DEPARTMENT OF BUSINESS AND MANAGEMENT

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DIGITAL TECHNOLOGIES TO SUPPORT THE CHALLENGE OF COMBATING CLIMATE CHANGE:

The case of the aviation industry

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INTRODUCTION

Nowadays, sustainability is a growing topic on the corporate agenda. The companies need to respond to the environmental and social challenges, but not as a geopolitical factor to consider or a simple marketing tool. Sustainability has proven to be a powerful opportunity for a company to create new value for their customers and a key player for a long-term strategy in a competitive market. For a sustainable transformation to take place, organisation need to measure the impact of their actions, identify possible opportunities, plan and rapidly accelerate the adoption of disruptive solutions to reduce harmful emissions.

With the arrival of the pandemic Covid 19, a considerable part of the population has been required to remain at home to reduce the spread of the virus. The collaboration of digital technologies has become essential to support economies and societies, principally those that allow working remotely. Furthermore, several studies state that digital technologies could be an accelerator to achieve sustainability and decrease other sector emissions by up 15% - 20%.

Between the wide variety of emerging digital technologies, this work has focused on one of them, Digital Reality technologies. They can simulate various situations, emerging people in a wholly digital environment or overlapping digital objects in the real world. These technologies offer several opportunities for business, such as reducing costs and improving efficiency. One of the most relevant benefits is the possibility to train employees within a variety of scenarios in a safe way. An example of this is the training of pilots.

This thesis aims to identify and clarify the environmental impacts and opportunities offered by applying digital reality technologies in the aviation sector. After a profound literature review of the current global interest in sustainability challenges and digital trends, the topic was chosen with the collaboration of Leonardo S.p.A, a multinational Aerospace & Defence industrial leader company in the Dow Jones Sustainability Index. Due to the lack of availability of similar studies, the methodology adopted was a systematic review to facilitate selecting relevant evidence, extracting, and assessing the data to bring a logical response to the research question: Is Digital Reality a good ally against the current environmental challenges of aviation?

The first chapter of this research presents the current sustainability background. The literature review aims to understand the main pillars that integrate Sustainable Development, the current challenges, and their relevance in today reality. Moreover, it searches to understand the crucial role of investors and corporations in achieving those goals.

The second chapter introduces Digital Technologies and their potential capability to accelerate the transition to a sustainable economy. It shows how the current pandemic of Covid- 19 has impacted the organisation's adoption of digital technologies and the current benefits and barriers. Finally, it describes virtual and augmented reality technologies showing their expected growth in the following years and highlighting potential benefits and challenges for organisations.

The third chapter searches to clarify the evidence base available around the relationship between virtual reality technologies used in the aviation sector and their impacts on the sustainable development goals linked to the environment. The evidence was selected and analysed through a systematic review of the scientific papers published during the last two years, company reports, journals and interviews with experts in the field of study. The chapter reports a description of the different steps of the methodology adopted to analyse the evidence and descriptive synthesis, exposition and discussion of the findings.

Through this, it is possible to conclude that those technologies could positively impact climate change. For example, Zero Flight Time simulators, based on Virtual Reality(VR) technologies, could reduce 100% of civil pilots' flight training hours, reducing aviation greenhouses emissions. Instead, the military sector uses Full Mission Simulators, which incorporate Augmented Reality technologies that can replace around 50% to 60% of military pilots' training hours. These numbers were obtained through interviews with a specialist in this sector working at Leonardo. Furthermore, through the articles selected in the systematic review, it was possible to identify one of the main benefits of those technologies, the increment of processes' efficiency and accuracy. Moreover, according to the "European Aviation Environmental Report 2019", there is an excess of around 6% of gate-to-gate CO_2 emissions at the European level due to inefficiencies. Consequently, those technologies could help to increase overall efficiency in the aviation system processes, cutting significant emissions and improving the use of resources.

Nevertheless, there are not enough studies available about the environmental impacts of those technologies. Moreover, it would be necessary to fully study the entire cycle of each digital reality application to confirm a positive impact in each specific case. Therefore, further research is needed about the environmental impacts of aviation emissions and the digital reality technologies used by different organisations to effectively communicate the benefits of these new technologies in combating climate change.

This study pays special attention to the current pandemic and international trends that linked the recovery measures to the green and digital transition. Therefore, this analysis suggests the importance of the company environmental assessment of their digitalisation process and transparent communication to all stakeholders. As a result of this, responsible investments decisions are facilitated by collaborating to achieve a sustainable future.

CHAPTER 1: SUSTAINABILITY FRAMEWORK

1.1 Historical Framework and definitions

Albert Einstein said once: "The world as we have created it is a process of our thinking. It cannot be changed without changing our thinking". This phrase is a good guide for the beginning of the research. This chapter will analyse how the ideas and innovations have changed our natural environment through time and how these changes impact societies and prosperity. In addition, how people thinking has started to lead the change through Sustainable Development.

1.1.1 A History of Change

During the research, one of the critical characteristics of humans' evolution is their ability to adapt, particularly in human beings' species, their ability to modify their environment during this process. In many animals, we can find the ability to invent new behaviours or find new solutions during adaptation. According to the article *"The magnitude of innovation and its evolution in social animals"* by Arbilly Michal, Laland Kevin N. (2017), this ability is called innovation. However, it clarifies that innovation differs between each species; it could be said that there are different scales of innovation. In humans, the capacity to innovate and modify their environment is considered an essential element of its success over the rest of the species.

There exist different theories about the reason and motivation to innovate. The most common between them is the 'necessity hypothesis' (i.e., that lack of access to or scarcity of resources prompts innovation). Between other reasons for innovating, we found the opportunity. Several people find different ways to explore existing technologies, what we call a continuous or incremental innovation. This type of innovation is competence enhancing because it builds on previous knowledge. For example, we have a new iPhone that adds additional value and unique characteristics each year without making significant changes. Nevertheless, it seems that innovation is not the result of a single factor, if not a combination of them; sometimes, the motivations come from intrinsic sources. Others are the results of pressures or norms that emerge from a live-in society.

Nowadays, this ability to change has the name of "Technological Innovation". It is defined as an act of applying the knowledge to introduce a new device, method, or material for application to commercial or practical objectives. These technological innovations are characterised in our evolution history by their velocity. When we talk about velocity, we need to remember that it is a vector; it has a rate and a direction. Technological innovation rate is how fast or how often. Whereas, technological innovation direction is about the radicalness of change, continuous or discontinuous. For example, a digital photo camera was a discontinuous innovation because it destroyed previous competencies of chemical manufacturer like Kodak.

Independent of the different direction of innovation through history, the starting point of an innovative process are ideas. More population will generate more ideas, and more ideas would accelerate technological progress, known as the scale effect proposed by Kuznets (1960) and Simon (1977, 1981). Figure 1 represents the strong positive correlation between increased population growth during the last century and increased technologies innovation.

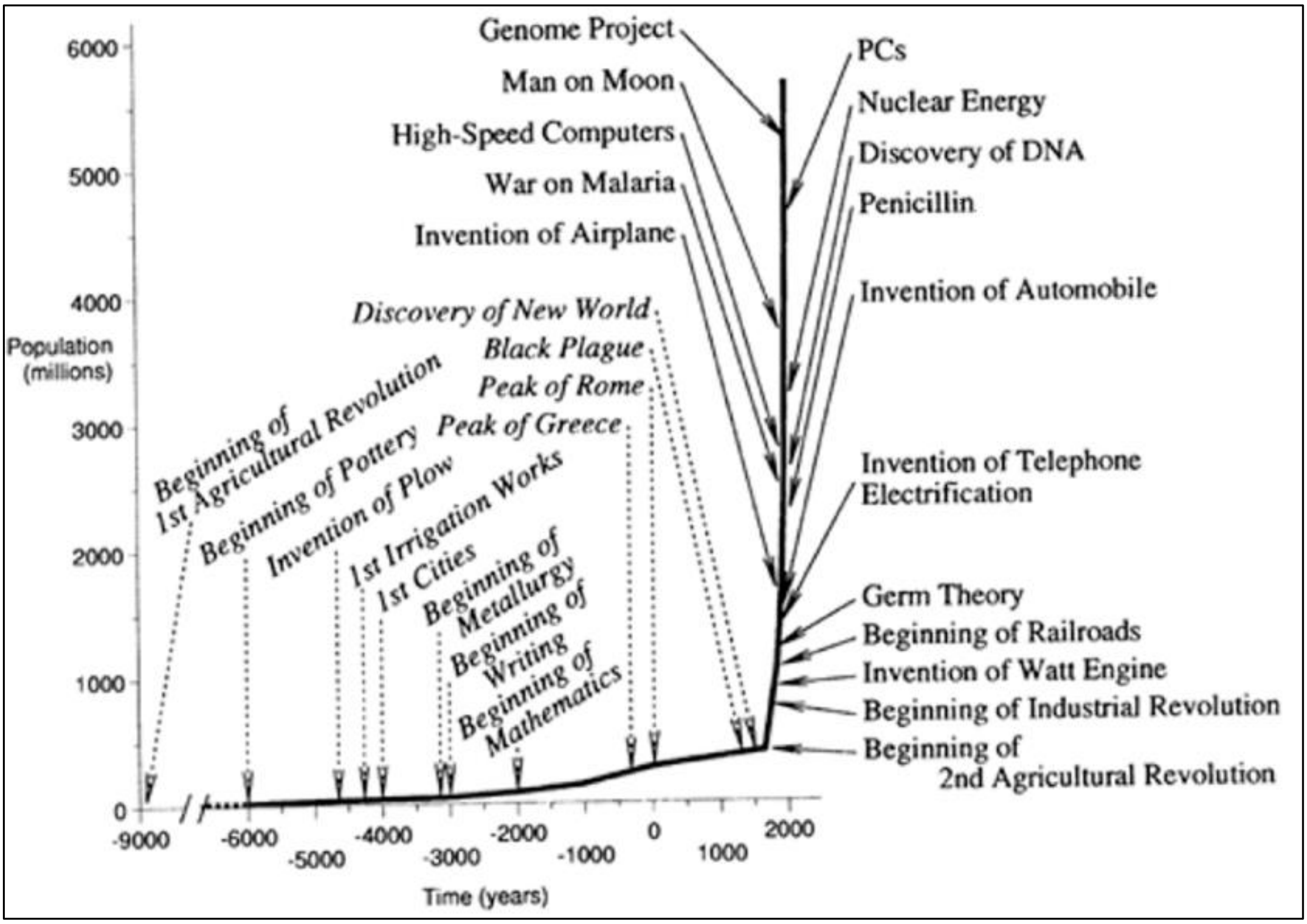


***Figure 1**. Fogel Robert W. (1999). The Growth of the World Population and Some Major Events in the History of Technology. Catching Up with the Economy, p. 2. The American Economic Review. https://www.diegdi.de/fileadmin/user_upload/pdfs/Me-ssner_WS_2016/Fogel_Catching_up_with_the_economy.pdf*

We can appreciate that in the last 50 years the population has grown more than in the previous 12000 years. Moreover, life expectancy has been incremented from 40 to 80 years, thanks to humans' ability to modify their environment. However, every innovation has also brought some negative externalities such as pollution, climate change, global warming, new diseases, or biodiversity loss.

In conclusion, we can see that changing and implementing new knowledge is a crucial element of human success over other species. The development of new disruptive technologies has increased considerably during the last 50 years, and we can find a positive correlation between it and the population growth. On the one hand, technological innovations are the cause of improvement and human life's progress, principally the capacity to live longer and augment our physical and social performance. On the other hand, the increase in the population and the modification that humans make to their environment can generate some challenges to our social and environmental sustainability.

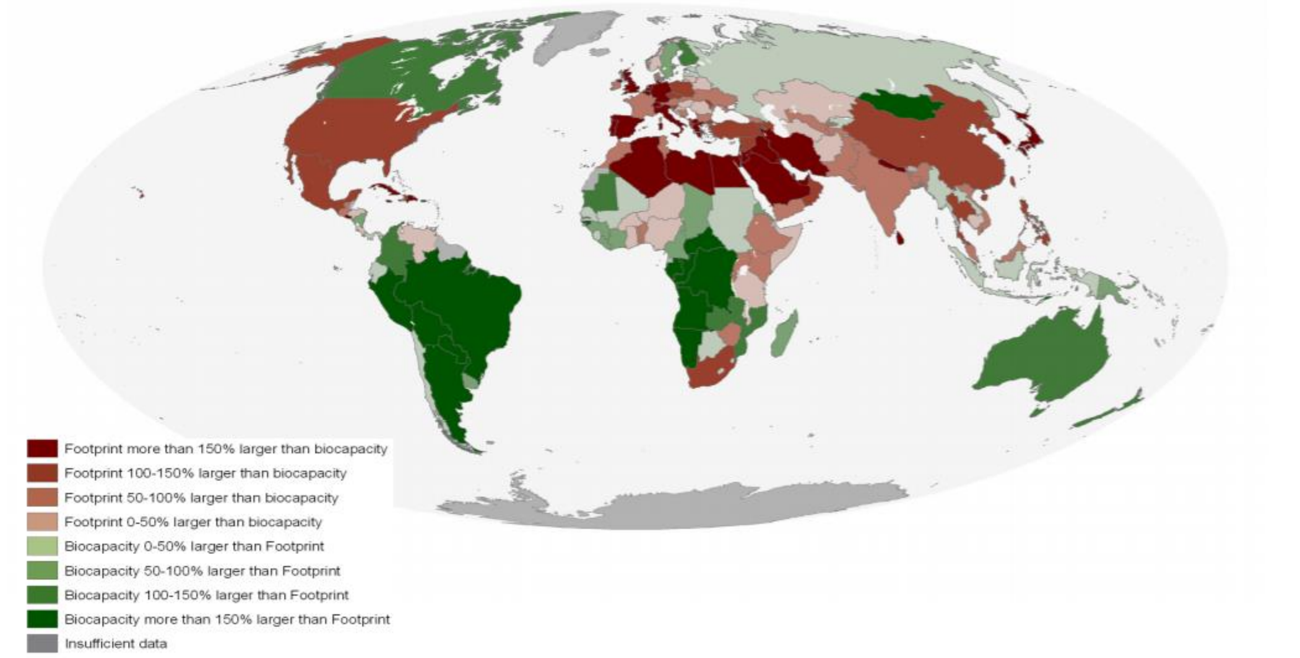
1.1.2 Defining Sustainability

"Sustainable development is the ability to meet the needs of current generations without compromising the ability of future generations to meet their needs and aspirations". This definition emerges in 1987, during a debate about environmental protection issues by the Brundtland Commission, formerly known as the World Commission on Environment and Development (WCED), which had the mission to unite countries to pursue Sustainable Development together.

There is a belief that sustainability is a recent environmental problem that has emerged because of the population's current exponential growth. Nevertheless, this first approach can lead to a wrong or limited conclusion. Data collected from Statista show an augment of the global world population from 3.683 billion in 1970 to 7.674 billion in 2019. It is an increment of around 108% in 50 years, which means that the population has almost doubled during the last 50 years. During the same period, consumption expenditures rose from about 2,212 Trillion to 64,269 trillion expressed in US dollars, approximately an increment of 2805%. Consumption has doubled approximately by 29 during the last 50 years. To finished, 80% of our planet's resources are consumed only by around 20% of the world population. In figure 2, we can see a map that compares the footprint and the biocapacity of the different countries in 2007. After analysing this data, it is possible to conclude that sustainability is much more than a unique and new environmental issue, such as global warming, a greenhouse effect, "overpopulation", or a pandemic as Covid-19.

Sustainability is more like a meta discipline. Sustainability integrates economic, environmental, and social. Economic gives as the framework in which the decisions are made, including all the development and transactions of knowledge, competencies, resources, and skills relevant to economic growth. Environmental recognises the interdependence and diversity within our ecosystems. Finally, social refers to the interactions between institutions and people and their function to protect human values, well-being, ethical issues and aspirations. These three aspects are the pillars to achieve sustainability, a long-term goal of holding up human existence.

For that reason, we do not have to think that sustainability is a fashion issue in the last few years. Holding up human existence was and will always be a challenge. As an example of this, we have the world's s first international urban planning conference to solve a common problem of the urban centres, "the horse's poof", carried out in 1898. In those years, horses were the transport by excellence, and their waste was transforming big cities, such as London or New York, into unsettling and unsanitary places. After a few days of debate, they did not find any solution, and the possibility to find a substitute for horses looked like an impossible goal. It was not until the early 20th century that the private automobile option appears to resolve horse pollution and other multiple problems, such as reducing traffic issues.



Map 4. Ecological creditor and debtor countries, 1961 and 2007. The ecological creditor and debtor map above compares the Ecological Footprint of consumption with domestic biocapacity.

Figure 2*. Global Footprint Network. (2010). Ecological creditor and debtor countries 1981 and 2007. The ecological creditor and debtor map above compares the ecological footprint of consumption with domestic biocapacity. Ecological Footprint Atlas 2010, p. 35. https://www.footprintnetwork.org/content/images/uploads/Ecological_Footprint_Atlas_2010.pdf*

Nowadays, 100 years later, cars are one of the most significant contributors to Greenhouse Gases worldwide. These prove that sustainability is a constant challenge of every epoch and that the innovative technologic solutions from today's sustainability issues could become a problem for tomorrow .

1.2 International Framework to tackle sustainability issues

In 1983, the UN created a unique, independent World Commission on Environment and Development chaired by Gro Harlem Brundtland. The Commission proposed environmental strategies for achieving sustainable development. One of the essential conclusions of this commissions was the link between economic, environmental, and social issues and the resolution that sustainable development was not a final state; if not, it is a behaviour. After this, several organisations such as the Millennium Ecosystem Assessment, the Intergovernmental Panel of Climate Change, the Organization for Economic Cooperation and Development, among others, have been issuing reports about different aspects of the current sustainable problems such as an increasing environmental degradation that causes significant ecosystem changes.

Some of those changes are the increase of the global temperature, variation in water and food quality, degradation of the lands and reductions in biodiversity. The big problem is that the harmful effects of the ecosystem's degradation affect disproportionally human well-being. The most affected are the poor communities that are more vulnerable to those changes, which contributes to increment the inequities and disparities across groups of people.

Today, with the world pandemic of Covid- 19, the governments and businesses have been pushed to shift the focus of their agendas, to stop the spread of the virus and at the same time protect themselves from economic, social and emotional consequences. On the *"Sustainability Development report 2020: The Sustainability Development goals and Covid-19"* by Cambridge University Press, it have been developed an index to summarise country performance during the pandemic taking into account three dimensions: mortality rate, ERR, and efficiency of control. The results have shown that countries equipped with effective social protection systems, universal health coverage, equality access to essential resources and strong leadership government capacity have performed better to the pandemic.

Moreover, it is crucial to invest in sustainable projects to recover and protect from possible future pandemics and work jointly at an international level. Most impoverished countries generally do not have access to sanitisation and adequate health services. Several rich countries have failed to collaborate on stopping the pandemic's diffusion on them and this impact worldwide.

To conclude, it is crucial not to forget that the survival, reproduction, distribution, and transmission of diseases are linked to specific environmental conditions, malaria and dengue fever are an example of this. Therefore, climate changes and global warming may affect infectious diseases by altering their environment. There has been a wake up for several institutions and people by experimenting with the effects of our decisions managing the earth resources. The following sections would analyse the international trends to aggressively decarbonise our economy and our daily lives, investing and driving to more sustainable economies.

1.2.1 Paris Agreement

In 2015 the Paris Agreements, a legally binding international treaty on climate change, seeks to avoid the dangerous effect of climate change limiting global warming below 2°C and pursuing efforts to limit it to 1.5°C. In 2020, 194 countries and the European Union signed the agreement, representing more than 97% of global greenhouse gas emissions. Moreover, governments have submitted their plans. They have communicated the actions they will take to reduce greenhouse gas emissions to achieve the Paris Agreement's goal, known as nationally determined contributions (NDCs). This agreement also provides a framework of financial, technical and capacity-building support to those countries who need it. For all of them, there is tracking progress through establish reports.

In Figure 3, we can see a comparison of the warming projected by 2100 depending on today's decision. Looking at this graph, one question comes to mind: Why it is so important to limit global warming when we are talking only about a few degrees of change?

