that it competes effectively, as an integral part of a seamless, door-to-door intermodal network, with virtual technologies for both business and leisure purposes.

Global transport networks are highly interconnected, seamlessly intermodal and provide door-to-door service globally. Where they are needed, airports are integrated in the urban environment. Activities specific to aviation, such as security checks and baggage handling, are integrated into the transport network and are transparent to the user. Systems based on artificial intelligence, machine learning and decision provide information and advice to the traveller for journey planning to optimise the door-to-door intermodal journey according to configurable criteria that include sustainability, time, cost, convenience and comfort. Similar information is provided during the journey to enable re-planning in the case of disruption. Skies are fully open.

The full spectrum of completely sustainable travel solutions is provided. At one end, there are luxury solutions that optimise the passenger experience, comfort, journey time and convenience. These solutions are provided at high price. At the other extreme, lower prices are used to attract travellers to basic, no-frills services.

Given the complexity of transport network in general and aviation in particular, advanced technologies and processes, such as artificial intelligence, machine learning, quantum and optical computing, cloud applications, are used to solve multi-constraint, multi-variable, highly non-linear problems. The

data generated are openly available, for experts to study and to develop new solutions, in collaboration with the other stakeholders, including passengers and citizens.

Research has enabled long journey segments to use sub-orbital hypersonic/supersonic vehicles that connect to fully electric aircraft and trains for shorter segments, with local transport being provided by sustainable urban air mobility (UAM) solutions both self-driven and through innovative UAM taxi services, electric cars, bikes and scooters, as well as cycling and walking. The environmental impact of these journeys has been minimised by successful development of sustainable fuels, new and optimised propulsion technologies and energy storage methods. Uptake of new technologies, including full autonomy, to improve efficiency and reduce negative impacts is rapid and facilitated by advances in artificial intelligence, machine learning and decision support, and quantum and optical computing. New operational concepts, such as formation flying, have progressed, and are routinely used operationally. New configurations of modular, multi-purpose aircraft have been developed and are used to improve flight efficiency.

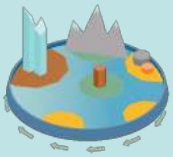
All of the components of transport and logistics networks are fully sustainable through combined development and use of zero emissions fuels and electricity generated using a wide range of renewable sources. There is no use of fossil fuels anywhere. All of the materials used right across the aviation value chain have been developed to be fully sustainable, as are production and manufacturing processes. End of life considerations are fully implemented and no disused vehicles are dumped. This has been achieved through various design approaches, such as modular design.

Signposts

The following table summarises the main trends and associated signposts that will indicate that the world is moving in the direction of the Optimising Together scenario.

Trend	Signposts
Unified world	• Consensual strengthening of global institutions • Creation of global regulatory frameworks • Fair allocation of scarce resources
Sustainability	• Global consensus on the need for sustainability • Global sustainability goals • Common approach and tools for meeting sustainability goals • Fossil fuels replaced by fully renewable energy sources • Emerging global circular economy • Full recycling with near zero waste • Decrease in need to use untapped natural resources
Free markets	• Fully liberalised, global single market • Internalisation of external costs • Stakeholder based governance • High efficiency and productivity • Increasing automation • Highly skilled workers
Support for aviation	• Fully sustainable aviation • Increasing demand • Increasing complexity • Risk of increased congestion • Evolution fully integrated, intermodal mobility solution • Wide range of vehicle types • Full spectrum of services, from luxury to no-frills
Balanced R&D	• Global level planning • Coherent mix of short- and long-term, international and national, government- and industry-funded programs • High rate of adoption of new technology • High innovation