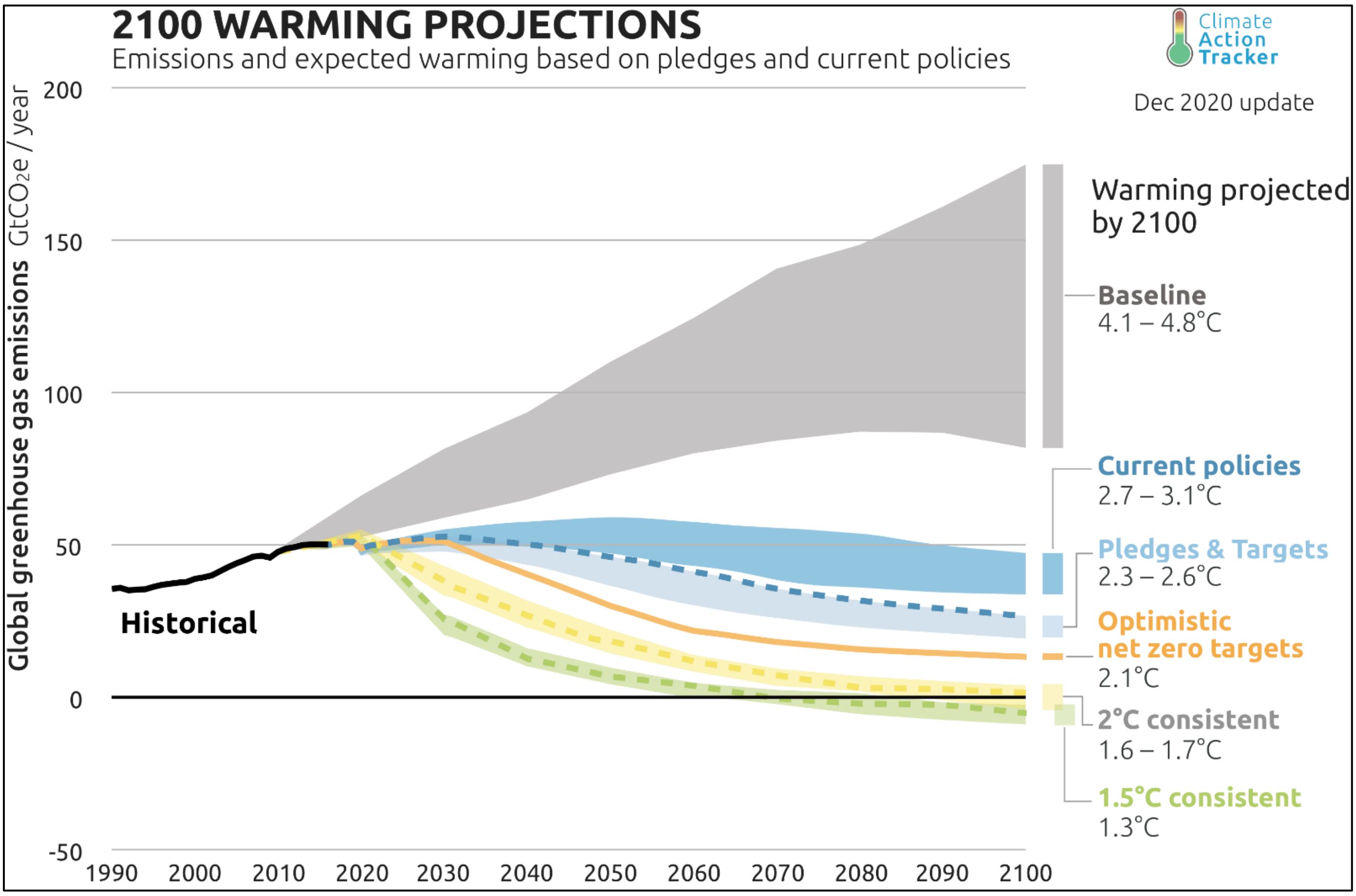


***Figure 3**. Climate Action Tracker. (2020). 2100 Warming Projections, emissions and expected warming based on pledges and current policies.* [*https://climateactiontracker.org/media/images/CAT-2100WarmingProjectionsGraph-PNGLarge500-202.origi-nal.png*](https://climateactiontracker.org/media/images/CAT-2100WarmingProjectionsGraph-PNGLarge500-202.origi-nal.png)

A possible answer to this question is in *"Part 2: Selected Findings of the IPCC Special Report on Global Warming"*, published by NASA's Global Climate Change Website. In this report, there is a comparison of the global effects to limit our global warming to 2°C or 1.5°C. These explain how a change of only 1.5 degrees Celsius warming can affect not only our temperature, if not also generates several problems such: severe heatwaves, droughts, water scarcity, extreme precipitations, loss of species and extinctions, increase risk of forest fires, extreme weather events and invasive species, ocean sea level rises, increase of ocean acidity and reduction of oxygen levels. Moreover, there will be an increase in poverty and heat-related illness, mortality, and pandemics risks. As we said before, environmental is not separate from economic issues, and we will see also their effect on the GDP of several countries.

We can take some examples to understand better the different impacts between limiting global warming increment to 2 or 1.5 degrees. Firstly, it is essential to understand that the temperature change is not equal across the world and time. Suppose we can limit to 1.5°C warmings that means that 14% of the population will be exposed to severe heatwaves at least 1every five years. Instead, if we change our limit to 2°C warmings, this number jumps to 37%. If we change our focus to the water resource, about 61 million more people in the earth's urban areas would be exposed to severe drought in a 2°C warmer world than at 1.5 degrees warming. Moreover, between 184 and 270 million people will be exposed to water scarcity increases in 2050 at about 1.5°C warmings than at 2 degrees warming. Also, around 105.000 species will experiment with climatical geographic reductions by more than a half at a 1.5°C warming.

We can conclude that limiting the warming to 1.5°C or 2°C does not ensure a promising future. For that reason, the Paris Agreement is only a first step taking by governments on the research of sustainable development, but it is not enough. If we want to gain this battle, all the stakeholders' participation is vital. The private sector and a focus on disruptive innovations can open new solutions to the current sustainable challenges.

1.2.2 The 2030 Agenda for Sustainable Development

As we have said before, climate change has a strong relationship with sustainability, but sustainable development is a much broad discipline. Between 2000 to 2015, the Millennium Development Goals (MDGs) provide the development framework and achieve success to reduce poverty and improve health and education in underdeveloped countries. Those were succeeded by The 2030 Agenda for Sustainable Development adopted by all the United Nations member states in 2015. It sets new challenges through the 17 Sustainable Development Goals (SDGs) and 169 targets to end poverty, protect the planet, and improve everyone's lives and prospects. It recognises that ending poverty and other deprivations must go together with strategies that improve health and education, reduce inequality, and support economic growth – all while tackling climate change and working to preserve our oceans and forests.

The well-know 17 Sustainable Development Goals that summarise in Figure 4 are:

1) End poverty in all its forms and everywhere.
2) End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
3) Ensure healthy lives and promote well-being for all ages.
4) Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5) Achieve gender equality and empower all women and girls.
6) Ensure availability and sustainable management of water and sanitation for all.
7) Ensure access to affordable, reliable, sustainable and modern energy for all.
8) Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9) Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.
10) Reduce inequality within and among countries.

11) Make cities and human settlements inclusive, safe, resilient and sustainable.

12) Ensure sustainable consumption and production patterns.

13) Take urgent action to combat climate change and its impacts.

14) Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

15) Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

16) Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

17) Strengthen the means of implementation and revitalise the global partnership for sustainable development.

Figure 4*. United Nations. (2015). The Sustainable Development Goals.*[*https://www.un.org/sustainabledevelopment/news/co-mmunications-material/*](https://www.un.org/sustainabledevelopment/news/communications-material/)

The SDGs act in five key areas, known as the "5 Ps ": People, Planet, Prosperity, Peace and Partnership. To ensure the goals' achievement, they are working to redirect global public and private investment flows towards the challenges they represent. For this, they also count on the support and complement of the Addis Ababa Action Agenda, which was the outcome of the 2015 Third International Conference on Financing for

Development, held in Addis Ababa, Ethiopia, that seeks to align financing flows and policies with economic, social, and environmental priorities. Those relate to domestic public resources, domestic and international private business and finance, international trade as an engine for development, international development cooperation, debt and debt sustainability, addressing systemic issues and science, technology, innovation and capacity-building, and data, monitoring and follow-up.

Moreover, the Division for Sustainable Development Goals (DSDG), in the United Nations Department of Economics and Social Affairs (UNDESA), is in charge to evaluate the implementation of the 2030 Agenda and provides support for the SDGs and their related thematic issues, including: water, energy, oceans, climate, urbanisation, transport, science and technology, the Global Sustainable Development Report (GSDR), partnerships and Small Island Developing States.

1.2.3 European Green deal

In December of 2019 was launched The European Green Deal. It is a set of policy initiatives by the European Commission to make the European economy sustainable, with a broad goal of net-zero carbon emissions by 2050 and between a 50% and 55% cut in emissions by 2030 (compared with 1990 levels). For reaching those targets, they require actions by all the economic sectors, but principally they make and enfaces on environmentally-friendly technologies, innovation industry, transport and energy.

To achieve those aims, they provide an action plan for moving to a circular economy, restoring biodiversity, and cutting pollutions. Furthermore, a European Climate Law to turn the political commitment into legal obligations and an Investment Plan to facilitate and stimulate the national public and private investments needed for the transition. The plan addresses three aspects:

- Financing: the Commission aims to mobilise at least one trillion sustainable investment over 2021 to 2030. The European Investment Bank would be a crucial partner in the mobilisation of funds.
- Enabling: the commission plants to use a mix of regulation and incentives to ensure that sustainability is taken into account in investment decisions. A clear example is the EU taxonomy and the establishment of an EU Green Bond.
- Support: the Commission will provide advisory and technical support to public authorities and project promoters to generate a pipeline of sustainable projects.

The European deal also counts with financial support to help those most affected by the transition to a green economy. It is called the Just Transition Mechanism. It provides a target to mobilise at least €100 billion to the most affected regions over 2021-2027.

In November 2020, the European Parliament consented to adopt the Sustainable Europe Investment Plan as a central tool to the green economy transition. Nevertheless, due to the pandemic's negative economic outlook, it called the Commission to revise the plan's architecture and estimate the European investment needs.

1.3 Responsible Investments

To achieve the sustainability goals proposed by the Paris Agreement, the 2030 Agenda and the European Green Deal, governments and public institutions should work together with the private sector. As a result of this, even before the Agenda 2030, a group of investors and experts from 12 different countries launched "6 Principles of responsible Investment in 2006", reflecting on environmental issues and supporting investor to integrate the ESG (Environmental, Social and Governance) criteria to their investment decisions.

Many institutions can perceive the risks and impacts of climate change as a long-term and not relevant issue for today's decisions. However, contrary to those beliefs, the transition to a low–carbon economy is a reality that impacts an organisation not only physical or in the long term. The European Green Deal is a clear example of the new investment opportunities that these changes bring. Instead, Covid -19 has highly the relevance of corporate governance and intangible asses as reputation, which are crucial to managing their relations with their employees and customer during crisis times.

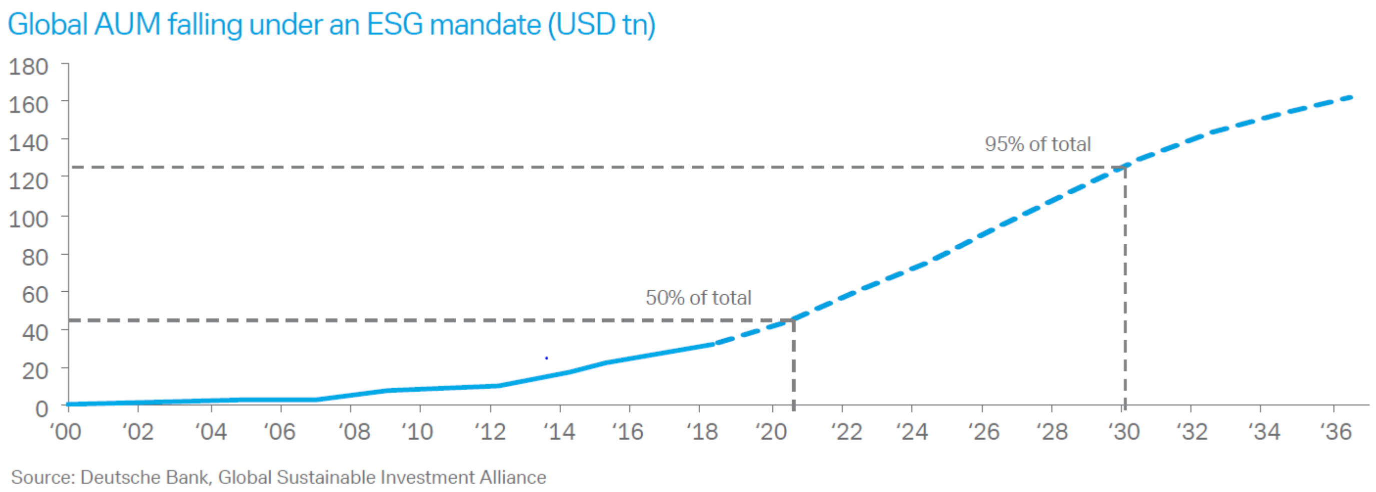


Figure 5. *Deutsche Bank, GSIA. (2019). Climate change and corporates: past the tipping point with customers and stockmarkets. Chart shows, the amount of assets under management (equities and fixed income) that fall into funds with ESG mandates is quickly growing and currently sits at about one-third of total AUM. Following current growth projections, this proportion will climb to 95 per cent over the next decade.https://www.dbresearch.com*

In this section, following the "Recommendation of the Task Force on Climate-related Financial Disclosures" report issue in 2017, some climate-related financial risks, opportunities, and their financial impacts would be exposed.

1.3.1 Environmental risks

Between the risks mentioned in the report, we have those links to the transition to a low -carbon economy, such as policy and legal, technological and reputation risks and the physical impacts resulting from climate change.

- **Policy risks:** there are two types of policies: those that search to force actions to cooperate to the harmful effects of climate change and those policies that seek to adapt—an example of this is the incentive policies to adopt hybrid or electric cars.
- **Legal risks:** climate litigations on the courts have increased due to the damages and failure of organisations to mitigate the negative impacts of their processes and actions.
- **Technological risks** are those risks associated with new disruptive innovations that can contribute to the change.
- **Reputation risks:** climate change trends and organisation behaviours can impact customer and community perceptions of an organisation as involved or in the transformation.
- **Physical risks:** the organisational financial performance may also be impacted by extreme temperatures affecting organisational operations and needs, availability of resources or even considerable losses for the increased extreme weather events, such as floods, storms or hurricanes.

1.3.2 Environmental opportunities

The Task Force has highly some areas and opportunities driven by the efforts to mitigate and adjust to the environmental changes, those are:

- **Resource efficiency:** there is a relation between efficient use of energies, material, water and waste management to reduce operating costs.
- **Energy source:** for the fifth year in a row, investment in renewable energy has exceeded fossil fuel generation investments. The improvement in storage capabilities and efficient use of energy could potentially reduce energy costs.
- **Product and services:** Sustainability offers the organisation an opportunity to innovate and create new value for customers, giving a competitive advantage.
- **Markets:** the sustainability solutions lead organisations to innovate not only in their products and services; if not, it is also an opportunity to diversify and enter new markets working together with governments, banks, community, and local entrepreneurs.
- **Resilience:** As mentioned in the first section, the ability to adapt and respond to changes and risks associated is a valuable and relevant characteristic for the organisation's long-term survival and long-term investments.

1.3.3 Financial Impacts

Climate change impacts every institution and community, but the way or type of impact changes depending on industries, sectors, geographic location, and organisation. To facilitate a responsible and correct assessment of investments opportunities, all the parties involved need to understand how climate risks and opportunities impact the financial position of an organisation or project. For that reason, standard communication and assessment methods are key factors in achieving sustainable development. Principally, the Task Force identify on their report four categories of financial impacts driven by environmental-related risks and opportunities:

- **Revenues:** the transition and trends may affect the demand for products and services. Identify potential opportunities for developing new resources are crucial for organisation and investors. Also, several countries are applying carbon pricing to impulse the reduction of emissions; organisations need to consider the impacts of new environmental policies on their revenues.
- **Expenditures:** the organisational response to environmental challenges may require different investments to profit from the opportunities or eliminate or mitigate the risks. Transparency and clear communication may provide higher access to capital markets or get better financial terms.
- **Assets and Liabilities:** the changes driven by this transition to a green economy could impact the valuation of institutions assets and liabilities. It is essential to communicate the impact principally on long-term lived assets.
- **Capital Financing:** environmental risks and opportunities may impact the capital structure of organisations. Also, it could impact the ability to issue new debt or the condition for refinancing existing debts.

In most G20 countries, organisations must include material environmental-related risks in their financial reports. However, the absence of a standard framework makes it difficult for organisations to determine what data they should present and keep off investors, underwriters, and lenders to incorporate them into their economic decisions. The unification, standardisation and regulation of assessment methods, comparable frameworks and useful ESG indicators are challenges to overcome to align the efforts to achieve the SDGs between governmental and private institutions.

1.3.4 EU taxonomy

To reach the objectives of the European Green Deal and the European climate and energy targets for 2030, it is essential to have a common language to identify sustainable economic activities. The EU taxonomy is a classification system in which there are listing environmentally sustainable economic activities. This taxonomy aims to help investors and companies to identify the activities that can be considered environmentally sustainable. In this way, companies and investors can collaborate on the transition, shift their investments where it is more needed and mitigate the market fragmentation.

In July 2020 entered into force Taxonomy Regulation published by the Official Journal of the European Union. It establishes the framework of the EU taxonomy, with six environmental objectives:

1) Climate change mitigation.
2) Climate change adaptation.
3) The sustainable use and protection of water and marine resources.
4) The transition to a circular economy
5) Pollution prevention and control
6) The protection and restoration of biodiversity and ecosystems

Moreover, it sets four overarching conditions that any activity needs to accomplish to be on the list:

1. Make a substantive contribution to one of six environmental objectives.
2. Do not significant harm to the other five, where relevant/mainly based on EU environmental regulations.
3. Meet minimum safeguards (e.g., OECD Guidelines on Multinational Enterprises and the UN Guiding Principles on Business and Human Rights)
4. Comply with quantitative and qualitative technical screening criteria (a Technical Expert Group (TEG) on sustainable finance has developed a report with recommendations for this).

The performing levels will help companies and project sponsors access green financing to improve their environmental performance. Therefore, it will aid to develop low-carbon sectors and decarbonise high-carbon ones. The EU Taxonomy is one of the most substantial advances in sustainable finance and will have broad-ranging implications for investors and organisations working in the European Union and outside.

1.4 Corporate sustainability: the role of companies to achieve SDGs

It is essential to understand that governments alone cannot successfully address the SDGs. Private business organisations and industries play a crucial role in the transformation to achieve sustainable development. Curiously, we can find a close link between these two concepts: Sustainable Development and Corporate Sustainability. The first one is defined for the United Nations as the "development that meets the needs of the present without compromising the ability of future generations to meet their own need". In contrast, Corporate Sustainability aims at "meeting the needs of a firm's direct and indirect stakeholders, without compromising its ability to meet the needs of future stakeholders as well". Following these concepts, we can see that both pursue the same aim: "to be able to meet future needs"; the only difference is on the owner of the needs, while sustainable development is a broad concept that encompasses all of humanity. Instead, corporate sustainability is focused on the firm's stakeholders.

Although we can understand the pivotal role of industries in addressing the SDGs, some issues can emerge when we tried to understand SDGs' role for industries. Which are the pros and cons of collaborating with these goals? Which tools do companies count on during these changes? Is there any possibility to adopt innovative technologies to deal with the new sustainable challenges? The following section will try to find some possible answers to those questions.

1.4.1 Why should a company integrate sustainability into their businesses?

Frequently, we can read some critics of the SDGs as a simple description or list of essential points of change, without showing how these goals relate to each other or the clear impacts that they seek to address. Moreover, a misunderstanding of them can lead firms to significant risks, an approach to the SDGs as a way to take the good part of their business and match them with one of the development goals, so they can just "tick the boss", doing the minimum to appear credible. In this way, several companies issue only an empty image that gives place to a phenomenon known as greenwashing, which is defined as creating a false impression or even disclosing misleading information about how a company's products are more environmentally sound. As a result of a misunderstanding of the goals' substance, companies lose a powerful ally for their success

Maybe this results in one of the main challenges that every firm must face: "unconscious biases". Usually, it is common to think negatively about sustainability, as problems to face: waste, destroyed environments and contamination. Instead, to discover that we are talking about resources, opportunities, efficiency, and new value creation. Suppose a company is not able to find the value proposition that sustainable development offers to them. In that case, they will not exploit the numerous advantages that they offer, such as production efficiency, customer satisfaction, improved market reputation, reduce risks, cost reduction, among others. Sustainable development will continue to be a beautiful but imaginative goal.