Overview of the Scenarios

	Mad Max	Tech for You	Stripping Down	Optimising Together
				
KEYWORDS	Individualism, capitalism, survival for the fittest, fragmented world.	Independent blocs in an fragmented world, customised technology for all customers.	Enforced sustainability, government oversight.	Harmonious world, responsible consumerism, optimism.
POLITICS	No global standard, anything goes depending on location.	No global standard, wide variation depending on location.	Unified governments, global standardised rules and regulations.	Sharing is caring, room for diverse people in a common world.
ECONOMY	Completely free market, high inequality. High dependence on fossil fuels.	Consumer focused, consumerism, lots of customisation and automation.	Open, strict market regulations on sustainability.	Open, free market with global regulations on certification.
INDUSTRY	Few big local players that dominate (and crush).	A lot of smaller players, all very different niches, all with their own rules and standards.	Few big local players developing sustainable solutions.	Completely free market, high inequality. High dependence on fossil fuels.
SUSTAINABILITY	Denial, but heavily impacted by the consequences of climate change.	Overall an underlying importance, tackled with local solutions.	Very important, but strategy and solutions are imposed.	There are many paths to a greener world, and we only get there together.
R&D	Little is shared, high royalty fees and strict IP.	Broad and varied, everything is possible.	Incremental development towards sustainable solutions.	Broad and varied, everything is possible.
TECHNOLOGY	Great solutions come at a great price. Only the rich can afford the best of the best.	Highly personalised solutions, the consumer decides.	There is a lot of standardization, high quality but limited choice.	Plenty of options, dynamic and fast-changing, based on cooperation.
TRAVEL	Limited and only for the rich. Virtual for the poor.	Low demand, people avoid due to the high cost, environmental concerns and other risks.	Done in standardised and sustainable way, working from home is encouraged.	Everything is possible with no environmental impact.
AVIATION	A luxury, with many obstacles because of extreme climate and scarcity of fuel.	Limited, but varied solutions to meet requirements.	Limited and in the most sustainable way possible.	Limitless. All zero emission.


EREA

The Future of Aviation for EREA

Common themes

As can be seen from the scenarios, the future is far from certain. However, the scenarios do show some common emerging themes, principally:

- The integration of aviation into a broader, comprehensive, transport system. Transportation itself and all ancillary activities will be integrated, resulting in an interconnected, multi-modal transportation offer.
- Drones and urban air mobility vehicles, will become part of the everyday panorama. Their applications will vary greatly depending on specific societal conditions and will cover already-emerging markets, such as logistics and security, and others which have not yet been foreseen.
- An increase in the costs and consequently in the price of aviation, both for producers and users. Whether it is driven by low demand, internalisation of external costs or by increases in the price of (customised) products, flying will become more expensive.
- An increase in alternative technologies to classic aviation and mobility. Whether out of security concerns or sustainability awareness, travelling and commuting will be reduced and be replaced by digital interaction or by different forms of transportation.
- An increased awareness and demand for security and safety and an increase in related challenges. Either caused by societal instability, by increased aversion to perceived risk or by increases in traffic, safety and security will be paramount aspects for aviation (and all transport modes).
- Beyond the impact on society and individual citizens, these trends will impact all aviation community stakeholders: industry, government bodies, educational institutions and the research community.

Impact on Aviation Stakeholders

Industry

The aviation supply chain is complex and extensive, including airlines and other aircraft operators, original equipment manufacturers (OEMs), maintenance, repair and overhaul (MRO) organisations, airports, service providers, such as ground handlers, and air navigation service providers (ANSPs). The trends emerging from the scenarios show that the current players will have to change and adapt strategies and business models to provide the products and services needed to serve future markets, in whichever direction that they evolve. It is likely that some of the current players will not adapt, either by choice or by inertia, and will disappear from the aviation landscape. On the other hand, it is certain that new players will emerge and, potentially, replace companies which are now worldwide leaders in the aviation market.

Governments

Government bodies will play a significant role while new trends unfold. Government involvement can be proactive or reactive, liberal or controlling. At the proactive end of the spectrum, governments will cooperate fully with research and industry partners to identify technological solutions, which can benefit society and increase industrial competitiveness. Government will support these solutions through appropriate policies, regulations and funding. At the reactive end of the spectrum, government will only act when forced to by societal pressure or in response to emergency situations. Liberal policies will be applied to facilitate market- or societal-driven outcomes, whereas the controlling approach will be taken to drive the outcome in line with the government's policy objectives. There is not necessarily a direct relationship nor a contradiction between the proactive/reactive and liberal/controlling approaches; the future is likely to be characterised by a mixture of all.

Education

Universities and education establishments will adjust their curricula to adapt to the demand of jobs in specific areas of expertise and to include activities to form professional profiles fitting the given work environment, not only in terms of technical skills but also in terms of communication and leadership competences. Education will also adjust to different demographics, as "lifelong-learning" will become more and

more common and as extended life-expectancy can open opportunities to be involved longer in the workforce, with evolving roles and contributions.

Research establishments

Research and development organisations exist at the interface of industry, government and academia. They have become experts in dealing with the specific character of aviation, thriving and excelling within the multi-player, multi-interest ecosystem. Regardless of which scenario for the Future will come into being, this ecosystem will evolve, twist and turn, reflecting the changes in the society and in the other stakeholders. Research establishments and overarching associations, such as EREA, will need to adapt their roles in order to ensure that research and innovation will continue on having the most beneficial impact on society, in individual countries and in collaborative research programs across Europe. In this respect a critical role of the research establishments, alongside actually undertaking R&D, is to provide impartial and independent advice to government and industry decision-makers on the implications of their policy and strategy. Irrespective of the scenario for the Future of Aviation, there is a number of common factors that research establishments need to understand and address in order for R&D to be successful.

Critical success factors for aviation research

Industrial context

Science enables technology; technology enables business. Science is based on long-term vision; technology on a medium-term vision; while business is based on a short-term vision to address and react to the dynamic business market.

Motivations in the science, technology and business worlds can be very different. In simple terms, science is based on inquisitiveness and a thirst for knowledge and understanding; technology is based on generating solutions to problems, which were often unknown beforehand; and business is based on generating wealth and profit. Too often, the different visions and motivations lead to misunderstanding and conflict. Therefore, there needs to be a common understanding and set of high-level objectives for aviation to enable all the actors along the aviation technology value chain – academia, research establishments, manufacturers, regulators, and technology operators – to work together harmoniously while fulfilling each of their own visions. This common understanding needs to be defined in policy based on societal values applied uniformly across the European Union and its R&D partners.

The aircraft industry operates in a world market, which is profit-driven. In addition to this, industry structure and competitive position are influenced by government industrial policy (tax incentives, R&D funding, financing through banks, other forms of political leverage) and is constrained by trade barriers, restrictions on state aid and boundaries to protect nations' strategic interests (protectionist measures, political guiding of demand, assistance for sales to foreign countries). As a prerequisite to invest in R&D, business requires favourable conditions for the rapid commercialisation of technologies with sufficient short-term return on investment. Business financing of R&D relies on access to adequate numbers of well-trained and mobile researchers, who are responsive to the needs of industry, and an excellent research base (research establishments and infrastructure), from which to extract knowledge and human resources. The research establishments are delivering value to business and need a reciprocal framework to ensure that they are adequately compensated for their contribution. This framework must also support the long-term sustainability of required infrastructures that are paramount to develop, test, validate and certificate emerging technologies.

To transfer knowledge from research to industry to the benefit of industry and the economy, European research programs have increasingly become industry-led and oriented. Therefore, in addition to the specific objectives of the research, these programs are defined to protect the interests of the industry participants, reflecting that many of them are competitors, as well as the national interests of the participating countries. Some of the considerations in defining European-level research, therefore, are:

- The short-term business objectives of the industry participants;
- Employment pressure in the participating countries;
- Protection of proprietary and intellectual property rights;
- A balanced distribution ("juste retour") of the budget among the European industry players.

As research establishments act as a connection from fundamental and academic knowledge to industrial implementation, their interaction with industry needs to account for the interests of the industry. Nonetheless, some aspects of this interaction need to be re-balanced to ensure a healthy research panorama; in particular:

- Business models;
- Intellectual property;
- Technology transfer policy and supportive policy for spin-off company creation (from research).

Business models

As described above, the conditions for participation of industry participants in publicly-funded R&D activities changes the nature of the research environment and can distort the objectives of long-term research projects and initiatives. There is also a risk that industrial participation re-focuses long-term research on short-term issues facing individual participants rather than maximising the long-term, collective benefit. In addition, European-level publicly-funded research should deliver benefits to European industry and society as a whole, not just to individual participants or countries. This should also include spill-over into other sectors if relevant.

Knowledge-based society requires investments in research, technology and innovation in order to enable a more dynamic business market, but there needs to be a clearer distinction between public and private research funding. The optimum balance needs to be found between the two funding streams of funding to ensure that both societal and business objectives are met.

Public R&D funding must finance both fundamental research (technology readiness levels (TRL) 1 to 3) which leads to breakthrough technologies in the long term, and applied research (TRL 4 to 7) closer to technological results. Public-funded research should be available to all players (across different sectors) in an equal way, through platforms and initiatives as open science, open access articles and journals. Private R&D funding should be directed to the development of products for the market (TRL 7 and above) and encompasses innovation that requires protection of intellectual property.