Nevertheless, to find the value proposition and satisfy the future needs of their stakeholders, a company needs to understand the reasons that move them to sustainable development. Usually, firms will find their motivation in the opportunity of technological innovations and solutions that allow them to address new market and achieve exponential price cuts, others instead as a mechanic response to the pressure of public demand and supply chains. Instead, investors search for limiting risks and increment future earnings. For them, a non-sustainable business represents a higher unwanted risk. Finally, customers can be motivated by moral reasoning, health or an international trend.

To conclude, seek for more sustainable solutions is an opportunity for organisations. If they can align their products and offer to the SDGs, they could also enjoy the current and future advantages.

1.4.2 Managing Sustainability: best practices

The first step to integrating sustainability into the core business is its integration in their management profiles. It is crucial to train people on those aspects and to understand what that means for them. However, the question is, how managers can manage effectively sustainable issues?

A study of the best sustainability practices, conducted by the management consulting firm Mckinsey and the Royal Swedish Academy of Engineering and sciences, and the NGO World Wide Fund for Nature. They come with five recommendations:

i. *Identify the priorities and the important sustainability issues for your industry (materiality analysis).*
   The companies can check the American Sustainability Accounting Standards Board, the GRI, or the SDG compass.
ii. *Decide how actively the material issues should be managed.*
   Some issues can be monitored from a distance, and others should be actively developed.
iii. *Define an action plan (practical actions).*
   Ensure that the chosen level of engagement is translated into practical action such as new market segmentation, products or services and new business model development.
iv. *Managing partnership*
   Frequently is needed cooperation and know-how from outside of the organisation.
v. *Communication*
   Communication is critical for managing stakeholders' expectations, and to attract customers, investors, new business partners and potential employees. An important way of communication is the sustainability report. There are two organisations: the UN Global Compact, the world's most significant corporate sustainable initiatives; and the other the Global Reporting Initiative (GRI), the world's leading organisation for corporate sustainability reporting; that have launched an action platform called "Business Reporting on the SDGs" to help companies to incorporate SDG reporting into their existing business and process to facilitate the accomplishment of the SDGs. The UN Global Compact and GRI define reporting as a strategic tool to engage stakeholders; supports sustainable decision-making processes at all levels within a company; shapes business strategies; guides innovation, drive better performance and value creation; and attract investments.

All these practices are essential for managing sustainability proactively, integrating the SDGs into their business, and finding new value creation opportunities. Finally, highlight the relevance of measuring the company performing, finding the right key performance indicators (KPIs), ensuring that the action plan drives your firm in the right direction and helping to achieve clear sustainable objectives. In this area remains much work to be done.

1.4.3 Accelerating the changes

Today and in the following years, sustainability will continue to grow in the corporate agenda. To accomplish SDGs, the Paris agreement goal, to avoid dangerous climate change, and achieve a Sustainable Transformation, there are three steps developed by Mission Innovation that companies can follow:

- **Reframe:** Measuring the impact of their action is the key to reframe an organisation's approach to tackling sustainability issues, resulting in a shift of focus from the problem to the opportunity to take action.
- **Reprioritize:** Following the process of reframing, organisations need to act on the knowledge they have gained and make substantial changes to take advantage of these opportunities.
- **Accelerate**: To avoid dangerous climate change, we will need to rapidly accelerate the uptake of disruptive solutions that can deliver fast and deep emissions reductions.

Finding suitable accelerators to achieve the change is a present goal of many companies and will drive us to new disruptive innovations and new markets. As an example, the global pandemic of Covid-19 has sped the adoption of digital technologies and transformed the way businesses operate. Today, it seems that digital technologies could also be the accelerators that we are searching for. However, history has shown that technologies bring powerful and exponential benefits but also exponential risks. We need to learn from the past that any new technology will be a definite solution by itself. Only a sustainable consciousness will help us use technology innovation for our benefit and future generations' benefit.

CHAPTER 2: DIGITAL SOLUTIONS FOR ENVIRONMENTAL CHALLENGES

2.1 Digital Evolution: key concepts and characteristics

This section aims to be a general introduction to the current digital world. Mainly, it aims to identify the meaning and differences between some vocabulary essential for this work, such as digitisation, digitalisation and digital transformation. Furthermore, it searches to understand the characteristics of the Digital Revolution that we are currently traversing.

2.1.1 Digitization, Digitalization and Digital Transformation

The first word to defined is digital. Nevertheless, we can not start to speak about Digital if we do not talk before of it opposite: analogue. In simple words, we will say that human beings experience the word analogically, because for example, with our vision, we can appreciate infinitely gradation of shapes and colours. For that reason, it is said that analogue systems stores data is stored in a continuous way. An example of an analogue device is the clock with the hands in a continuous movement.

The opposite word is digital because we are talking about discretely storing data. However, what does it mean? The word Digital also comes from the same source as the word digit and digitus, which in Latin means: finger or toe; because until ten, we can count with our fingers. A digital system is a way to store information in a binary way; every bit of information can not have another value than zero (off) or one (on). The computer is the digital machine by preference because it can only distinguish between those two values: 0 or 1. So, all the data that the computer processes must be encoded digitally. In contrast with the analogue clock, a digital clock can only represent only a finite number of times, for example, only an hour and minutes.

So, why digital has become so important if it has a limited ability to represent data? The answer is simple: Digital is a relatively easy way to store and manipulate data electronically. The only trick is converting from analogue to digital and the other way around. Computers are digital machines that can combine many bits in complex ways to simulate analogue events. Briefly, Digital is all about store data.

After clarified what digital means, we would like to deep on the meaning of three keywords that derivate from it: Digitization, Digitalization and Digital Transformation.

The first one, digitisation, is defined as the conversion or representation of something non-digital such as identity cards, papers, health, songs, photographs, among others; into a digital format (bits and bytes) be used by a computing system for multiple purposes. An example is when we took physical information, a paper document, and digitised it using a document scanner. This document scanner creates a digital representation.

The second concept is digitalisation. Some times, this word can be interchangeable with digitisation, but it is something else. Digitalisation is the process of digitisation applied to societies and, principally, economies. It is the turn of interactions, business functions, business models and communications into digital. While digitisation is about store information systems, digitalisation is centred on the interactions between the digital, the physical and the society, with and specific benefit in mind. In business, this mind improves and transforms processes, operations, activities, and functions through digital technologies. It also means that the workforce works differently; they work digitally, using digital tools and devices, creating new interactions inside and outside (customers, suppliers, partnerships, among others).

The last concept is Digital Transformation. Digitalisation leads towards digital business and digital transformation; for that reason, it is easy to confuse them. Digital transformation comprises the integration of digital technologies into every aspect of a business. The acceleration of technology adoption and change leads to an entirely new market, customer and business realities, opportunities and challenges, that drive a new economy. Fundamentally, it leads to a change of culture and how the company operates to create value.

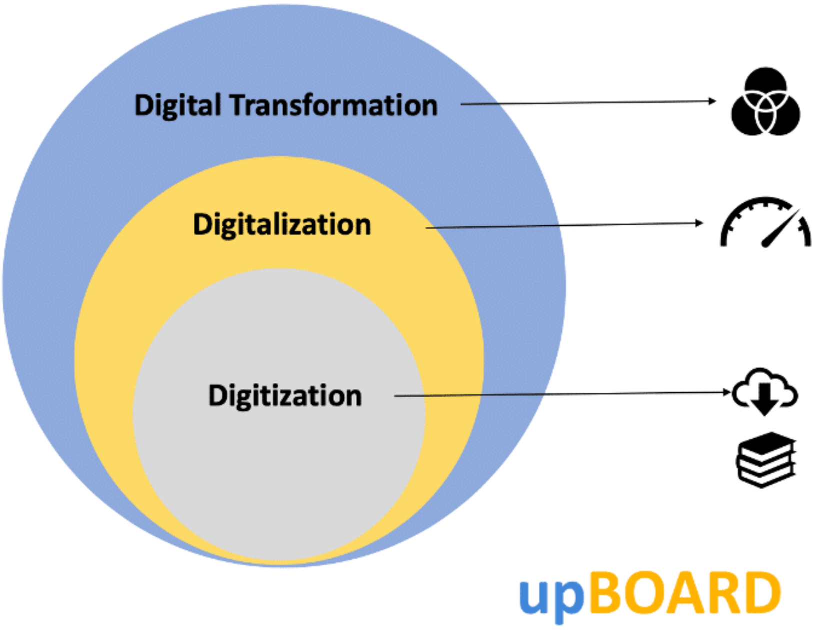


Figure 6. *upBOARD. (2020). The Digital Organization – Business Process Transformation through Digitization.* https://upboard.io/wp-content/uploads/2020/07/Digital-Digitalization-Transformation.png

To summarise, we can describe digitisation as the first step to covert analogue and physical information in digital data. Digitalisation requires digitisation but with a more extensive scope; it uses digital data, tools, and technology to provide more excellent customer value. Furthermore, Digital Transformation encompasses both Digitization and Digitalization. It can be described as all the projects, initiatives and process to bring the company from a stage of building digital competencies to a stage of true digital capability.

2.1.2 Digital Revolution: Industry 4.0

Digital Transformation is not something of the future. We are talking about a current event that is impacting our societies, economies, and environment. To manage and take advantage of these changes, we need to understand their benefits and challenges.

In the chapter before, it was explained how several technological innovations have affected and changed our living habits, work, and even our ecosystems during history. However, only a few of them have driven humanity to a revolution. There is a brief graphic description of them in Figure 5.

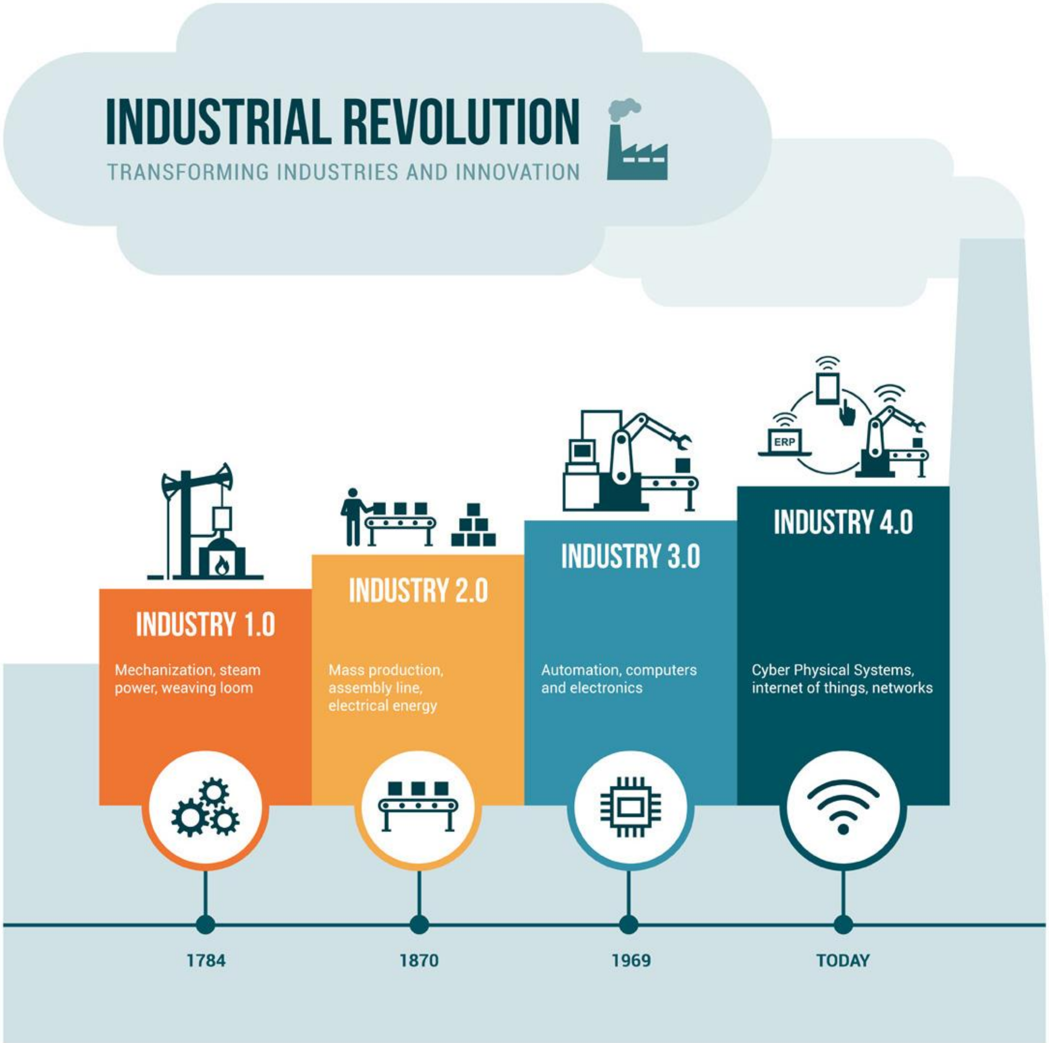


***Figure 7**. Skyray Technologies. (2020). Industrial Revolution – Transforming industries and innovation. https://www.skyraytechno.com/industries/industrial-equipment/*

At the end of the 18th century, the first industrial revolution took place with mechanisation, through water and steam, to mechanise production. The second Industrial Revolution start almost a century later, in 1870. It is characterised by using new sources of energy such as electricity, gas and oil, which allows for massive production. Almost a century later comes the third one. It was characterised by electronic products and information technology to automate production.

Nowadays, many observers believe that we are traversing a new revolution, the fourth one. It has been labelled as Industry 4.0, and it is characterised by the emerge of digital technologies. The German chancellor Angela Merkel defined it as 'the comprehensive transformation of the whole sphere of industrial production by merging digital technology and the internet with conventional industry'. The new revolution has the objective to set up "smart factories", characterised by an interconnection of machines and systems within the production site and outside, providing a highly integrated value chain.

Some of the main drivers of Industry 4.0 are:

- **Cyber-physical systems (CPS)**

They are defined as "transformative technologies for managing interconnected systems between its physical assets and computational capabilities" (Viles, Ormazabal, & Lleo, 2018 p. 346). Some examples are medical monitoring and automatic pilot avionics.

- **Information and communication technology (ICT)**

These are products that store, process, transmit, convert, duplicate, or receive electronic information. To digitise information and integrate systems at all product creation stages and use, both inside companies and across company boundaries.

- **Networking and servicification**

The new revolution has a strong focus on customers and the "value of use".The internet has had an essential role in this, allowing multiple devices to be connected between them, and this interconnection adds value for customers. As an example of this, we have our mobiles, laptops and smartwatches. They have a self-use value: the value of using them alone and a networking value, which is the extra value from the connection between them. The second one is key to increase the "value of use" and shifting from a product perspective to a service perspective.

- **Virtualisation**

The massive amount of data comes from digital systems providing valuable knowledge about customers and manufacturing processes. Moreover, simulators, digital modelling, and new technologies, such as augmented reality, robots, and intelligent tools, support human works and change the traditional processes of manufacturing.

2.2 Digital acceleration

2.2.1 Acceleration of Digitalization: Covid-19

Nowadays, we are traversing a global pandemic produced by the virus Covid- 19. A standard tool that most government and scientific communities have suggested to combat the pandemic are social distancing policies. On the one hand, some of these policies have shown some beneficial effects for combating the pandemic's spread. On the other hand, several sectors, principally economic and businesses, have suffered from adverse impacts caused by customers' habits, behaviours, and priorities.

Many companies have been forced to change their way of interactions inside and outside the firm. Those circumstances seem to create the perfect scenario for accelerating the digitalisation of their business and economies. According to a new McKinsey Global Survey of executives, their firms have accelerated the digitisation of their customer and supply-chain interactions and their internal operations by three to four years. What is more, the share of digital or digitally enabled products in their portfolios has accelerated by seven years. The digitalisation changes arrive in their interaction with customer and supply chain, and that the report also shows and increases digitisation of their core operations.

Some examples of the changes that the application of digital technologies has brought to our societies and economies are:

- **Remote working**: the transition from work in the office full-time to working remotely is one of the pandemic's most significant impact. This situation has push companies to evaluate and separates the tasks and activities that need physical interaction from those that can be done from home without losing productivity. Moreover, after all the investment and knowledge acquired on this modality of working and increased job satisfaction and productivity, some companies plan to shift to flexible workplaces permanently. These also impact the retail sector, where homes planning from 2021 will count with coworking spaces.
- **Online shopping:** the policies restriction and the fear of being infected have kept many shoppers away from stores. The mix of these two issues gave origin to the perfect conditions to accelerate the online shopping and e-commerce sector growth. A survey conducted by UNCTAD and Netcomm Suisse eCommerce Association, in collaboration with the Brazilian Network Information Center (NIC.br) and Inveon, shows that online purchases have increased by 6 to 10 percentage points across most product categories.

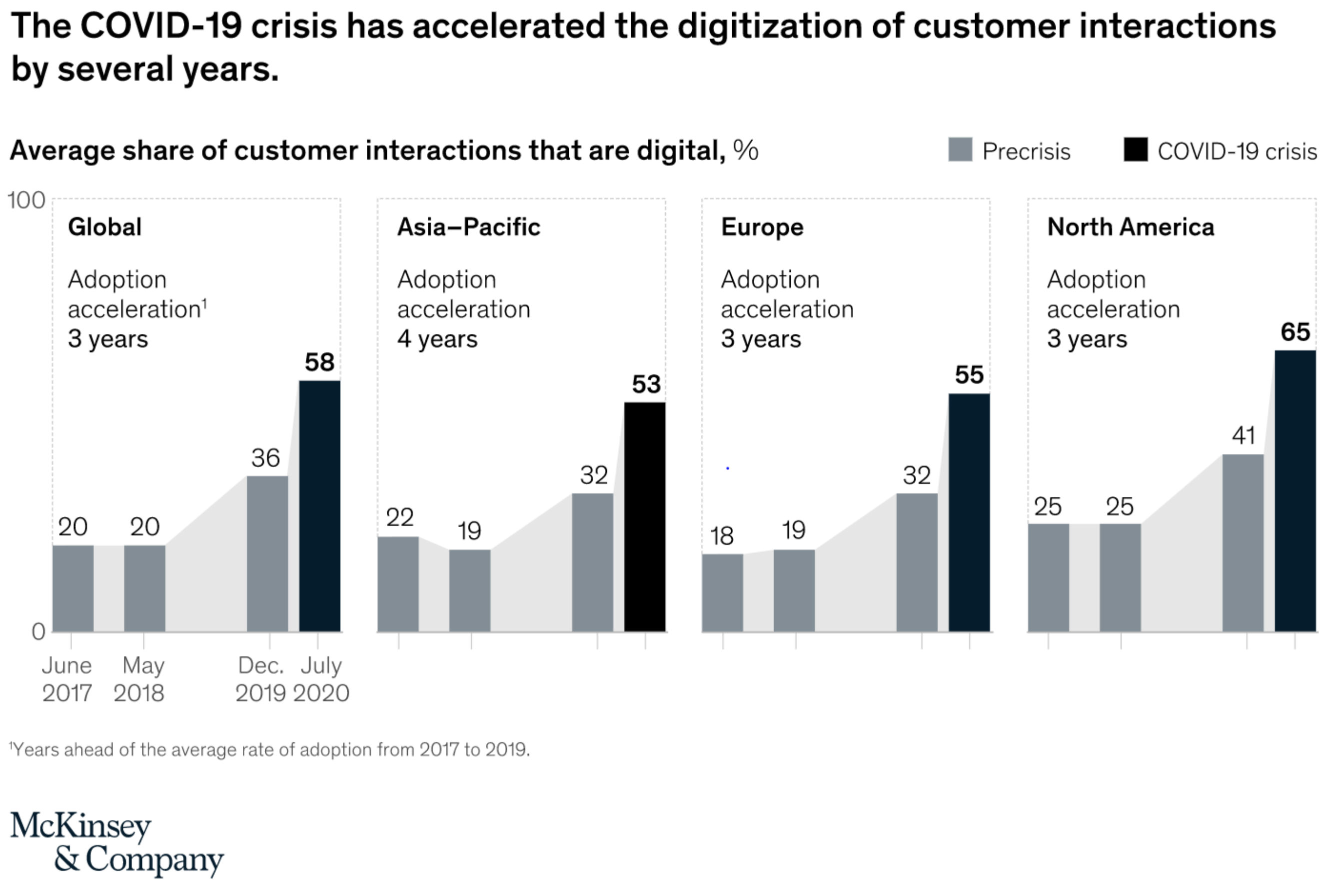


***Figure 8**. McKinsey & Company. (2020). How COVID – 19 has pushed companies over the technology tipping point – and transformed business forever.* [*https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever*](https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever)

- **Digital Content Consumption:** the policies restriction and fear have affected people's shopping habits and entertainment, learning practices, and communication. In general, we can see an increment of internet users worldwide, Netflix subscribers, youtube video plays and social media platforms. Moreover, several graduates programs have shifted to an online modality, and several people take advantages of the lockdown period to acquire a new skill online. Also, the fitness industry has been impacted. A lot of new platforms for holding virtual fitness classes and complement services has become popular. Many traditional industries are thinking about adopting a hybrid approach in the future because they recognise a change in their customers and see digital as a critical tool for their business.