Intellectual property

Intellectual property (IP) is a concept strictly related to the business world, as it provides a link between innovation and the market. Intellectual property has different forms, such as copyrights, patents, trademarks, and trade secrets. Seen in a positive light, intensity in protecting intellectual property reflects the capacity of exploiting knowledge and transforming it into economic gain; it can be seen also as a means to avoid duplication of innovation, but the strict limitations in using protected knowledge are an obstacle towards further development by building on existing innovation. It also prevents communication and real impact of innovation and research outcomes.

Therefore, the creation, spreading and strengthening of an industrial policy for intellectual property protection, should be encouraged as an asset that will increase competitiveness, lead to the generation of income with a positive impact on the economic development of Europe and as an indicator of the scientific performance and innovation in any sector. Those supporting actions should still enable the research community to access and elaborate intellectually protected information for fundamental research at low TRL, in possible collaboration with the owner of the IP knowledge, but while ensuring that the IP-owner is not the only beneficiary of the new research. Industry should not use IP to claim knowledge and research, preventing researchers to work on and further develop it, especially if the knowledge has been generated by public funding.

Technology transfer and research spin-off

Not all science must necessarily generate business, but the science which does should be supported to do so. Pro-technology transfer government policies play an essential role in encouraging both research organisations and enterprises to transfer knowledge and technologies. The industrial mindset needs to adapt, more and more flexible and agile start-ups are being created to drive innovation because of the inertia of big industrial players.

Efficient and effective technology transfer brings several benefits:

- increases in international competitiveness;
- direct return on R&D investment by commercialisation of the research idea into a product or service for sale in the market;
- indirect return on R&D investment, such as a highly trained workforce with valuable and transferable skills, and high-quality employment for that work force;
- access to new and expanded markets intra-sector and across sectors;
- providing a platform for small innovative enterprises to access niche, international markets.

Effective technology transfer requires the creation of supporting institutional and physical infrastructure. This will include processes and mechanisms to ensure that technologies can be transferred and do not become trapped within a specific innovation arena, for whatever reason. There must also be appropriate platforms to enable the exchange of practices and knowledge between different industries and sectors.

Government support

The World Economic Forum identifies 12 pillars of competitiveness[25] grouped into four main categories, as shown in Figure 9.