It seems that the current environment situation demands new strategies and practices in order for a business to stay competitive in the market. Many companies admit that they were not implementing these changes because it was not between their priorities and afraid of customer reactions. While in the past, many companies declare to see digital technologies only as a tool to reduce costs, today, companies see the importance of investing in technology as a real competitive advantage and a new value creation source.

Most companies believe that "there is not a return to normal", and clear proof of this is the considerable investment of many time and resources ongoing digital. It seems that it is not a temporary change; those changes will stick in the long term. During the crisis, companies increased their investment in those sectors: migration assets to the cloud, remote working, data security, online presence and use of advanced technologies in operation and decision-making processes. The pandemic has shown the relevance of investing in innovation and building a culture of experimentation to react faster to the changes and profit the advantages of being the first to enter and create new markets.

Data suggest that the Covid 19 pandemic has been a breaking point in history and an accelerator for digitalisation. The capability of adaption to change would be critical for the success of the different organisations. The changes that the crisis brought will remain during the following years. History has taught us the relevance of learning from change and evaluate the impacts of our actions and decisions to manage it in the best direction for our society, economy, and environment.

2.2.2 Benefits of Digital Technologies

Industry 4.0 and the acceleration of digitalisation due to the Covid-19 crisis are changing the manufacturing industries, customer engagement, and business models. Some of the expected benefits from those changes are:

Productivity

With the increase of production optimisation through programmes that can avoid machine failures and automated robots that can continue the production even without lights, companies' production capacities will augment. Thanks to digital design and virtual modelling, the speed of production will also improve. Moreover, integrating digital tools, big data during the product development process has been associated with a rise in the quality of products and reduced errors. The increase of quality and reduced errors is a powerful tool to use the resources and reduce cost, enhancing competitiveness efficiently.

Flexibility

As we explained before, digitalisation will allow increasing the workforce's flexibility, allowing workers to perform specific tasks remotely, reducing the waste of time of movements to fixed locations and giving workers more autonomy to organise their personal and work time efficiently. It is known that higher autonomy at work is directly correlated with higher job satisfaction and, therefore, more outstanding performance.

Moreover, smart factories also allow an augment of flexibility in their productions. Because the automation of production and the possibility of using robots will allow the opportunity to make a variety of different products with the same production facility. Flexibility encourages innovation and gives the customers the possibility to be involved during the design process. Any personal adaptation or change of the same product can be made quickly and cheaply.

Business models

A business model describes an architecture and the rationale of how an organisation creates, delivers, and captures value in economic, social, cultural or other contexts. Industry 4.0 is changing the way that value is generated. Companies are not competing only on costs, if not based on innovation. With the digitalisation and access to big data, companies are changing their focus on satisfying personal customer needs and improving the quality of products delivered. Digitalisation is influencing customer relationships, the value proposition and the management infrastructure. The shift from a product perspective to a service perspective is opening to companies new markets and an opportunity to increase revenues.

2.2.3 Barriers of Digital Transformation

Most of the benefits mentioned before continue to be purely expectations. Most of them have not been achieved yet or are far away to be achieved on a considerable scale to be considered a global benefit for societies. They are several doubts about the long term implication of digitalisation and new technologies. To see the benefits of this revolution, it will be necessary to traverse some barriers and find solutions to some of the following issues:

Investments

Covid- 19 has been an essential accelerator for digitalisation, but it still too much to get done to perceive the revolution's benefits. Industry 4.0 requires considerable investments in new technologies, infrastructure, research and skills. Many companies have a lack of capital or capacities to handle the change. For others, this digital transformation implies a leap in the dark, without a clear vision of its impact on their value chain and future revenues.

Security

All companies want to be protected from risks because they can cause significant damages for a company and even, in some cases, their bankruptcy. Coming back to Mckinsey Global Survey, we can see that the acceleration in digitalisation of the last year has also increased investments in data and cybersecurity because one of Digital's characteristics is the possibility to receive, store, and analyse large quantities of data. Nevertheless, these data are private information about a company, customers, partnership, or stakeholders, expecting a proper and limited use of their data. For example, we have the video conference platform Zoon that, with the high increase of users due to the pandemic, also appears several criticisms for a range of privacy issues. Several examples show that confidentiality and trust, through the protection and appropriate use of data, are crucial for the new revolution.

Legal issues

Another challenge that is arriving more in the courts is Intellectual Property Issues. When a company include their customers in different parts of the production process, usually call open innovation, or if a company design a personalised product, who is the owner of the Intellectual Property rights? The French Conseil d'analyse économique has called for a balance between innovation by protecting IP and sharing knowledge necessary for population development. Another legal issue that arrives is a dangerous or defective product; it results from extensive labour through artificial intelligence and other robots during the production; who will be responsible? The company, a supervisor or the robot designer? All these legal questions should be resolved to avoid, protect, and understand the new liabilities and rights that emerge through the use of new technologies.

Employment and skills development

The new revolution will shift several manual or simple labour for machines. Several employees risk becoming replaceable, and at the same time, the market will require new skills and capabilities. To make this transition, without a negative impact on society, economy, reputation, or employer branding, a company should be able to go along with their employees during changes and give them the necessary tools to face it. Among the essential skills necessaries for digital transformation, we can mention critical thinking, complex problem solving, adaptability, creativity, data management, programming, software development, people managing, design and service orientation.

To conclude, during this section, we have presented the principal elements of the Industrial Revolution, how the current pandemic has pushed and accelerated digital technologies' adoption. Some of the present and future expected benefits from it. However, as we have explained above, there are still many issues linked to the changes that bring about Industry 4.0. The private sector and public institutions should tackle those challenges to ensure a successful transition and sustainable development.

2.2.4 Green and digital recovery

The European Technical expert group (TEG) on Sustainable issues make some recommendation for the recovery of Covid 19 and argue the importance of using the pandemic's economies response to tackle the planet's environmental issues to ensure greater resilience in a future crisis. Moreover, the European Commission's Green Deal chief Frans Timmermans has assured that "every euro" spent on economic recovery measures after the pandemic Covid 19 would be linked to the green and digital transition.

Nevertheless, digitalisation impact should not be evaluated isolated from other economic sectors and activities. Digitalisation's sustainable benefits can be understood not as a unique technology or industry but as an interconnected system that interplays in many fields. Even if the global greenhouse gases emissions that correspond to the ICT sector are approximately 1.4% of the overall global emission, the potential benefits of digitalisation could outperform the negative impact decreasing other sector emissions by up to 15-20%. Moreover, according to *"Digital with Purpose: Delivering a SMARTer 2030"*, a report by the Global Enabling Sustainability Initiatives (GeSI) and Deloitte, supported by the EIT Climate -KIC; Digitalization could accelerate the progress toward the Sustainable Development Goals by 22%.

The SMARTer 2030 report identifies some of the potential benefits of digitalisation in the fight against climate change. Firstly, digital technologies allow monitoring and tracking the world; hence the present state and the action impacts can be evaluated, learning how and choosing the best mitigation efforts. For example, in some sectors, smart sensors have allowed measuring CO2 and methane emissions. Another example of monitoring technology is satellites. They allow monitoring and mapping a wide range of climate-related activities such as deforestation, urbanisation, ice sheet melt, wildfires, and methane emissions.

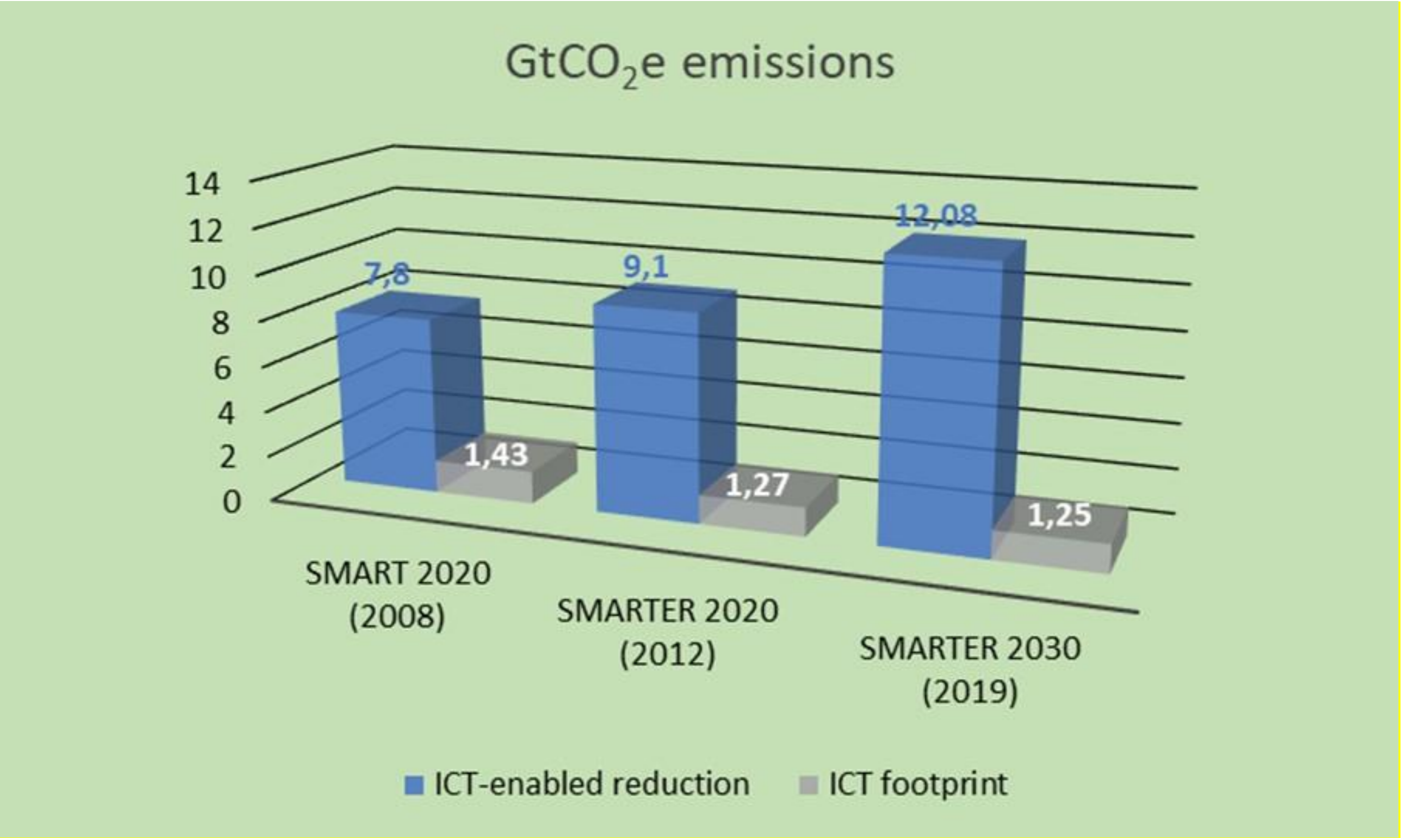


Figure 9. *Bogucka Hanna. (2020). Green Communication and Computing for 2030. Based on the slideshow by Luis Neves, GeSI Chairman, "#SMARTer2030: ICT – Disruptive Technologies for Sustainable and Better Living" at 5th ITU Green Standards Week, Nassau, The Bahamas.* https://www.rimedolabs.com/blog/green-communication-and-computing-for-2030/

Furthermore, the report state other advantages of the use of digital technologies, such as the opportunity to analyse a massive amount of information, from which it is possible to optimise the process and resources. Moreover, it has been estimated that through the optimisation of different process in the agriculture, transport, energy, and manufacturing sectors, it would be possible to reduce greenhouse gases equivalent to 1.3% of global emissions in 2030. Additionally, the possibility of digital design, modelling, and simulations can contribute to the dematerialisation of the economy activities, reducing valuable energy and resources.

In contrast, digital technologies also can bring some negative externalities to the environment. Between them is the augment of emissions directly related to that sector, extraction of scarce resources and the inadequately managing of e-waste. From the publication *"The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential"* by the United Nations University, we can see that 53.6 million metric tons of e-waste were generated in 2019. From them, only 17.4% was officially documented as properly collected and recycled. Moreover, with more than 25 billion devices connected, the increase of energy demand for digitalisation cannot be overlooked.

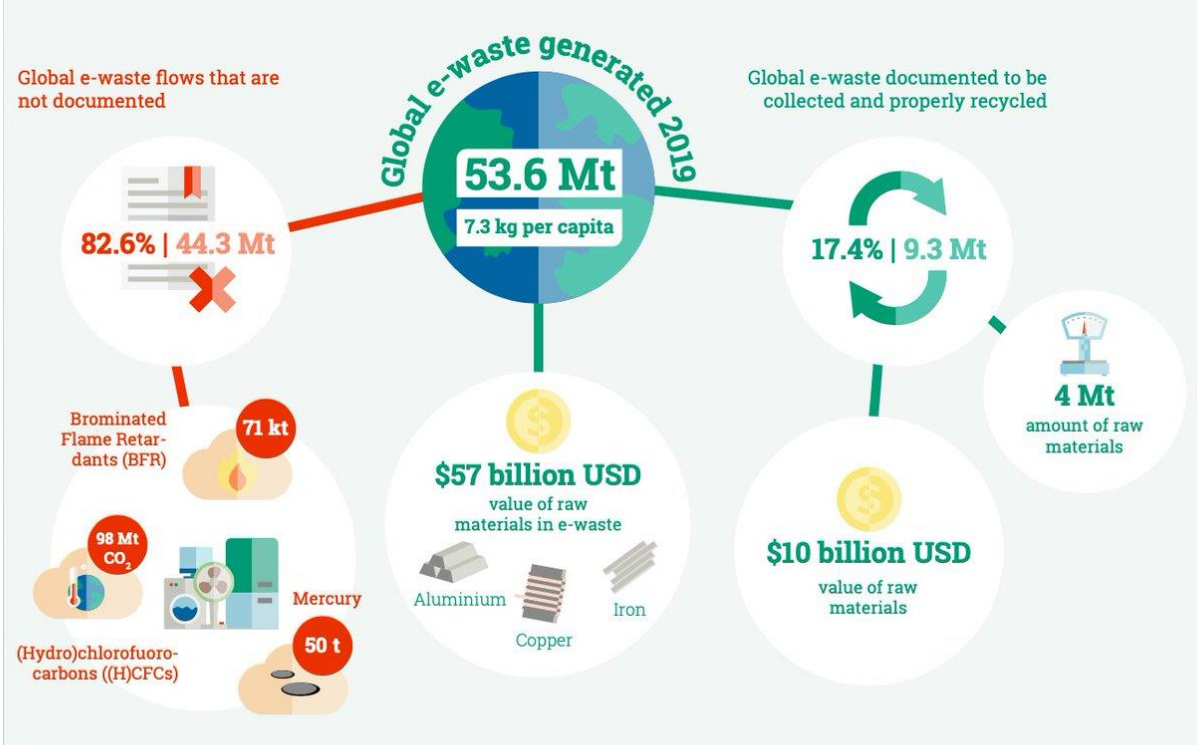


Figure 10. *Forti Vanessa, Baldé Cornelis P., Kuehr Ruediger, and Bel Garam. (2020). "The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential.* *https://www.itu.int/en/ITU-D/Environment/Documents/Toolbox/GEM_2020_def.pdf*

To conclude, it seems that digital technologies can help achieve decarbonisation across many sectors, promote circular economies, efficient use of resources, and achieve more sustainable development. Nevertheless, these potential benefits will not happen by themselves; the current and negative impacts prove that digital technologies are far from a circular economy model and a sustainable society. Understanding and correcting the current situation is essential to profit from digitalisation and achieve a sustainable transition.

2.2.5 Essential Digital technologies to the earth

The *"Digital with Purpose: Delivering a SMARTer 2030"* report also identify some prominent digital technologies groups with global and cross-industry impact during the following years.

Those technologies are:

- **Cloud technology:** enables the supply of computer applications and services over the internet, decreasing storage and computing power needs.
- **Digital access:** connectivity from people to people, and people to the internet.
- **Cognitive:** the application of advanced analytics, machine learning and artificial intelligence approaches to big data to develop insight.
- **Blockchain:** a digital and distributed electronic ledger that record and confirm transactions, governed by a network of computers.
- **Fast internet:** next generation of connectivity, 5G.
- **IoT (Internet of things):** the connecting of physical objects to the internet can collect and exchange data over the internet and enable smart solutions.
- **Digital reality:** Computer-generated simulation of a three-dimensional image superimposed to the physical world (augmented reality) or a complete environment (virtual reality).

The seven technologies vary significantly in maturity. Each of them has plenty of opportunities to scale in terms of deployment, and consequently, in terms of impact. This thesis focuses on the impacts of the digital reality group.

2.3 Digital reality technologies

Digital reality technologies is a growing and expanding market for the following years. Contrasting other technologies using flat screens (e.g. a computer or television), Digital Reality submerges you in the content providing you with a first-person perspective that allows the user to simulate reality in various ways. This section aims to be an introduction to the wide variety of digital reality technologies, such as virtual reality (VR), augmented reality (AR) and mixed reality (MR).

2.3.1 Augmented reality, virtual reality, and mixed reality

- **Augmented reality (AR)**

It is an interactive experience of a real-world environment where the objects that belong to the real world are enhanced by computer-generated perceptual information. These objects can appear as a flat graphical overlay or can behave as actual 3D elements. It is a flourishing trend among companies implicated in mobile computing and business applications in particular.

- **Virtual reality (VR)**

It is an entire replacement of your real-world environment. This environment can be computer-generated or filmed in 360-degree video. It also takes full advantage of the body- and motion-tracking capacities, with many claiming that this leads to a superior sense of presence and involvement. Currently, most applications of VR are in the gaming industry. Nevertheless, the variety of training scenarios and architecture and engineering applications is rising quickly.

- **Mixed reality (MR)**

It does not fully occur in either the physical world or virtual world but is a hybrid of reality and virtual reality. It merges real and virtual worlds to create new environments and visualisations, where physical and digital elements co-exist and interact in real-time. Using MR devices such as the Microsoft HoloLens or the Magic Leap, it is possible to project 3D holograms into your field of vision.

Applications for MR are nearly all of those for AR and VR technologies.Therefore this research will focus principally on the application of virtual reality and augmented reality technologies

2.3.2 Business potential benefits

An economic impact assessment conducted by PwC economists estimates that VR and AR technologies can deliver a $1.5 trillion boost to the global economy by 2030. These technologies are becoming more sophisticated and approachable each day. Some of the potential benefits detected on the "Seeing is believing "report are:

- **Product and service development**

These technologies allow the exploration, test, and assessment of different concepts quickly without investing in physical prototypes during the design and production phase. Therefore, organisations can bring higher quality products, saving money and reducing risks.

- **Development and training**

These technologies allow the employees training and exposure to some situations that would be impractical or too risky to do in the real world. For example, to train military pilots for a situation of war or extreme climate conditions. Moreover, with the current pandemic situation, several studies of applying these technologies in different fields claim that VR and AR training boost knowledge retention and engagement compared with other remote technologies.

- **Process improvements**

Through the variety of information collected from VR and AR technologies applications, it is possible to improve workers and processes' efficiency and accuracy.

- **Consumer experience**

These technologies also give news possibilities and creative ways to interact with customers. Gaming is one of the most popular industries to interact with these technologies. However, other sectors are also exploring the opportunities that these technologies could bring them, such as the possibility of creating a virtual fitting room for fashion stores or helping to choose the best furniture, giving customers the possibility to see and test how it would look in their houses.

2.3.3 Business potential challenges

Equally to any innovation, there exist some challenges that those technologies need to face:

- **Adaptation and adoption**

The adoption of digital technologies such as VR and AR impact the culture of business and societies. It is needed that more people have the opportunity to understand the technology, to try it and to express their concerns about it.

- **Communication of benefits and limitations**

There is also a lot of confusion about how this technology will be used: the benefits and limitations or negative consequences. Trust is a crucial factor to manage during the adoption of new technology. Therefore, organisations developing these technologies need to do more than only implementing them. Companies need to study how their technology could create value for society, economy and environment and should communicate all the benefits and limitations that the technology present clearly and through factual evidence.

- **Focus on cost**

Even if the cost of most of these technologies has decreased over the last years, they continue to represent a limit for some businesses. Nevertheless, instead of focusing just on cost, organisations and investors need to understand the benefits, the opportunity of savings in different processes and create new value for customers. Moreover, a company should evaluate the risks of competitors applying this innovation and creating a competitive barrier for them.

To conclude, this section has overlooked some possible benefits and challenges of the business application of some digital reality technologies such as AR and VR. However, each company should do this analysis to evaluate the impact of applying these technologies on their specific market sector.

CHAPTER 3: ENVIRONMENTAL IMPACTS OF DIGITAL REALITY APPLICATIONS IN AVIATION

3.1 Sustainable Development in the Aviation Sector

Aviation is a growing sector that currently is facing multiple environmental challenges. In 1999, an Intergovernmental Panel on Climate change report that aviation accounted for near 2% of global greenhouse gas emissions due to human activity. Additionally, it was highly that aviation emissions are particularly challenging due to the chemical interactions at high altitude. This has incremented the spotlight on aviation, and consequently, the market participants have been affected by a variety of targets, regulations, possible solutions, and practices that emerged during last years.

In 2009, the International Air Transport Association (IATA) presented to the United Nations Framework Convention on Climate Change a strategy to reduce carbon emissions. The targets proposed were:

- From 2009 to 2020, an average improvement in fuel efficiency of 1.5%.
- From 2020, a carbon-neutral growth.
- By 2050, a reduction in net aviation CO_2 emissions of 50% relative to 2005 levels.

In March 2021, the European Union launched their Destination 2050 initiative to target net-zero carbon emissions by 2050 for all flights within the EU, United Kingdom and the European Free Trade Association. To accomplish these goals, they proposed to focus the market efforts on four pillars:

- Economic measures (i.e. credits)
- Sustainable aviation fuels
- Improving aircraft and engine technologies,
- Improving air traffic management and aircraft operations.

Green financing incentives must be available to promote change and accomplish a meaningful reduction of emissions across the aviation sector. For example, in the EU Taxonomy on green financing, it is necessary to determine technical screening criteria for aviation. Moreover, the Aviation Working Group has published a letter to the European Commission that set the principles to apply the EU Taxonomy to aviation to encourage a greener future in this sector.

From a Market Research Report Record, it has been projected that the augmented and virtual reality market in aviation will grow from USD 78 million in 2019 to USD 1375 million by 2025, an annual growth rate of 61,2%. Moreover, AR and VR technologies claimed to improve efficiency in operation and save cost in diverse aviation functions. This survey will investigate the environmental impacts of the aviation industry and how digital reality technologies on the aviation sector could help fight against climate change, giving the companies on this sector the opportunity to create new value for all the stakeholders involved. This work attempts to discover existing publications on the topic and classify them in a meaningful way. In addition, interviews have been done with the specialist in the aircraft and sustainability divisions of Leonardo S.p.A. company, one of the world's major players in Aerospace, Defence and Security, to complement the systematic literature research with a practical case.

As far as this author knows, this is the first survey to cover the topic of virtual reality technologies for green development in the aviation sector. It has been analyzed how the aviation sector impacted the environment principally, focusing on climate change and how current and upcoming advancement on augmented and virtual reality in these areas can contribute to achieving the desire green targets. The chapter is organized as follows: firstly, with a description of the exact methodology (keywords, sources, selection criteria and statistical analysis). Secondly, a presentation of the studies selected with a quantitative assessment. Thirdly, a detailed analysis of the articles and key insights. Then, a study case of flight simulators used by Leonardo company has been added. To conclude, it exposes a summary of the research gaps and future research directions and possible developments on this topic.

3.2 Review Methodology

A systematic research procedure was applied to address the objective of this thesis, minimize the risk of bias during the search, and find an answer to the following research questions:

- Which are the environmental impacts of the aviation sector?
- What is the utility of digital reality technologies in aviation?
- Are virtual reality technologies good to reduce the environmental impacts on the aviation sector?

3.2.1 Identification of studies

Based on the research questions and the theoretical framework, appropriate keywords were identified. Nevertheless, the combination of all of them does not lead to any result. For that reason, it was decided to divide into two search strings illustrated in Figure 11. The search string A included keywords related to the contextual framework of the environmental Sustainable Development Goals, and the Paris Agreement aims (Emissions/ Climate/Environment/Greenhouse/Impact / CO_2/global warming) and the subject aviation. It is complemented by the search B that included keywords related to the Digital reality context (Virtual Reality/Augmented Reality) and the aviation and environment (Aviation / Flight / Pilots / Environment / Emissions).

Search A was performed using search queries in different data sources. Leading data sources were Scopus (https://www.scopus.com), Google Scholar (https://scholar.google.com/) and Summon Luiss (https://luiss.summon.serialssolutions.com/), which provides extensive coverage of scientific literature and offer a functional interface for detailed analysis and data extraction. Instead, search B was limited only to Google Scholar source due to an absence of limited or repeat articles on the other databases.

Apart from searching on these databases it was also explored newspapers, related reports of public and private organizations, related studies and it was carried out interviews with experts on the field of study. The literature search was performed by the end of April 2021.

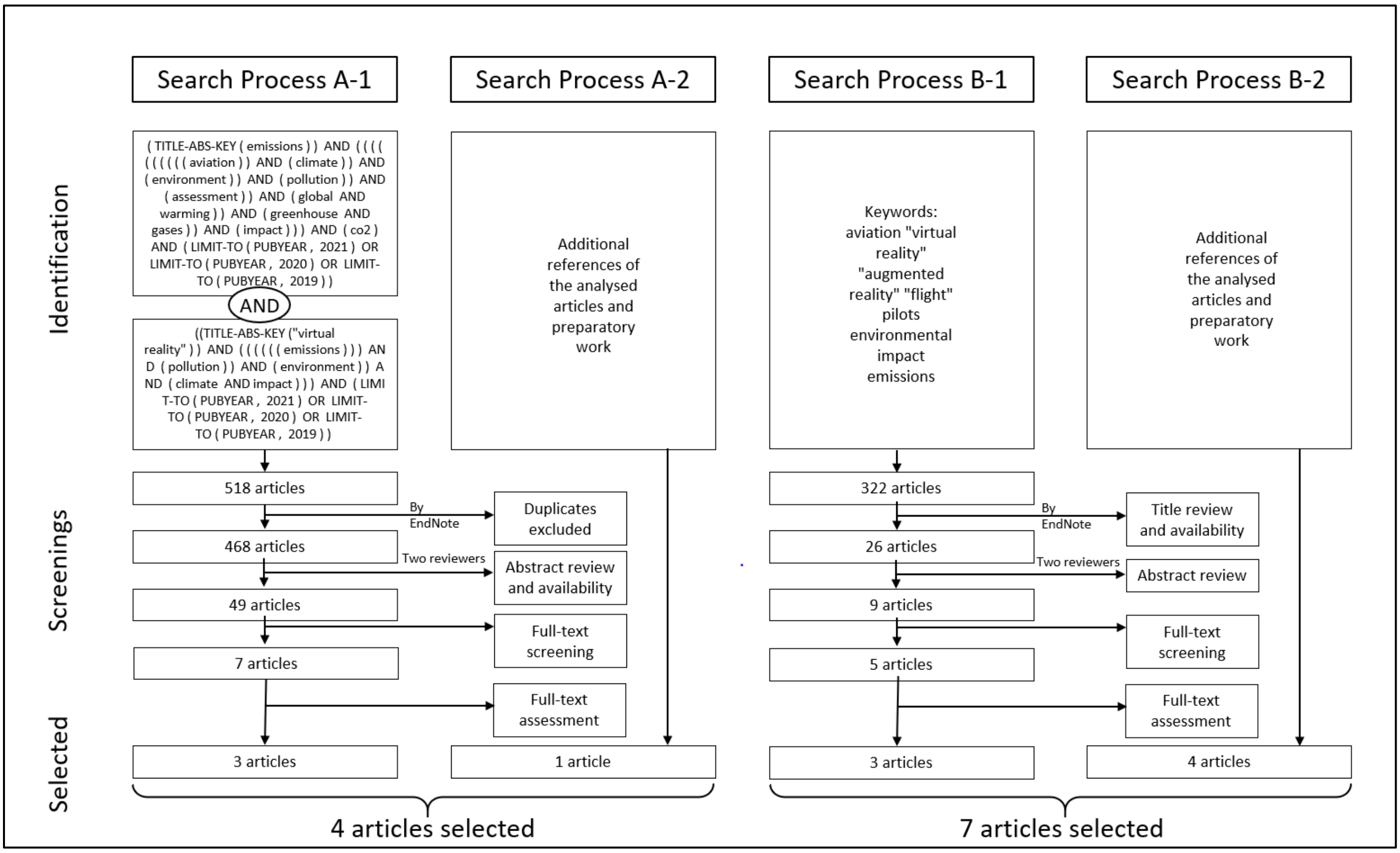


Figure 11. Search Strategy and results

3.2.2 Selection criteria

The results from the different database search were analyzed in a structured screening process. First, language criteria were applied to include articles that were written in English. In addition, publication date criteria were also applied. For search A articles published from 2019 to April 2021 and search B, the period was extended from 2017 to April 2021.The search led to an initial identification of 518 articles for search A and 322 articles for search B through this procedure.

Second, all record were collected into one Endnote group in order to delete duplicates. All references that have the same title and author, published in the same year, and the same title and author, and published in the same journal, were deleted. This step was done only within search A, because it is the only one that involves different data sources; there were eliminated 50 articles, leaving a total of 468 articles for search A. Alternatively, search B was done a title screening to minimize the chance of including non-relevant articles and an availability criterion to ensure free access to the full text. To reduce the chance of error and elimination of relevant articles, two reviewers did the scrutiny. This step leaves a total of 26 articles for search B.

Then, the abstracts of the remaining articles were analysed by two reviewers and considering the following criteria:

- Relevance: the articles that provide and reply to one or more of the research questions, or those works that are closely related to the proposed work.
- Originality: If several papers addressed similar topics and with similar methodology, it was kept only one of them, together with those articles that address innovative aspects.
- Availability: the possibility to have a free access to the full text.

Within search A, only 49 articles remained after this filter was applied, and within search B a total of 9 articles.

The following steps were a full-text screening to identify the cover topics and methods utilized in each article. This reduces to 7 articles remaining in search A and three articles in search B. Finally, a full-text reading was done and applying again the selecting criteria described during the abstract review. The final selected papers are exposed in Table1 and Table 2 of the appendix. Additional references were identified during this step and were added to the review database (search process A-2 and B-2), resulting in 4 articles for search process A and 7 articles for search process B. A total of 11 articles were the result of this strategic selection process.

3.2.3 Statistical analysis

For a first overview, the distribution of the publication output over time is analysed. Even if for search A it is possible to find some articles published in 1985 and for search B the first articles published on the data source chosen in 1992, it was decided to put the focus on the last 10 years, which seems to be the most relevant to appreciate the general interest trend on the topics of research. Complementary, it was added the number of articles published during the years 2000 and 2005. For 2021, the results are only partial, as the research for papers ended on April 2021.

Figure 12 and Figure 13 illustrates the number of articles by the publication year of search A and search B, respectively. The growth in the number of publications on both overtime reflects an increased interest in the environmental impacts of the aviation sector and principally in applying augmented and virtual reality technologies on the aviation sector.

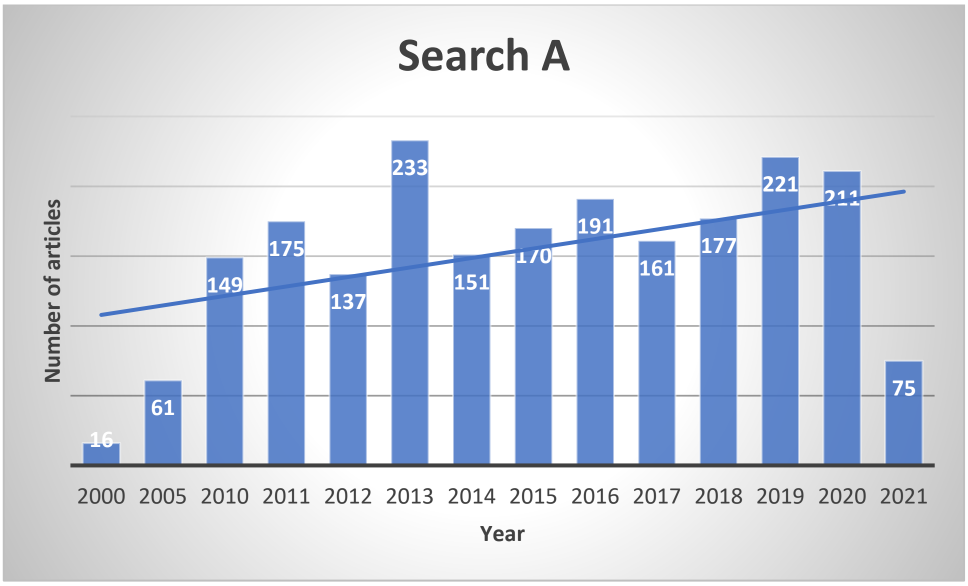


Figure 12. *Distribution of articles by publishing year - Search A*

In 2013, the International Civil Aviation Organization (ICAO) requested its technical experts to develop a global CO_2 emissions standard for aircraft and voluntary plans to reduce emissions. Notably, this year, looking at Figure 12, it is possible to observe a considerable increase of conducted researches on this topic.

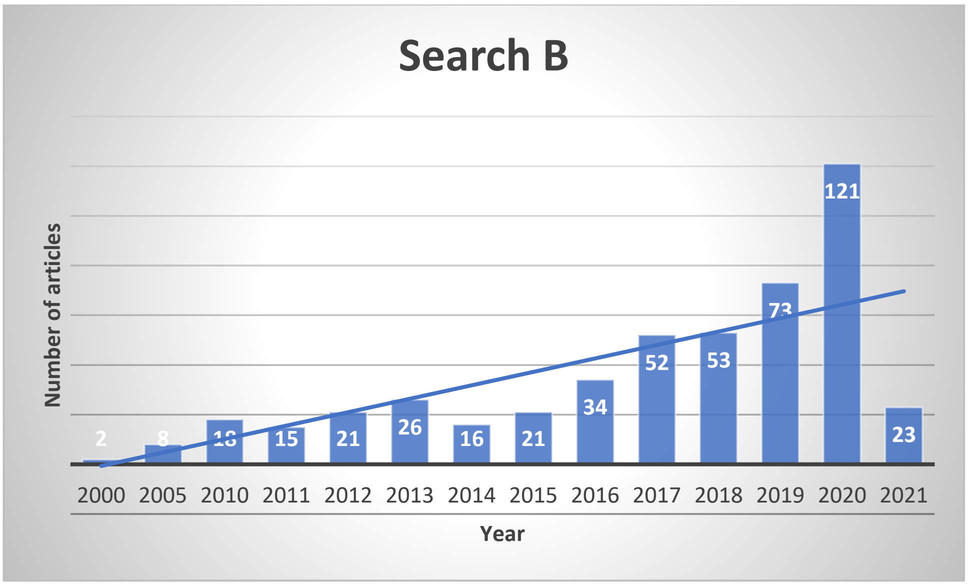


Figure 13. *Distribution of articles by publishing year - Search B*

Moreover, in 2020 due to the Covid- 19 pandemic, there was a considerable acceleration of digital technology development and digitalization of several sectors (Section: 2.2 Digital acceleration, Chapter 2). Observing Figure 13, it can be appreciated a considerable growth of the number of researches published during this year about the application of augmented and virtual reality technologies in aviation with an impact on the environment and climate change.

In their totality, these literature analyses by publishing year seem to demonstrate that the interest in the research of the environmental impact of the aviation sector is higher than the research on the application of digital reality technologies in the same sector. Nevertheless, observing only the last 10 years, the growth rate of interest in VR and AR technologies on the aviation sector is almost the doble of environmental impact. Therefore, it could be estimated that with time, more research will be done on this area, simplifying for investors and organizations the understanding and communication of the sustainable impacts of the application on those technologies in the aviation industry.

3.2.4 Contents analysis of the selected literature

In this section, a first analysis of the selected literature of search A regarding the type of impact, the aviation emissions and mitigation options proposed is conducted. Following by an analysis of the selected literature of search B regarding the digital reality technologies application on aviation, the market sector and potential benefits. In addition, in Table 1 and Table 2 in the Appendix section, it is possible to find a description of the articles selected in search A and B, respectively.

- **Aviation and climate change – Search A**

Given the European commitment to the Paris Agreement and their firm goal of achieving a climate-neutral economy by 2050, research in decarbonization has been intensified in the last years. This research addresses the scientific works and reports that focus mainly on the environmental impacts of aviation. Particularly in the emissions assessment on aviation, which represents a current uncertainty for this industry.

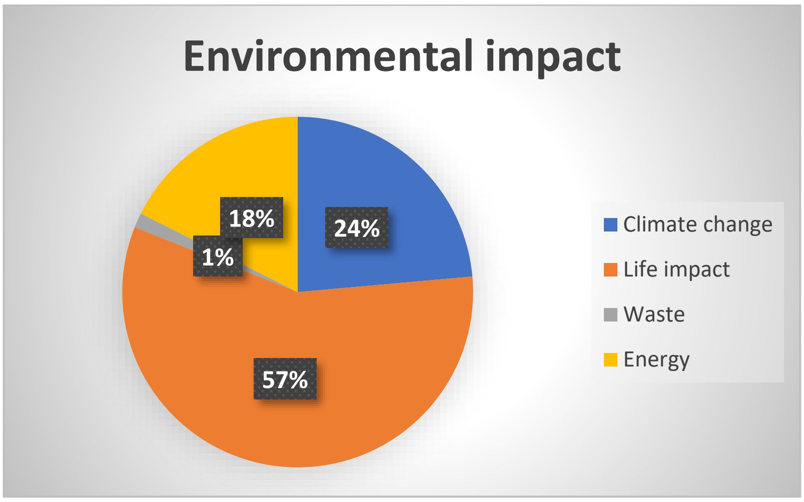


Figure 14. *Environmental impacts of aviation – Search A*

Figure 14 shows how often different environmental impacts are considered in the literature investigated. Between the main effects of aviation, we found those related to climate change and global warming and those related to life quality, such as noise or air quality change. Secondly, it is possible also to identify any impact on energy consumption and waste disposal. Due to the small amount of information respecting those last impacts, this work will focus on aviation emissions and their impact on climate and life.

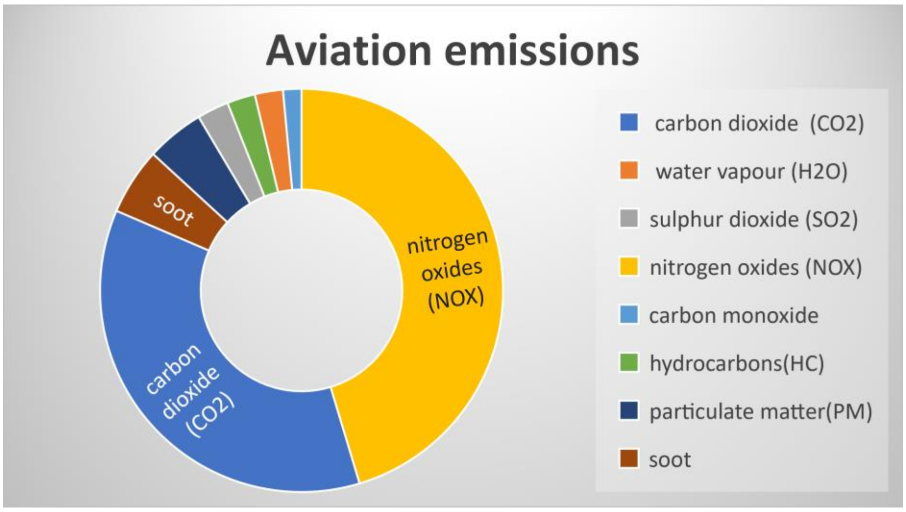


Figure 15. *Aviation emissions focus in the research literature – Search A*

Regarding the different types of emissions of the aviation sector that impact on climate temperature and air quality, there have been identified eight principal on the literature investigation: carbon dioxide (CO_2), water vapour(H_2O), sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC) particulate matter (PM) and soot. Figure 15 make a comparison of the frequency of these terms in the articles investigated. From this assessment, it is possible to conclude that nitrogen oxides and carbon dioxide emissions have an important role in the research of environmental impacts of aviation.