These pillars are the foundation on which a competitive and

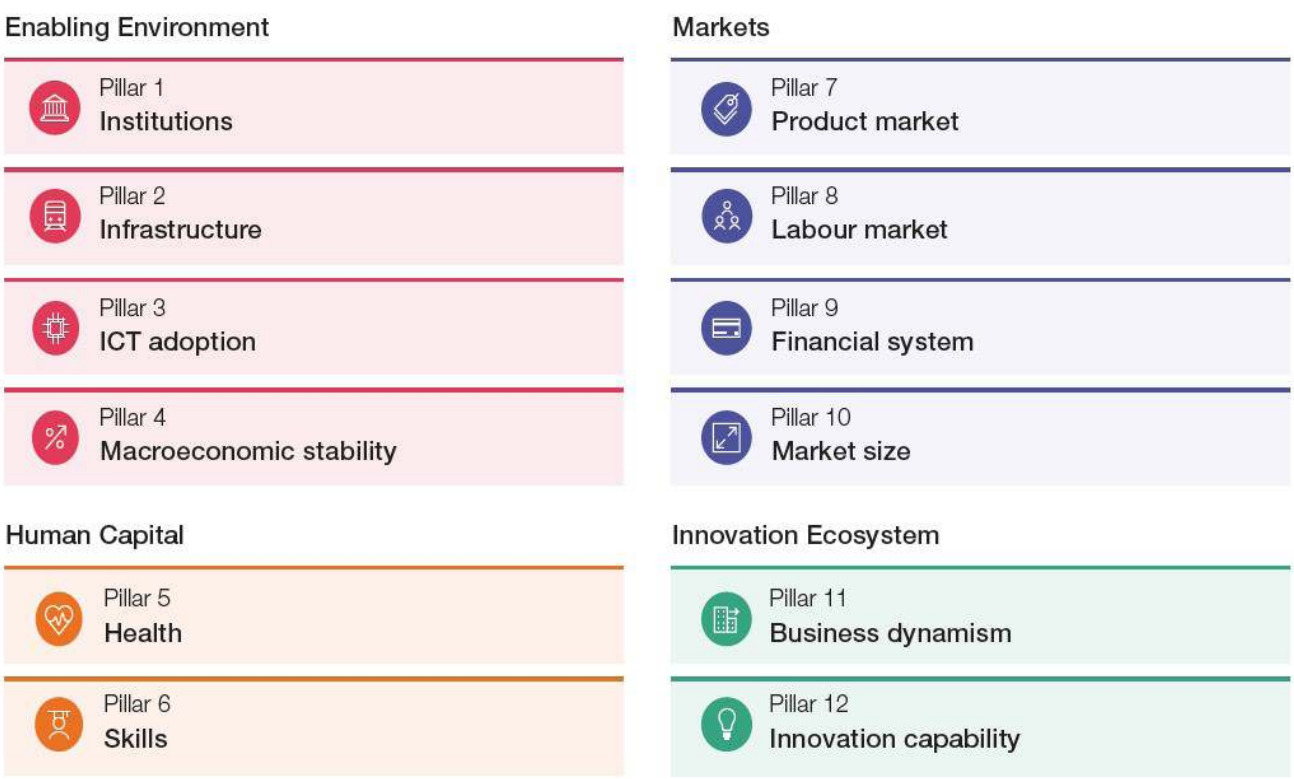


Figure 9: the 12 pillars of competitiveness (Source: World Economic Forum)

[25] *World economic Forum, the Global Competitiveness Report, 2019*

highly productive economy is built. Performance along each of the pillars is highly dependent on the policy, regulatory and organisational arrangements within an economy. Government, therefore, has a major and significant role in putting in place the platform on which research organisations can make the most effective contribution.

Technological developments and research activities are located in universities, in R&D departments within industry and in research establishments. However, technological implementation needs to be addressed at institutional levels. To achieve the best results, a parallel, simultaneous and comprehensive approach is essential to transform policy, regulation and operations, managing the link between research and industry. In this way government plays the role of facilitator and mediator.

The capability to integrate and create synergies among government institutions, research and technology development organisations (universities, research centres) and companies, defined as the triple-helix, is of paramount importance in science-based sectors, in which the ability to create technological innovation is strongly dependent on the availability of scientific knowledge.

Government support, based on a consistent industrial policy and a clear vision of the evolution of the knowledge and the technology, is essential to drive the changes needed to enable the successful and timely application of the new technologies.

Government support is essential for a more innovation-friendly European environment (science-based, technology-oriented and business-competitive), and an enterprise environment more receptive of research and technology inputs. It is also essential in enabling alliances and national, international and inter-sectorial partnerships aimed at technological innovation and the development of new programs.

Macroeconomic settings (the surrounding environment of institutions, legal arrangements and funding) set the rules and range of opportunities for innovation and competitiveness. Governments need to create pan-European supportive public policy covering the legal framework (legislation, regulations, procedures and operations of the aviation industry) and funding.

Government intervention is also fundamental with respect to the third leg of the triple helix: education. Higher education and specialized training need to be available to a broad and diverse number of citizens. Public policy should increase the initiatives for the education and training of specialized staff in collaboration projects defined by research centres, training organisations, and academia.

Connecting with education

The ideal role for universities and educational institutions is to shape the future researchers and innovators, by providing them with solid foundations in core science, technology, engineering and mathematical subjects, in research and innovation techniques and by introducing them to the soft and other skills needed beyond technical expertise.
Universities should cooperate with research institutes, enabling the flow of fundamental knowledge towards the research environment, and adjusting curricula to introduce the latest trends to students and trainees. The capability for research and development needs to be embedded in the labour force (skilled worker, engineers, as well as sales-people and managers). Equivalent vocational education is needed to ensure the availability of suitably qualified technicians and assistants.

The traditional approach to education, focused on young people before they enter the work force is becoming less applicable. Skills requirements are becoming more volatile and can leap in response to disruptive technologies rather than evolving smoothly. The approach to education needs to adapt to cater for this new volatility, using innovative approaches to provide a life-long learning capability.