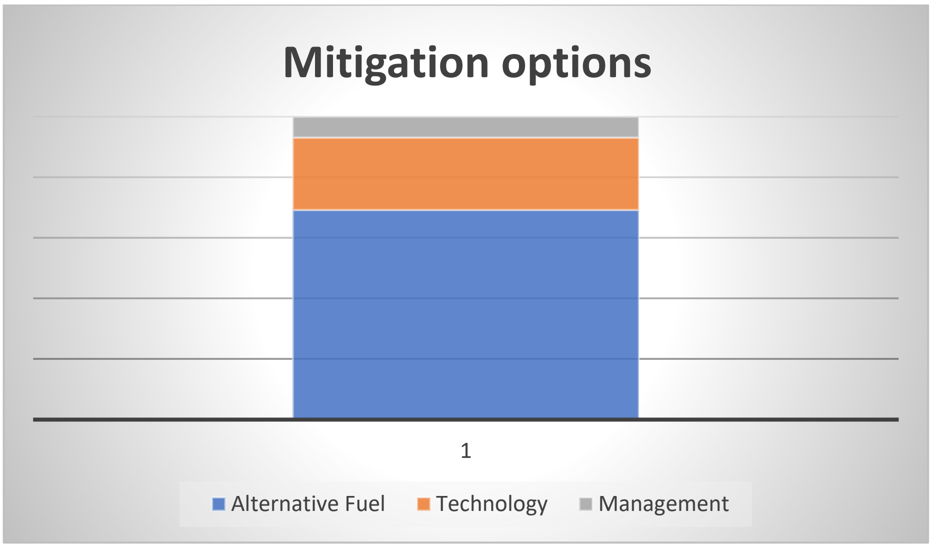


Figure 16*. Mitigation tools for climate change – Search A*

Finally, to mitigate the negative impacts of aviation and reduce the number of harmful emissions, the literature selected mentioned the following solutions: Technology and Design, Sustainable Aviation Fuels, Air Traffic Management and Operations. Figure 16 shows the number of times these three mitigation options appear on the articles. It is possible to observe that alternative fuels are the solution with more weight. Nevertheless, technology and innovation appear to have a growing role in the reduction of emissions. Finally, at the last place but not less, it is management. The literature only makes a few mentions about a managerial solution to mitigate adverse impacts of aviation, giving the possibility open to further research on this.

- **Digital reality applications in the aviation sector**

The Digital reality technologies selected for Search B were principally Virtual Reality and Augmented Reality technologies. However, some articles are only concentrated on applying these technologies to the creation of simulators of different types of process for the aviation industry. Firstly, due to the topic's novelty, it was decided to understand the different utilities of these technologies in the aviation industry. Then, between the different repeated keywords, it was also possible to identify that the studies focused on different market sectors with different characteristics and requirements. Finally, it was identified in the literature some benefits of the use of these technologies in aviation.

In Figure 17, the most relevant applications of digital technologies among the research are represented. These kinds of literature primarily focus on using these technologies for training or as support during flights. The second place is applying VR and AR during the manufacturing and design process on aviation and the maintenance operations. Finally, only a few comments in the selected articles about VR and AR to monitor and entertainment purpose appear in the literature.

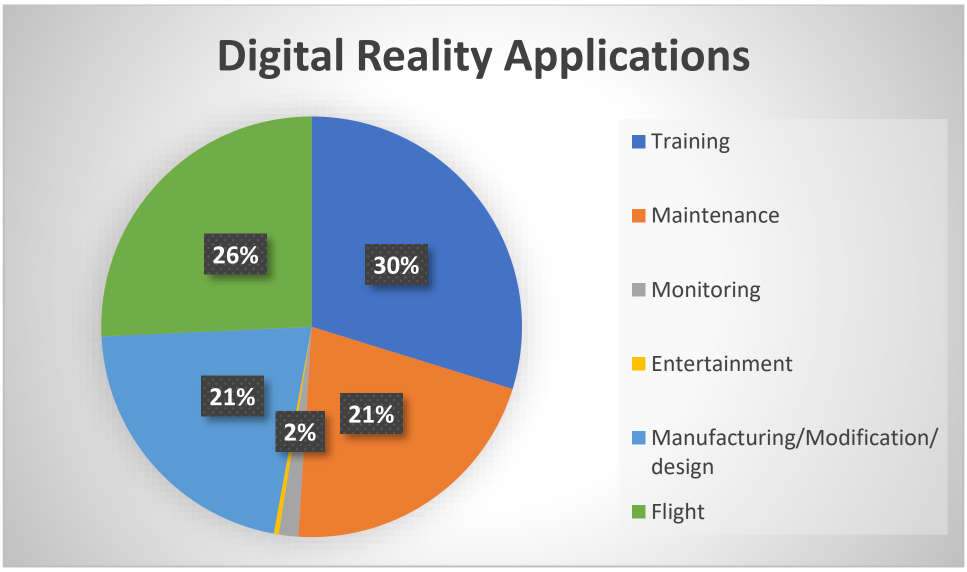


***Figure 17**. Digital reality applications on aviation – Search B*

These articles focus on different market section into the aviation industry. Some of them are based on aviation in general terms, but most of them make studies on applying those technologies in a particular sector. In the literature selected, we can distinguish between two types of articles, civil and defence or military aviation. Civil aviation includes the air transport category that involves all passenger travelling in regularly scheduled routes and general aviation, including all other civil flights, as private and commercial. Instead, on military aviation, all the state-owned aircraft engage in transport, training, security, and defence are compressed.

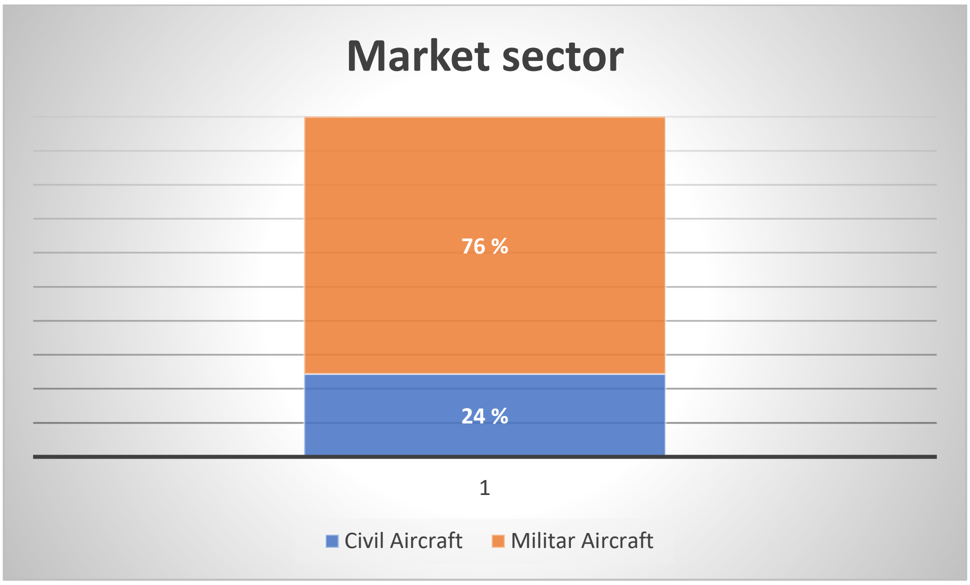


Figure 18. *Market sectors tackle on the literature – Search B*

As illustrated in Figure 18, the articles selected in the research are focus principally on the application or experiments carried out in the military sector. Nevertheless, independent of the experiment of focus, most of the applications propose are suitable for both sectors.

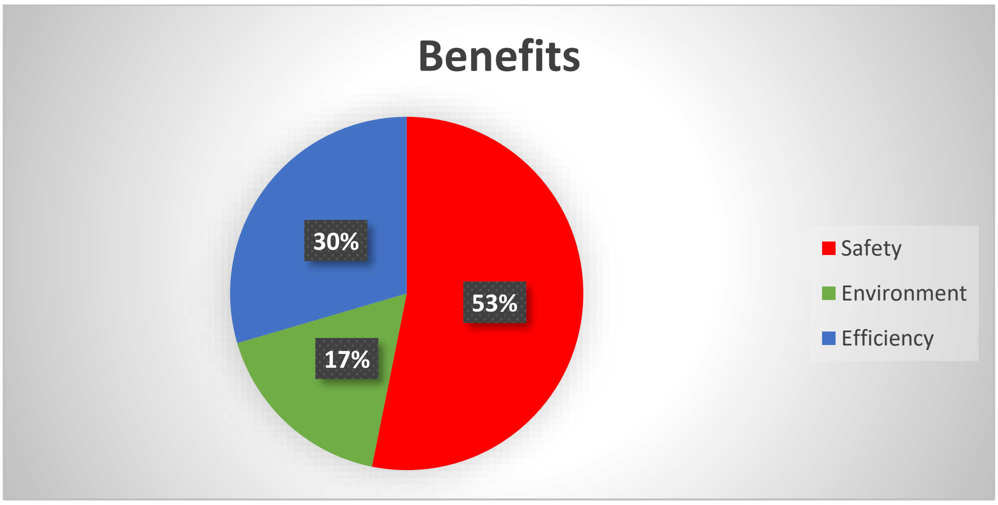


Figure 19*. Digital reality benefits for aviation – Search B*

After identifying the different AR and VR technology applications and the market sectors where the literature is concentrated, some potential benefits of those technologies have been detected. Understanding the use and advantages of these technologies in the aviation sector is possible then through a deep analysis to find some connections between digital reality technologies and the environmental opportunities that they can offer to the sector.

Figure 19 illustrates the weight of three main benefits identify by the number of time that keywords are repeated in the articles selected. It seems that these technologies could be an excellent ally to increase safety in this sector while increasing efficiency and helping the environment during the process.

3.3 Detailed analysis and key insights

In this section, the selected articles are analysed, and the information is organized to answer the research questions of Section 3.2. To address these questions, it is needed to understand the problem; therefore, it has been compilated the environmental impacts of aviation. Then, different application of VR and AR technologies in the aviation sector were collected. Finally, the possible links between digital reality technologies and the development of a green aviation industry have been studied.

3.3.1 Environmental impacts of aviation

Most of the articles agree that aviation was responsible for around 2.6% of the world CO_2 emissions of 2019. Moreover, in 2015 European aviation accounted for 20% of global aviation's CO_2 emissions and the second-largest source of greenhouse gases after traffic. Nevertheless, carbon dioxide is not the only problem of aviation. A considerable amount of non- CO_2 emissions account for more than 60 % of the climate change effects, plus air quality impacts on health and increasing noise levels. The following section would compile the main impacts and mitigation solutions proposed in the articles selected in Search A.

- **Aviation emissions and climate change**

The principal pollutants produced by the aviation sector are carbon dioxide (CO_2), unburnt hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), contrail-cirrus clouds, water vapour (H_2O), sulphur dioxide (SO_2), soot particles and particulate matter (PM). The CO_2 emissions are the consequence of fossil fuel burning, whereas the SO_2 emissions of kerosene combustion and soot the result of incomplete fuel combustion from aromatic and naphthalene.

As explained in Chapter 1, the Intergovernmental Panel on Climate Change (IPCC) is the international body responsible for assessing climate change and supporting the Paris Agreement goal to stabilise warming below 2ºC, preferable 1.5ºC above pre-industrial levels. The IPCC considers carbon dioxide as the primary greenhouse gas. Usually, to measure the climate effects of greenhouse gases it is used a matric called

"Radiative Forcing" (RF), expressed in watts per square metre (W/m²). It represents the balance between the energy received by the Earth from the sun and the energy that Earth radiates back into space, taken as base pre-industrialization. To understand, the overall global warming of 0.78ºC of the last century results from an increase in RF of 2.29 W/m². The literature suggests that the Effective Radiative Forcing (ERF) outcomes from the sum of non- CO_2 emissions have a positive or warming effect that accounts for more than half of the net forcing.

Figure 20 represents how the different types of aviation emissions contribute positively (warming) or negatively (cooling) to climate change. Nevertheless, there are still many uncertainties about the impacts of non- CO_2 emissions on climate change. One of the principal difficulties for measuring the impacts of aviation emissions is that they are conditioned not only to the aircraft type, fuel burn or hours of flight but also by the altitude, location and chemical interactions with the background atmosphere.

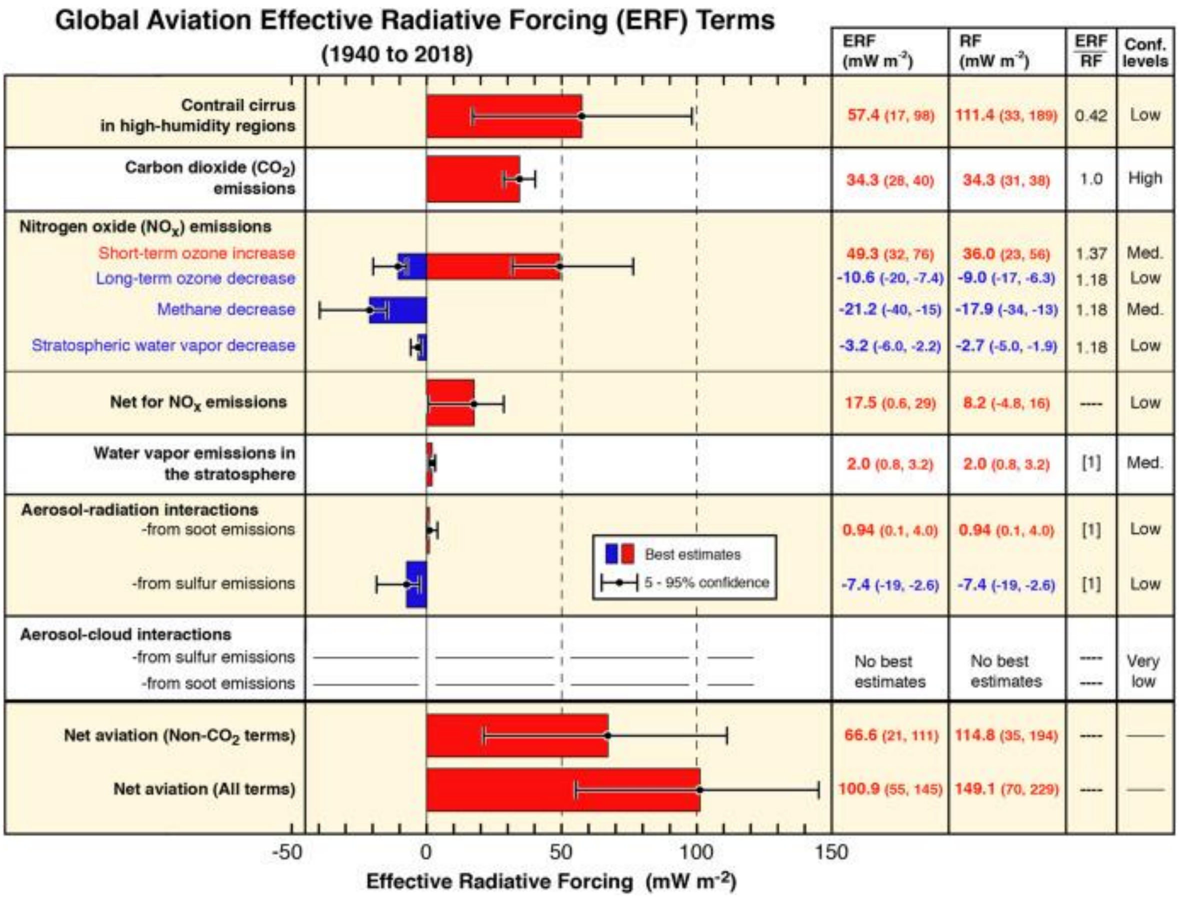


Figure 20. *An overview of aviation's climate impact from global aviation from 1940 to 2018. The bars and whiskers show the best estimates and the 5–95% confidence intervals. Red bars indicate warming terms and blue bars indicate cooling terms.Lee, D.S.; Fahey, D.W.; Skowron, A.; Allen, M.R.; Burkhardt, U.; Chen, Q.; Doherty, S.J.; Freeman, S.; Forster, P.M.; Fuglestvedt, J.; et al. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmos. Environ. 2020, 244, 11783* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7468346/

Understanding the different types of emissions, how they impact climate change and the number of uncertainties in the procedures to measure those impacts is the first aim of Search A. Then, to recognize the magnitude of the impacts of aviation emissions, one of the articles "Simulation and evaluation of sustainable climate trajectories for aviation" contributes to putting those numbers in perspective with the Paris Agreement objectives.

As mentioned before, in the year 2019, the entire life cycle of the aviation industry is responsible for 1134 Mt, or 2,6% of the world CO_2 emissions. By adding the non- CO_2 effects estimated in 2011, it is possible to reach 3.5% of world radiative forcing. If we want to maintain and steady warming above 1.5ºC or 2ºC until 2050, the carbon budget available would be 378Gt and 865Gt, respectively.

Figure 21 is a work of The Air Transports Action Group (ATAG) that has modelled some scenarios with the trajectory of global CO_2 emissions for aviation projection by 2050. The article has quantified that under this scenario analysis, the expected cumulative global emissions for aviation until 2050 are equal to 30.5Gt. This indicates that aviation will consume 8.1% of the world carbon budget for 1.5ºC and 3.5% for the 2ºC.

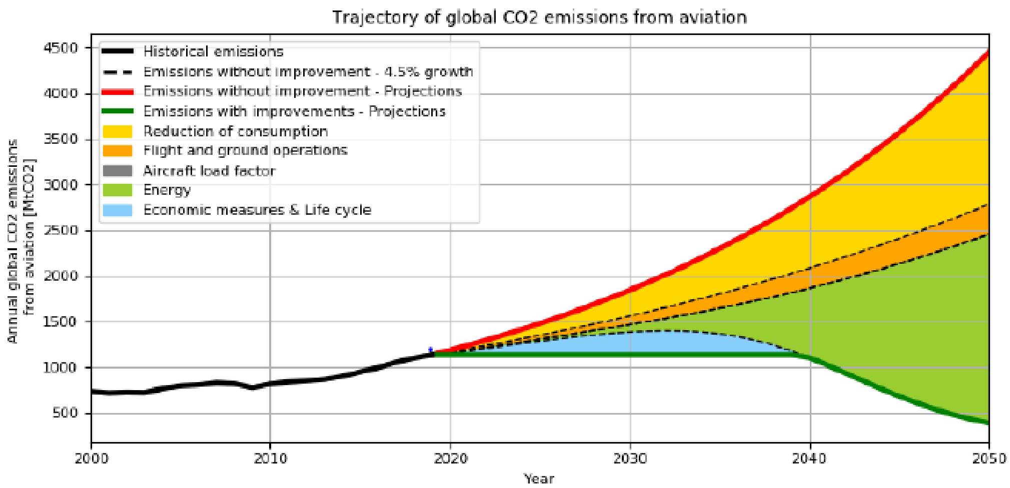


Figure 21. *Modelling of ATAG commitments.Air Transport Action Group - ATAG. Waypoint 2050 Report: Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency. 2020* https://aviationbenefits.org/media/167187/w2050_full.pdf

Due to the pandemic situation, the aviation sector has been severed impacted, and ATAC has updated the scenario model. In Figure 22, it is possible to appreciate the new global emissions trajectories.

Under this new scenario, the cumulative global CO_2 emissions are around 24.7 Gt by 2050, representing 6.5% of the world carbon budget for 1.5ºC or 2.9% for 2ºC. Furthermore, the total ERF aviation would consume 51.6% of the world ERF budget in 2050 for 1.5ºC and 18.9% of the ERF budget for 2ºC. These results show how significant is the climate impacts of aviation activity and the necessity to take actions to achieve the Paris Agreement aim and ensure a sustainable future.

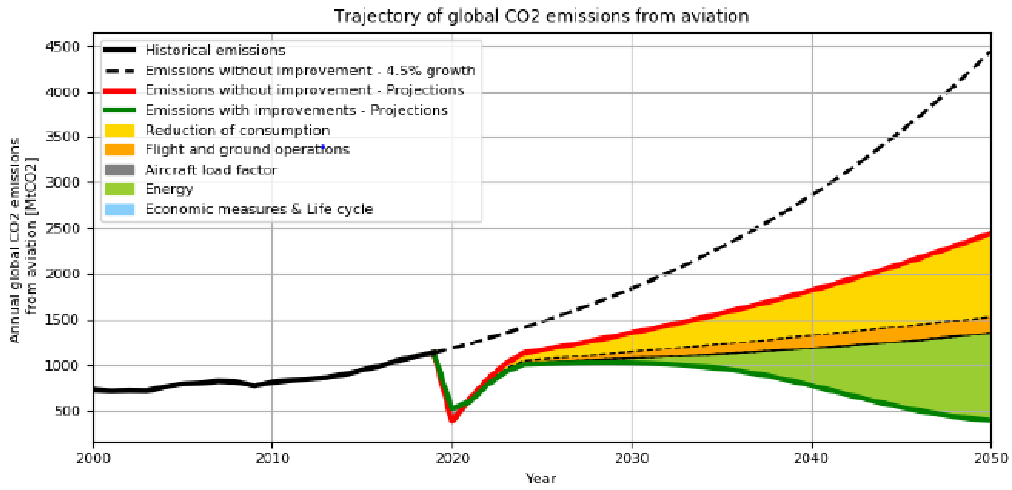


Figure 22. *Modelling of 2020 ATAG commitments including Covid-19.Air Transport Action Group - ATAG. Waypoint 2050 Report: Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency. 2020* https://aviationbenefits.org/media/167187/w2050_full.pdf

- **Air quality and noise impact**

Aviation emissions have a powerful impact on climate change, and also they are dangerous for health. The most dangerous pollutants for humans are nitrogen oxides (NOx), associated with lung inflammation. Then, particulate matter (PM), which are very small solid and particles that can deposit in the human lung, trigger inflammation reaction and introduce a toxic substance to the human body. Finally, ground-level ozone has the potential to produce several respiratory problems. The "Marginal climate and air quality costs of aviation emissions" article estimates around 16000 annual premature deaths linked to a high concentration of air pollutants.