In addition to their education role, universities also engage in research, development and technological innovation activities, which may be complementary to or in competition with the activities of the research establishments. To ensure align-

ment of the roles of universities and research establishments whilst preserving their distinct roles and avoiding conflict, a platform for cooperation between research establishments and universities is essential. This platform could be facilitated by EREA and its counterpart organisations for universities, the European Aeronautics Science Network (EASN).

Framework for cooperation

One of the roles of research establishments is to improve the coherence and coordination or aviation research and innovation activities conducted at national level.

Innovation implies wide-ranging co-operation between government bodies, research organisations, universities, firms, and individuals. It is the result of the interaction between economy and technology. The measures introduced in the earlier sections, above, are aimed at creating the most cooperative environment possible.

As pointed out long ago in the Green Paper[26] (2007), fragmentation of public research diminishes Europe's attractiveness for business for R&D investment. Statistics show that 67% of people consider that there should be more coordination of research activities between the Member States of the European Union[27]. Uncoordinated research leads to dispersion of resources, duplication and unrealised benefits from spill-overs. The involvement of industrial partners and its impact on an ideal climate of cooperation has been addressed earlier.

New technologies leading to radical change in aviation are possible if developed and deployed appropriately and in time. This can only be achieved if all players involved are open to collaboration and information exchange. In particular, in order to quickly realise the benefits of new aircraft, propulsion and other new technologies, including reduced environmental impact, the long timeframe between development and entry into operational service needs to be shortened. This will require much higher cooperation between research, industry and regulators to shorten the certification cycle. The risk of not improving cooperation is that emissions will not be reduced sufficiently in time to meet sustainability targets.

International cooperation strengthens the integration of funds, and therefore to an "integrated funding policy", rather than simple availability of funds along with integration of plans is necessary.

[26] *The European Research Area: New Perspectives, Green Paper, European Commission, 4 April 2007*

[27] *http://ec.europa.eu/public_opinion European Commission, (2010), Eurobarometer Europeans, Science and Technology*

Moving forward towards a technological strategy for R&D

EREA's vision for the Future of Aviation to 2050 comprises two documents.

This, the first document, has described the context and current baseline from which the future of aviation will evolve. Four alternative future scenarios are introduced and described. Although these scenarios are not intended to be entirely realistic, they cover the complete spectrum of credible future worlds including their implications for aviation and aviation research. The common themes emerging from the scenarios are identified and highlighted. Irrespective of the scenario that will actually happen in the future, the factors that are needed to ensure the success of aviation research are highlighted. These factors include the creation of a supportive policy framework, platforms for successful technology transfer from research through innovation to operational deployment and arrangements for successful cooperation between research establishments, universities, industry and regulators.

The second document addresses the specific trends, technologies, infrastructures and research themes that would be needed in each of the scenarios. The combination of the two documents will direct EREA to synthesise a coherent roadmap for the course of research activities to 2050.


EREA

EREA, its mission, goal and strategy

The Association of European Research Establishments in Aeronautics, EREA, is a non-profit association, represented in 14 European countries, with the objectives to:

- promote and represent the joint interests of its members in aeronautical research;
- intensify the co-operation between its members, aimed at further integration of their activities in the field of civil, military and space-related aeronautics;
- improve and intensify the co-operation of EREA and its members with third parties in the field of aeronautics;
- facilitate the ultimate goal of the Members of an integrated management of joint activities, thereby contributing to Europe's role as a global player in aeronautics.

Within those objectives, the strategy of EREA is to:

- Provide scientific and technical support to industrial projects;
- Cooperate with authorities and industry to define and implement a long-term research policy encompassing both commercial and technological dimensions;
- Provide objective, neutral and impartial expertise to EU, national authorities, industry and other bodies.

Presently EREA full members are: AIT (Austria), CEiiA (Portugal), CIRA (Italy), CSEM (Switzerland), DLR (Germany), FOI (Sweden), ILOT (Poland), INCAS (Romania), INTA (Spain), NLR (The Netherlands), ONERA (France), VZLU (Czech Republic), in addition to one associate members (VKI, Belgium), one affiliate member (AFIT, Poland) and one strategic partner (TsAGI, Russia). The implementation of the EREA strategy runs both through EREA's specific initiatives and through initiatives and strategies of its individual members.

EREA has a major role in the harmonisation process leading the implementation of the prerequisites for success: competition, competence and cooperation (3 Cs). Providing a vehicle for cooperation and coordination between its national members, EREA extends the coherence and coordination of aviation research and innovation to the European level, multiplying and optimizing investments and avoiding duplication and waste of resources. EREA is the means for joint programming in European aviation research contingent on the establishment of the necessary framework conditions.

Given that the scenarios presented in this document are EREA's own view of possible alternative futures, a question to answer at this point is how EREA sees its own role contributing to those scenarios and to those trends. EREA's "Future Sky" is one step in answering this question.

Future Sky – an overview

Future Sky is the EREA initiative to propose a common view on the "next plus one" generation of aviation in Europe, to promote coordinated action in fundamental and applied research in Europe along the lines of Flightpath 2050 and ACARE's Strategic Research and Innovation Agenda (SRIA), and to remedy to the lack of attention paid to mid- to long-term research and the lack of European support for coordination between national institutional programs. In a nutshell Future Sky envisages an efficient, safe and environmentally friendly aviation system in line with societal expectations. The Future Sky Initiative is devoted to preparing key technologies and capabilities for a cutting-edge green and seamless air transport in Europe by 2050. Such an aviation system complies with all goals set by Flightpath 2050, contributing to the objectives maintaining European global leadership and serving Society's needs while contributing to the achievements of COP21 goals and the 2030 Agenda for Sustainable Development subscribed by Governments and civil society.

The Future Sky Initiative consists of multidisciplinary programs – so-called Future Sky Themes – where major innovation areas of future aviation will be investigated. Each cluster will investigate aspects affecting the desired features, derive technical solutions, verify concepts, validate technologies, suggest regulation or standardisation rules and evaluate the

overall impact. The overall Future Sky program is subdivided into six themes focusing on different aspects or challenges on track to the future Air Transport System: Safety, Quiet, Energy, Urban Air Mobility, Security and Circular Aviation.

Globally, the Future Sky program is aiming at technologies and solutions beyond the scope of currently running Joint Technology Initiatives Clean Sky 2 and SESAR 2020, thus increasing global air mobility by preparing new technologies, concepts and operation. Substantial and coordinated involvement of research establishments makes this challenging goal possible.

One major feature of the Future Sky program is involvement of national research establishments gathered in EREA and linking their institutional research programs. Joining forces by linking research efforts at European level will magnify scope and impact of the results impossible to achieve through individual national efforts. In order to fulfil this goal, EREA is committed to involve third parties in the research activities of Future Sky, so that a proper knowledge and technology transfer between basic research into industrial applications can be ensured. Future Sky does not intend the creation of new European funding instruments but will make use of existing ones.

Safety

Flightpath 2050 is based on the expectation of up to 25 million commercial flights by 2050. The ability of the future aviation system to deliver excellent safety performance, independent of any environmental hazards or disturbances, is not a given. While any spare capacity is taken up by the growing traffic load, a new demographic is entering the industry both in the air and on the ground; thus when combined with new business models, new vehicle technologies, and new entrants in the ATS, the goal of reducing the accident rate to less than 1 accident per 10 million flights presents a formidable challenge.

This topic thus calls for enhanced cooperation between research establishments, working closely together with European Aviation Safety Agency (EASA) and EUROCONTROL, other oversight authorities, service providers (airport operators and airlines), universities and industry in order to ensure the integration of research results at EU level.

Quiet Air Transport

Up to 2.5 times of the 2015 traffic is anticipated by 2050. Due to limited airspace and ground area, this traffic volume cannot be sustained from the noise perspective by current European air traffic management (ATM). In addition to that, continuous urbanisation demands more sophisticated interaction of the overall air transport system (especially airports) with its neighbourhood. These two opposing trends make another goal defined by the SRIA comprehensible: reduction in noise emission by 65% as well as substantial reduction of further emissions. Even more stringent noise requirements recently appeared with the “Environmental Noise Guidelines for the European Region” released by the WHO on mid-2018: airport authorities and noise regulators do not know yet how to address these requirements.

In addition, there is a complex scheme of intricate noise regulations applied throughout Europe (national, regional, local) but most of them are only based on averaged intensity-based metrics, disregarding aspects such as emergence, duration and repeatability and non-acoustical factors. Last, considering the above-mentioned trends, it is foreseeable that new quiet aerial vehicles have to be developed and existing regulations have to be further refined in order to cope with Flightpath 2050 goals.