Furthermore, we need to consider the increased levels of noise above the threshold decibel levels in the areas around the airport. The literature identified some of the health effects of aviation noise. They are sleep disturbance, annoyance, ischaemic heart disease, and cognitive impairment in children. According to the latest World Health Organization Europe guidance, in 2017 around 3.2 million people were affected by aircraft noise around 47 major airports in Europe.

- **Mitigation opportunities**

The literature selected also proposed some possible solutions to reduce emission and mitigate the impacts of aviation on climate change and human health. Among the most frequent solutions mentioned are technologies and designs development, sustainable aviation fuels, efficient air traffic management and operation, policy actions to reduce non- CO_2 climate impacts and market-based measures.

Innovative ideas and new technologies are essential to achieve a sustainable future. The Clean Sky initiative was undertaken by the European Commission and the European aeronautic industry to develop more efficient and sustainable engines in the aviation sector. Moreover, from the European Aviation Environmental Report 2019, it is possible to identify an excess of CO_2 emissions of around 5.8% due to network flight inefficiencies. For that reason improve efficiency in air traffic management and operations is also an opportunity to mitigate emissions. Lastly, it seems that new policies with possible charges and regulation on emissions could be applied in the following years. Emissions charges could be a good incentive but, at the same time, could signify a risk for those airlines that fail in the process.

3.3.2 Digital reality technologies in Aviation

As the same of other digital technologies, augmented reality and virtual reality are evolving fast. AR and VR technologies are associated with the real world and virtual environments. The difference is that VR lets complete immersion in the virtual environment allowing experiment, test and assess a product in full context at a low price. Instead, AR does not suppress the perception of the real world; it adds to the users world perception some virtual content to support them in accomplishing a task.

This section analyses different applications of those technologies in the aviation sector to understand their benefits and possible direct or indirect connection to environmental impacts.

- **Maintenance, Repair and Overhaul (MRO)**

The aviation system is comprised of four key elements known as hardware (buildings, aircraft, material structures), software (organization, regulations, information, etc.), environment (weather, physical and social policies, etc.) and liveware (human resources: maintenance operators, ground crew, pilots, among others). Usually, accidents appear due to a poor link between some of those elements. Regular maintenance is required to avoid accidents, ensuring the correct working of aircraft. The impacts of VR and AR technologies for maintenance operations could significantly impact efficiency, saving time, reducing costs and incrementing safety.

Firstly, the literature highly that AR could be a valuable tool to replace traditional paper manuals that cannot clearly explain complex operations with AR-based manuals and illustrated catalogues of the different parts and procedures to maintain. Many difficulties can appear due to faulty installation components, electrical wiring discrepancies, inadequate lubrication, and wrong fitting parts. In those cases, AR can help to reduce workload time in complex tasks and errors.

Another of the AR benefits for maintenance is the staff's opportunity to receive 24 hours advice and instructions through real-time video, images and audio information from colleagues off-site. Additionally, these technologies are being used to train technicians to inspect different aircraft parts without leaving their desks.

- **Training and Simulations**

AR and VR are valuable tools not only to train engineers and technicians but also to instruct the crew staff responsible for ensuring passengers' safety. Boing predicts that these interactive technologies could reduce the overall training time by approximately 75% compared to traditional classrooms and teaching applications.

However, the most relevant impact of those technologies comes from the pilots training. Compared with airborne training, flight simulation is more secure, markedly cheaper, significantly less environmental impacting and highly efficient. In addition, it gives the possibility of pilots to train more hours and experiment with a variety of scenarios and situations.

The main advantage of a flight simulator is the opportunity to have safety training where pilots can make mistakes and errors, learn from them, and obtain clear feedback to improve their performance. Nevertheless, it is essential to consider the negative effect of a false sense of safety or competence. This could yield deviations from reality and increase the exposure of accidents during actual flights.

Modern simulators can replicate aircraft characteristics with high fidelity. Even for some pilots, the flight-crew training can be conducted entirely in the simulator, this is known as zero flight-time training, and it is commonly applied for the civil sector. Moreover, flight simulators permit training pilots for emergencies, such as complicated weather conditions or engineer system failures, that would be impossible or too risky for practice in a real aircraft.

- **Aircraft designs and development**

Simulation is also a valuable tool to reduce development cost. VR and AR technologies let manufacturers design, modify, and test an aircraft in different situations before building it. Hence, it enables designers to rearrange, modify, improve their models, avoid costly design error, and save valuable resources.

- **Aircraft Towing**

Between 2014 to 2019, 35 mishaps and 24 hazards incidents were experimented with by the United State Navy. These incidents had a direct cost of 14.4 million dollars. The literature affirms that those accidents were caused by inexperience and lack of supervision, and therefore wholly avoidable. The studied application of AR technologies in those cases could provide additional information and increase awareness in the tow crew, consequently dropping the number of aircraft collisions during this operation, reducing costs, time and the number of people required for this operation.

- **Aero Glass, entertainment, and others**

AR also can be implemented to bring control information to the pilots during flights. Aero Glass help pilots to increase situational awareness and improve their performance during flights. Furthermore, some airlines are using virtual reality to provide passengers with immersive entertainment systems to enjoy films, television series, matches or relaxing landscapes during their flights. Finally, AR technologies are also being tested for improving cabin crew services. In these cases, the HoloLens headset could inform the crew about the passenger flight details, time since previous served and even emotional state.

3.3.3 Environmental benefits of AR and VR solutions for Aviation

Climate change is a relevant risk for the aviation industry that will grow in the following years. Hence stakeholder need to contemplate them on their planning process, risk assessment evaluations and future investments. The impact of climate change will be variable depending on the geographic locations and particular circumstances. Some of the increasing physical risk highlights in the literature are:

- Heat damages in infrastructure,
- More uncertainty in climate modelling will increase delays, re-routings and consequently, there will be an increment of fuel burn.
- Climate change will also rise clear air turbulence in frequency and strength.
- Higher and extreme temperatures limit the departures for colder times of the day, changing schedules and reducing payloads.
- The rise of sea level and natural disaster will create a permanent or temporary loss of airport capacity and network disruptions in the long time.

Similarly, policy and legal risk have also need to take into consideration. The literature study showed the possibility to apply in the following years a charge on the total NOx emissions and also the possibility to include them in the EU Emissions Trade System (ETS). The vital need to reduce carbon emissions has prompted a Carbon Offsetting and Reduction Scheme for the aviation industry (CORSIA). CORSIA is an offsetting scheme that allows compensating the emissions reductions that cannot be achieved in the aviation sector, with cuts in other sectors where the potential for faster reductions is larger, and the linked costs are lower.

Finally, it is essential to consider the reputational risks, taking into account that the current projection reveals that if the sector does not apply any changes, the total Effective Radiative Forcing consume by the aviation sector will be 51.6% of the world ERF budget in 2050 for 1.5ºC. Those numbers could have a negatively impacts on customers and organizations perception of this sector.

In Figure 23, it has been identified some of the SDGs more affected by aviation emission. Therefore, the environmental risks and the significant contribution of greenhouse gases emissions of aircraft have encouraged stakeholders to search for innovative solutions that could help in the reduction of impacts. As a result, different application of AR and VR technologies in aviation have been studied to identify how they could contribute to the fight against climate change.

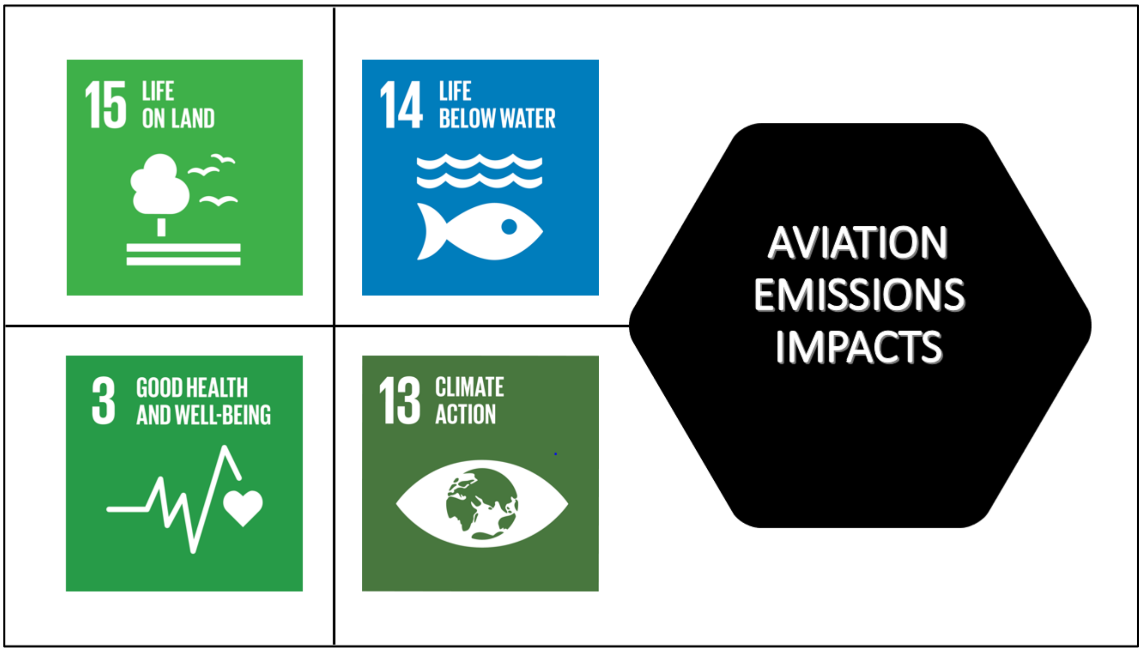


Figure 23. *Sustainable Development Goals affected by aviation emissions*

This systematic review has identified some of the main opportunities that digital reality technologies present to help the aviation industry to become a more sustainable sector. Those are:

- **Cutting flight hours**

The report "CAE 2020 Airline and Business Jet Pilot outlook update" published by the company CAE estimates that the civil aviation market will require between 2020 to 2029 around 264000 new pilots for airline flights and business jet flights. Moreover, the average emission of CO_2 that we can find on the internet by an hour of flight is approximately 3.08 tonnes. Depending on the type of license, the pilots will need around 40 hours of flight for a Private Pilot License, 250 hours for a Commercial Pilot Certificate and 1500 hours Airline Pilot Transport License. If we decide to simplify 250 hours of training by pilot, it is possible to calculate around 203 Mt of CO_2 avoided by flight simulators, which represents around 22% of the aviation CO_2 emissions in 2019.

This quick estimation has been done only to illustrate the capacity of emission reduction using flight simulators. Further research will need to be done to estimate accurately avoided emissions numbers, considering civil aviation and military flights, CO_2 and non- CO_2 emission by aircraft models, and pilots' percentage worldwide training hours. Therefore, the possibilities of reduction of emission by use of flight simulators should be much higher.

- **Reducing flight and operation inefficiencies**

The literature shows that in 2017 the gate-to-gate actual trajectories of all the European flights compared with their unimpeded trajectories produce an extra of 5.8% gate-to-gate CO_2 emissions at the European level. Also, there are airport inefficiencies where a significant variation of the average additional Arrival Sequencing and Metering Area (ASMA) time can be appreciated. In 2017, inefficiencies in the arrival flow at the top 30 airports in Europe caused 8.33 million minutes of additional ASMA time.

These inefficiencies result from multiple factors such as adverse weather, avoiding dangerous areas, need to maintain minimum separation, pilot's ability, management and coordination issues, among others. VR simulations could help optimize flight routes, and AR is a significant support to improve pilots' awareness and performance during flights. In the literature selected, there is a comparison between the times needed in a Landing and Take-off test (that involves each phase of flight: taxi, approach, take-off, and climb) in an actual airport and a flight simulator. The results of those experiments indicate that CO, NOx, HC and PM emissions were lower through flight simulation in ranges between 14% to 54%. This study showed that flight simulation could affect positively pilot efficiency and consequently reduce emissions.

- **Improving environmental awareness**

AR and VR technologies have shown to be powerful tools to provide information, creating awareness, helping users improve their performance in an efficient and didactic way. Although if the literature does not mention this specific application, we find that it could be helpful to add the number of emissions inside the AR data transmit to pilots during flights, to improve the emissions flight performance.

Another suggestion from this research has been inspired by airlines' experimental use of VR as an entertainment tool. It could be helpful to take advantage of the educational benefits of those technologies, allowing passengers to experiment and appreciate the amount of air pollutants on the atmosphere during their flights and the effects of those greenhouse gases in climate change and earth life. Similar tests have been carried out using simulators to create ecological awareness in other sectors such as ocean life or the Amazon forest. As a result, they have a positive effect on changing environmentally negative behaviours and increasing economic cooperation for combating those effects.

- **Social and economic benefits**

Apart from the above-mentioned environmental benefits, digital technologies have a powerful impact on other Sustainable Development Goals such as Quality Education (SDG #4), Good Health and Well-Being (SDG #3), and Decent Work and Economic Growth (SDG #8). Considering the literature informs of approximately 907 deaths during the period between 2017 to 2019 due to airline crashes and failures, the safety benefits of AR and VR technologies identified in Figure 19 could be essential to ensure workplace security and decrease considerable cost from those accidents. In addition, digital reality technologies seem to be powerful educational tools that could be applied to train employees in various activities efficiently. Together with the informational support that those technologies provide during the development, assessment, and maintenance of aircraft, this training could be a powerful tool to increase process efficiency and accuracy, reducing significant waste, times, and cost.

3.4 Case study: Digital reality solutions for the military aviation sector – Leonardo S.p.A

The literature market analysis represented in Figure 18 shows that the frequency of the military application of digital reality technologies represents 76% compared to civil applications. Nevertheless, even if most of the articles mentioned using those technologies by the military sector, there is not much detailed information about their environmental impacts and specific applications. To cover those gaps from the systematic review was decided to conduct further research, interviews and analysis of a specific case of the worlds' major players in the Aerospace, Defence and Security (A D& S) business sector, Leonardo S.p. A company.

3.4.1 Military aviation and climate change

Civil and military markets are different markets with different dynamics. While the civil aviation segment has been negatively affected by the pandemic, the military aviation segment has experimented an increase in aircraft demand due to international tensions and technological evolutions.

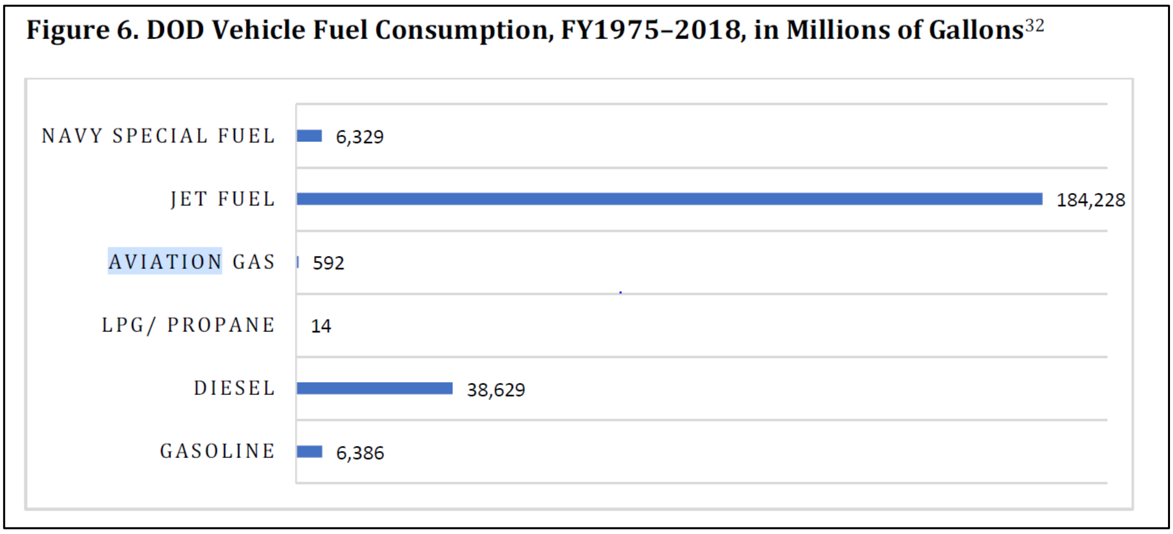


***Figure 24**. Mix of fossil fuels by type from 1975 to 2018. Crawford Neta C. (2019). "Pentagon Fuel Use, Climate Change, and the Costs of War." Brown University and Boston University. https://watson.brown.edu/costsofwar/papers*

For a long time, the military sector has been excepted from reporting its GHG emissions. However, due to their significant consumption of fossil fuel in October 2020, a comprehensive analysis of the carbon footprint of the EU military sector was commissioned to the Conflict and Environment Observatory (CEOBS) and Scientists for Global Responsibility (SGR). Those studies have estimated that the CO_2 emissions by the EU military sector in 2019 were around 24.83 million tonnes. This number is similar to the annual emissions of 14 million cars.

Furthermore, in the “Pentagon Fuel Use, Climate Change and the Cost of War” published by Brown University, it is done an approximation of 56 million metric tonnes of CO_2 equivalent emitted by the USA Department of Defence in 2018. This number is higher than the total emissions of most countries in the world.

Figure 24 permits the appreciation that jet fuel is the major source of vehicle military greenhouse emissions for the USA Department of Defence. To sum up, this means that the greenhouses emissions due to the military aviation sector significantly impact climate change, which will need to be carefully studied by further research.

3.4.2 Company overview

Leonardo S.p. A served military and civil requirements. They create innovative solutions to strengthen global security and protect people, territories, infrastructure, and cyber networks. The headquarter of the company is in Rome. However, they have a presence in four domestic countries: Italy, United Kingdom, United States, and Poland. They operate with an international network delivering products and services to over 150 countries worldwide. The principal business sectors covered by the company are Helicopters, Defence, Electronics & Security, Aeronautics and Space. According to their Integrated Annual Report 2020, 73% of their sales belong to the military sector.

Emissions				GRI 305-1/2/3/4/7
CO_2e emissions (GRI305-1/2/3)	**Unit**	**2018**	**2019**	**2020**
Direct emissions (Scope I)	t CO_{2e}	286,643	332,780	359,711
Indirect emissions (Scope II market-based)	t CO_{2e}	65,110	70,856	63,003
Indirect emissions (Scope II location-based)	t CO_{2e}	262,331	267,468	248,958
Other indirect emissions (Scope III)	t CO_{2e}	311,078	281,701	207,425
Total Scopes I, II market-based, III	**t CO_{2e}**	**662,832**	**685,337**	**630,139**
Total Scopes I, II location based, III	**t CO_{2e}**	**860,053**	**881,949**	**816,094**
CO_2e emission intensity (GRI 305-4)	**Unit**	**2018**	**2019**	**2020**
Total emissions (Scope I + Scope II market-based)/Revenues	g/ €	28.74	29.28	31.52
Total emissions (Scope I + Scope II location-based)/Revenues	g/€	44.85	43.55	45.39
Other emissions (GRI 305-7)	**Unit**	**2018**	**2019**	**2020**
NOx	t	162	193	178
SO_2	t	3	3	1
VOC	t	109	127	109
VIC	t	1	2	2
Heavy metal	t	0.2	0.1	0.6
Particulate	t	20	22	17

Figure 25. *Leonardo's emissions from 2018 to 2020. Leonardo Company (2021). “Integrated Annual Report 2020”* https://www.leonardocompany.com/it/about-us/sustainability/approach-and-reporting/reporting

As an innovative company with unique customers, such as governments and international institutions, Leonardo works with a long-term perspective and needs to anticipate future needs. Consequently, a sustainability plan is part of the value chain and the strategy of the company. The company has sustainability targets links to four pillars: governance, people, planet and prosperity.