This Future Sky Theme will investigate the noise aspects of increased air transport and its impact on the environment. The aim is to derive new approaches to aviation noise – addressing noise at source (aircraft), air transport scenarios and community noise. Links will be established with Fu the top-down approach of Clean Sky and with SESAR.

Energy

Flightpath 2050 sets ambitious goals relating to environment and energy supply in aviation. The ambition is to improve eco-friendliness of aerial vehicles and to cut CO2 and NOx emission by 75 % and 90 % respectively while preserving European competitiveness.

One first step for the European aviation community is to enlarge the adoption of alternative fuels which is a rather mature technology but needs the full deployment in daily business for the complete aircraft fleet.

Substantial energy saving and pollution reduction are expected by the introduction of hybrid-electric aircraft and by implementing emission-free ground handling and taxiing at airports.

This Future Sky theme will deal with new propulsion systems and concepts, innovative aircraft architectures, and on-board energy systems. The objective is to focus on medium- and long-term R&TD preparing the scientific and technical basis for the European aviation beyond 2035 aiming at zero CO2 emissions.

UAM

Urban air mobility (UAM) aims to improve the efficiency of transportation in urban as well as inter-urban areas while reducing environmental impact. Considering the costs and the value of time saved by airborne solutions, UAM will offer attractive mobility on demand alternatives at urban, suburban, and inter-urban levels. The aim is to shift a part of medium- and long-distance single passenger car trips as well as short- and medium-distance cargo transport to small aircraft. In summary UAM sets out three main objectives: on-demand mobility in high density as well as remote areas, regional seamless mobility in terms of Flightpath 2050 goals, and efficient and environmentally friendly unmanned cargo and piloted/autonomous passenger transportation.

Innovative solutions for UAM will address vehicle and system integration concepts with regard to the development and implementation of safe, secure, efficient, integrated and sustainable air mobility systems over large metropolitan areas.
UAM faces a broad variety of challenges. A whole set of new technological and regulatory standards have to be developed to provide a solid basis for innovative and sustainable aerial solutions. The competitive concepts in this theme cover manned and unmanned system approaches in the areas mobility services for people, emergency services and freight. Challenges need to be addressed under the broad headings of: autonomy, safety, security, societal acceptance, integration, regulation and certification, simulation and testing.

Security

Since 2001 the way to envisage aviation security has deeply evolved because of terrorist attacks and the increase of emerging threats and vulnerabilities. Although many projects focused on detection and prevention, studies need to be carried out to determine the best measures for protection and the most appropriate reactions and to develop a joint simulation environment to evaluate the efficiency of security concepts or security systems. Technological developments in aviation require systematically security assessments to assure the high level performance of the security measures. The performance assessment of security solutions and the definition of appropriate key performance indicators (KPI) are now essential needs to build an aviation security policy considering the issues of the development of autonomous systems, which increases dramatically the complexity of threat management.

The main goals are to identify the best solutions in a standardised way regarding their efficiency and trust for the protection and to improve the resilience of the whole aviation system and the passenger survivability. Furthermore, the aviation community has to anticipate unknown future threats instead of reacting continuously in hindsight with new strict regulations.

Circular Aviation

FlightPath 2050 highlights that aviation must be actively engaged in *"protecting the environment and the energy supply", providing "sustainable [...] connectivity for passengers and freight", and "protecting the environment and enabling the use of sustainable energy and alternative energy sources".*

To date, sustainability in aviation has mainly focused on reducing polluting emissions from operations. Though useful, this approach only covers part of the lifecycle of an aircraft, and only a limited amount of the overall energy consumption and pollution emissions related to aviation. Recently, sustainability has also approached aspects related to production and manufacturing, both the traditional manufacturing process for old aircraft, and the recent, innovative processes and advanced materials for new aircraft designs. Although the design and manufacture of recyclable air vehicle is one of FlightPath 2050's goals, most aspects such as production, end-of-life solutions, maintenance and (most of) operations of aircraft and airports have been neglected in the life cycle analysis.

Circular economy principles focus on minimizing systematic leakages and negative externalities; such principles can enhance the already ongoing research activities and industrial implementations of more sustainable solutions in aviation, by expanding their current fields of application (from local to global) and by initiating new applications. Applying sustainable solutions only locally will never allow achieving the reduction in emissions desired to reduce the effects of the climate change. The overall aircraft lifecycle, from cradle to cradle, needs to be reassessed.

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