Despite the increase of CO_2 emissions since 2018, the Sustainability Report shows a clear commitment to reducing 4% of their location-based emissions by 2025 and 40% of their CO_2 market-based emissions by 2030. Moreover, the leading international trends to a digital and environmental transition to achieve the European Union`s climate neutrality by 2050, have strengthened their focus on innovation and digital transformation to achieve the desired change.

3.4.3 International Flight Training School (IFTS)

During an interview with Leonardo's current Head of Simulation & Training, it was possible to obtain a description and comparison between the simulation technology applied in the military and civil sector. While in civil aviation, the pilots have to repeat a limited number of manoeuvres, in the military sector, pilots learn how to fly during different missions, which entails different manoeuvres, higher speed, higher risks, and a continuous training process to improve their skills and preparation from different missions. Those difference made currently impossible for the military aviation to achieve a 100% fidelity or Zero Flight Time as in civil aviation segment.

Despite the difficulties, Leonardo has developed an innovative training system that allows the substitution of around 50% to 60% of the military pilot flight training hours. In the following years, it expects to accomplish 70% of fidelity. The technology behind those simulators included a Live, Virtual and Constructive Simulation (LVC). Those technologies permit that simulators in the ground interact with the pilots in the air, during the same training missions, through augmented reality applications. Therefore, this complex technology creates a safety scenario avoiding accidents by aircraft's collisions. Also, improve the efficiency of the training, giving pilots the possibility to simulate situations that would be too costly or risky to simulate in reality.

The International Flight Training school is a collaboration between Leonardo and the Italian Air force that has reduced actual flight hours through full mission simulators, providing 26000 hours of virtual training and avoiding around 116,000 tonnes of CO_2 emissions since 2018. Those emissions are equivalent to the carbon sequestered by 142,121 acres of US forest in one year.

The potential environmental emissions saved by digital reality technologies in the military sector could be significant if it is taken into consideration the continuous pilots training requirements and a large amount of GHG emissions coming from this sector. In the meantime, further research of the amount of CO_2 non-CO_2 emissions provides by those sectors and their respected climate effects is needed; those data could be crucial to understand and expand the digital reality applications for the fight against climate change.

3.5 Research outcomes and Future Research Directions

The handled literature analysis has confirmed that some environmental benefits of digital reality application of the aviation sector are already well identified in the scientific literature and by the business organization related to the sector. Nevertheless, further research needs are also identified. This section will discuss the main findings of this research to answer the research questions and give some recommendations about research gaps and further research directions.

- **Which are the environmental impacts of the aviation sector?**

From the literature, the use of kerosene and other petroleum-based fuels are the principal source of various greenhouse emissions that affect climate, air quality, and consequently different forms of life on the planet, including human beings. In addition, higher levels of noise produced by aircraft harm human well-being.

It already exists a variety of data about the amount and types of gases emitted by civil aircraft. However, so far, it has not been provided with a profound analysis of the military aviation environmental impacts worldwide because some GHG are not actually communicated or reported. In addition, the difficulties of the chemical altitudes, where the gases emissions interact, present difficulties to understand the concrete effects of most of those emissions concerning climate change. Significant studies would be required to develop and implement data monitoring systems to analyse and measure the specific climate effect of those gases.

- **What is the utility of digital reality technologies in aviation?**

The scientific literature and aviation journals show how Virtual Reality and Augmented Reality applications are significantly growing in the aviation sector, from design, manufacturing, and modification until maintenance, training, or even entertainment tools for passengers. The main focus of the literature lies on their advantage in improving safety and efficiency, reducing costs, and creating added value for customers by delivering a unique experience. However, further experimentation of the application of those technologies needs to be done to assess their convenience.

- **Are virtual reality technologies good to reduce the environmental impacts on the aviation sector?**

Concerning digital reality technologies in aviation with positive environmental impacts, some authors present experimental studies of applying those technologies for improving times and reducing accidents, adding some comments on the environmentally friendly qualities of those technologies. However, only one of the selected article measures some of the potential environmental impacts of those technologies. Further research of environmental impacts could help to the investment and development of those technologies. Specifically, flight simulators seem to have the potential power for reducing approximately 90% of the flight training hour emissions.

Finally, besides quantifying the potential reduction of CO_2 emissions from the adoption and development of those new technologies, further investigations on the impact of non-CO_2 emissions, principally NOx and contrails, on the different altitudes of flight is needed. On this basis, it would be possible to create a framework for the environmentally and sustainability assessment of the emerging digital aircraft technologies. Moreover, considering that the variability of future digital reality technologies and their complexity will increase, the analysis of their environmental impacts will become much more complicated. Therefore, it would be essential to develop models and tools that allow to better understand the sustainability impact of those technologies, supporting green investments decisions in the future of aviation.

CONCLUSIONS

The transition towards a greener economy is strongly related to a change in society and organisational behaviour toward sustainability and digital solutions. There exists a strong belief that digitalisation could be a key ally for economic and sustainable recovery. Although some studies report that digital solutions could decrease an average between 15% to 20% of the global CO_2 emissions, there needs to be further study into the particular environmental benefits and challenges that they represent for each industry.

In this work, a general framework of the overall sustainability challenges and digitalisation evolution has been presented. Then, it was decided to analyse the environmental impacts and opportunities of digital reality technologies on the aviation sector. Consequently, due to the topic's novelty, a systematic review of the scientific literature, organisational reports, and company experiences was conducted. By compiling the evidence available by a methodical process, it was possible to identify the potential benefits of Virtual and Augmented reality technologies to reduce aviation environmental impacts.

Through a scientific literature review, this survey has found that aviation contributes to around 2.6% of the worldwide CO_2 emissions. This number could be considered slow, but pondering that aviation is also responsible for other greenhouse gas emissions whose warming effects seem to be higher to those from CO_2 emissions, it is not the best parameter to measure aviation impacts on climate change. A better parameter to determine the greenhouse effect of aviation could be Effective Radiative Forcing, which is the difference between solar irradiance absorbed by the Earth and energy radiated back to space. According to ATAG estimations, aviation could consume 51.6% of the world ERF budget in 2050 for 1.5ºC. However, even if it could be a better indicator, there are still many doubts about the actual impacts of those gases because, depending on the altitude and the chemical background, their warming or cooling effects change considerably.

So, the aviation sector is conscious of those numbers and principally of the risks and costs that climate change signified for the industry. Infrastructure damages, an increase of accidents and schedule changes and delays are only some examples of the physical environmental risks with which aviation stakeholders need to deal with. For that reason, they are invested in disruptive solutions. The EU has invested approximately €5 billion over the last decade to support various programmes and measures, such as Clean Sky, SESAR, CORSIA, to transform the aeronautics industry to become more environmentally-friendly.

At the beginning of this research, the objective was to identify the opportunities of VR and AR technologies in the aviation fight against climate change and measure those impacts through some common indicators. However, difficulties finding existing and comparable articles to approach this issue has led to division of the systematic review into two parts. The first one, a search to understand the environmental aviation challenges and, the second one, to find the VR and AR applications in the aviation sector. This methodological path to approach the topic leads us to understand that one of the main problems of the aviation sector is the lack of a clear understanding of the climate impacts of their emissions. Therefore, it would be more challenging to understand the possible solutions if one cannot understand the problem. Nevertheless, this leads to the first conclusions: the necessity to establish a KPI for the aviation sector that serves as a parameter to understand and compare the environmental benefits of different technological solutions. The standardisation of comparable indicators is essential to facilitate green investment decisions.

Secondly, the systematic review concluded that the main environmental benefits of VR and AR technologies in aviation are indirect effects linked to their educational advantages. Consequently, those technologies have allowed flight simulators with Zero Flight Times, which means no more emissions due to civil pilot training. Due to the complexity of the military sector, the flight simulators combined virtual and augmented reality technologies allowing a reduction of around 50% to 60% of the actual flight training hours. Moreover, those technologies help to improve the efficiency of the whole aviation system operations. Considering the studies that show around 6% of the aviation emissions are linked to systems inefficiencies, the support of those technologies could be significant. Finally, we also believe that their immersive characteristics could be helpful to develop educational programmes during the flight that allowed to increase climate awareness and support green initiatives.

Apart from the described research outcome, the results of this work show that even if there is a lot of information available about different sustainable and innovative initiatives, there is a limited amount of scientific evidence and literature available assessing the environmental impacts of those technologies. Further research about aviation emissions effects will be needed to measure and report the ecological benefits and challenges of digital solutions in the aviation sector. In retrospect, the primary purpose of this work has been to explore the digital reality environmental benefits and opportunities that are not often considered, searching to increase awareness in the aviation stakeholders and scientific community, and create a direct reference of the existing works for the future.

REFERENCES

- Arbilly M., Laland Kevin N. (2017). "The magnitude of innovation and its evolution in social animals." The Royal Society Publishing. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5310607/

- Arvidsson, Niklas and Mannervik, Ulf. (2009). "The Innovation Platform. Enabling Balance Between Growth and Renewal."https://www.vinnova.se/contentassets/410f5157e1804911985a36092a1c30ca/vr-09-25.pdf

- Baecker O., Finger K., and Mesic Elvedin. "Digital Reality explained... in under 100 words." Deloitte https://www2.deloitte.com/ch/en/pages/innovation/articles/digital-reality-explained.html

- Balcerzak T., and Kostur K. (2018). "Flight Simulation in Civil Aviation: Advantages and Disadvantages." Revista europea de derecho de la cadémicos maritime y cadémicos, Servicios cadémicos Intercontinentales SL, issue 35. https://ideas.repec.org/a/erv/rednma/y2018i3515.html

- Bell J., Hammersley Z. (2021). "Green shoots – Sustainability developments in the aviation sector". Watson Farley & Williams. https://www.wfw.com/articles/green-shoots-sustainability-developments-in-the-aviation-sector/

- Bogucka Hanna. (2020)." Green Communication and Computing for 2030." https://www.rimedolabs.com/blog/ green-communication-and-computing-for-2030/

- Buis Alan. (2019). "Selected Findings of the IPCC Special Report on Global Warning." Second Part of: *A Degree of Concern: Why Global Temperatures Matter*. NASA's Global Climate Change Website. https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

- Ceruti A., Marzocca P., Liverani A., and Bil C. (2019). "Maintenance in aeronautics in an Industry 4.0 context: The role of Augmented Reality and Additive Manufacturing." Journal of Computational Design and Engineering. https://www.researchgate.net/publication/330853244_Maintenance_in_Aeronautics_in_an_Industry_40_Context_The_Role_of_Augmented_Reality_and_Additive_Manufacturing

- Crawford Neta C. (2019). "Pentagon Fuel Use, Climate Change, and the Costs of War." Brown University and Boston University. https://watson.brown.edu/costsofwar/papers

- Dorleon G., and Gervais S. (2017). "Industry 4.0 – What we need to know." International Francophone Institute for Computer Science.

- EASA, EEA, EUROCONTROL. (2019). "European Aviation Environmental Report 2019." https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf

- EIT Climate-KIC. (2020). "The European Union has the tools to boost a sustainable recovery from the COVID-19 pandemic, say TEG experts." https://www.climate-kic.org/news/eu-has-tools-to-boost-sustainable-recovery-from-covid-19-says-teg/

- EPRS – European Parliamentary Research Service. (2015). "Industry 4.0 – Digitalization for productivity and growth." https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf

- European Commission. (2019). "A European Green Deal – Striving to be the first climate-neutral continent." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

- European Commission. (2020). "Sustainable finance: TEG final report on the EU Taxonomy." https://knowledge4policy.ec.europa.eu/publication/sustainable-finance-teg-final-report-eu-taxonomy_en

- Fetterolf, Colton S. (2020). "Using Augmented Reality to Enhance Situational Awareness for Aircraft Towing." Calhoun: the NPS Institutional Archive Dspace Repository/Thesis https://calhoun.nps.edu/handle/10945/65517

- Forti V., Baldé Cornelis P., Kuehr R., and Bel G. (2020). "The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential." https://www.itu.int/en/ITU-D/Environment/Documents/Toolbox/GEM_2020_def.pdf

- Galant M., Nowak M., Kardach M., Maciejewska M., and Legowik A. (2019). "Using the simulation technique to improve efficiency in general aviation." AIP Conference Proceedings 2078, 020097. https://aip.scitation.org/doi/abs/10.1063/1.5092100

- Grobler Carla. (2019). "Marginal climate and air quality costs of aviation emissions". Environmental Research Letters , Volume 14, Number 11. https://iopscience.iop.org/article/10.1088/1748-9326/ab4942/pdf

- I – SCOOP. (2020). "Digitization, Digitalization and digital transformation: the differences. " https://www.i-scoop.eu/digital-transformation/digitization-digitalization-digital-transformation-disruption/

- iED Team. (2019). "The 4 Industrial Revolutions." Institute of Entrepreneurship Development. https://ied.eu/project-updates/the-4-industrial-revolutions/

- Izzo Maria F., Ciaburri M., and Tiscini R. (2020) "The Challenge of Sustainable Development Goal." https://www.mdpi.com/2071-1050/12/8/3494/pdf

- Kiron D. and Uhruh G. (2018). "Corporate 'Purpose' Is No Substitute for Good Governance." https://sloanreview.mit.edu/article/corporate-purpose-is-no-substitute-for-good-governance/

- LaBerge L., O'Toole C., Schneider J., and Smaje K. (2020). "How COVID – 19 has pushed companies over the technology tipping point – and transformed business forever. "McKinsey & Company. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever#

- Lee David. (2020). "Updated analysis of the non CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30 (4)." EASA European Union Aviation Safety Agency – Manchester Metropolitan University's Research Repository.

https://www.easa.europa.eu/sites/default/files/dfu/201119_report_com_ep_council_updated_analysis_non_co2_climate_impacts_aviation.pdf

- Leonardo Company. (2021). “Integrated Annual Report 2020” https://www.leonardocompany.com/it/about-us/sustainability/approach-and-reporting/reporting

- Markets and Markets. (2019). “Augmented and Virtual Reality (AR VR) Market in Aviation by Technology (AR, VR), Function (Training, Operations), Component (Hardware, Software), Application (On-Board, Off-Board), Product, Vertical, and Region – Global Forecast to 2025.” https://www.researchandmarkets.com/categories/virtual-augmented-reality

- Mureșan S., Tang P. (2019). “Legislative Train Schedule – European Green Deal Investment Plan (Sustainable Europe Investment Plan).” European Parliament. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-european-green-deal-investment-plan

- Parkinson S., Cottrell L. (2021). “Under the Radar – The Carbon Footprint of Europe’s Military Sectors.” SGR and CEOBS. https://ceobs.org/wp-content/uploads/2021/02/Under-the-radar_the-carbon-footprint-of-the-EUs-military-sectors.pdf

- Pinner Dickon. (2020). “The challenge of climate change.” McKinsey & Company. https://www.mckinsey.com/business-functions/sustainability/our-insights/the-challenge-of-climate-change.

- Planes T., Delbecq S., Pommier-Budinger V., and Benard E. (2021). “Simulation and evaluation of sustainable climate trajectories for aviation.” ISAE – SUPAERO Université de Toulouse. https://arxiv.org/pdf/2102.01574.pdf

- Pwc. (2019). “Seeing is believing – How virtual reality and augmented reality are transforming business and the economy.” https://www.pwc.com/gx/en/technology/publications/assets/how-virtual-reality-and-augmented-reality.pdf

- Reader Simon M., Morand-Ferron J., and Flynn E. (2016). “Animal and human innovation: novel problems and novel solutions.” In *Philosophical transactions of the Royal Society B.* Vol. 371, issue 1960. The Royal Society Publishing. https://royalsocietypublishing.org/doi/10.1098/rstb.2015.0182#d3e1444.

- Sachs J., Schmidt-Traub G., Kroll C., Lafortune G., Fuller G., Woelm F. (2020). “The Sustainable Development Goals and COVID-19. Sustainable Development Report 2020.” Cambridge University Press.https://s3.amazonaws.com/sustainabledevelopment.report/2020/2020_sustainable_development_report.pdf

- Schilling Melissa. (2012). “Strategic Management of Technological Innovation.” Fourth Edition. McGraw – Hill Education.

- Sharma Devender. (2017). “Virtual Aircraft Environment to Evaluate Modification Proposal.” Asian Journal For Convergence In Technology. https://asianssr.org/index.php/ajct/article/view/645

- Stinson S. (2009). “Ecological diversity and modern human adaptations.” In *Human resources and their development*. Vol. 2. EOLSS. https://www.eolss.net/sample-chapters/C11/E1-10-03-02.pdf

- TCFD – Task Force on Climate-related Financial Disclosures. (2017). "Recommendations of the Task Force on Climate-related Financial Disclosures – Final Report." https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf

- Tecknotrove Systems (2021). "Virtual Reality and Augmented Reality Solutions for the Aviation Industry." Aviation Pros. https ://www.aviationpros.com/gse/gsetechnology/blog/21219689/tecknotrove-systems-virtual-reality-and-augmented-reality-solutions-for-the-aviation-industry

- Theis T., Tomkin J. (2015). "Sustainability: A Comprehensive Foundation." OpenStax CNX.

- TWI2050 – The World in 2050 (2019). "The Digital Revolution and Sustainable Development: Opportunities and Challenges." Report prepared by the world in 2050 initiative. IIASA, Laxenburg, Austria. http://pure.iiasa.ac.at/id/eprint/15913/

- Umachandran K., Jurčić I., Della Corte V., and Ferdinand – James Debra S. (2018). "Industry 4.0: The New Industrial Revolution." In Dey N. And Tamane S., *Big Data Analytics for Smart and Connected Cities* (pp. 138-156). IGI Globa

- United Nations, Department of Economic Social Affairs – Sustainable Development. (2015). "The 17 Goals." https://sdgs.un.org/goals

- Wikipedia. (2021). "Augmented reality." https://en.wikipedia.org/wiki/Augmented_reality

- Woodrow Bellamy III (2017). "9 Companies Using Augmented and Virtual Reality in Aviation." Aviation Today. https://www.aviationtoday.com/2017/08/24/9-companies-using-augmented-virtual-reality-aviation/

APPENDIX

Author	Year	Name	Citation	Language	Location	Method	Focus	Source
Grobler, Carla	2019	Marginal climate and air quality costs of aviation emissions	13	English	USA	Quantitative study	air quality Nox/CO2/contrails non-CO2 emissions Social cost radiative forcing	IOP Publishing Ltd/Environmental Research Letters, Volume 14, Number 11
Lee, David	2020	Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30 (4)	2	English	Europe	Report	non-CO2 emissions The Effective Radiative Forcing (ERF) Climate change Policy	European Aviation Safety Agency/ Manchester Metropolitan University's Research Repository
Planès, Thomas	2021	Simulation and evaluation of sustainable climate trajectories for aviation	3	English	France	Scenario simulation	Commercial aviation Co2 emissions Paris Agreement Climate Change Carbon budget	Elsevier
EASA, EEA, EUROCONTROL	2019	European Aviation Environmental Report 2019	2	English	Europe	Report	CO2 emissions non-Co2 emissions noise policies Technology and Design Sustainable Aviation Fuels Air Traffic Management Radiative forcing Clean Sky 2	EASA

Table 1. *Literature Selected - Search A*

Author	Year	Name	Citation	Language	Location	Method	Focus	Source
M Galant	2019	Using the Simulation Technique To Improve Efficiency in General Aviation	6	English	Poland	Quantitative study	General Aviation Efficiency Flight Simulation Technology Educational Assessment Ecology	AIP Conference Proceedings
Ceruti, Alessandro	2019	Maintenance in aeronautics in an Industry 4.0 context: The role of Augmented Reality and Additive Manufacturing	81	English	Italy	Study case/Experimental	Augmented Reality Aeronautical mantainance Aerospace Efficiency /time Safety	Journal of Computational Design and Engineering/ Elsevier
Fetterolf, Colton S	2020	Using Augmented Reality to Enhance Situational Awareness for Aircraft Towing	N/A	English	USA	Experimental	Augmented Reality Virtual reality Aircraft Towing Naval/Militar Aircraft Safety Economy Training maitenance Simulation	Calhoun: The NPS Institutional Archive DSpace Repository /Thesis
Sharma, Mr Devender	2017	Virtual Aircraft Environment to Evaluate Modification Proposal	N/A	English	India	Quantitative assessment/ Experimental	Virtual Reality Modifications/design Efficiency Aircraft/ Case study Airbus A 320	Asian Journal of Convergence in Technology
T Balcerzak, K Kostur	2018	FLIGHT SIMULATION IN CIVIL AVIATION ADVANTAGES AND DISADVANTAGES	N/A	English	Europe	Narrative	Civil aviation, training, Flight simulation, Zero flight time training, Safety, Pilots, Cabin crew	Revista europea de derecho de la navegación marítima e aeronáutica
Tecknotrove Systems	2021	Virtual Reality and Augmented Reality Solutions for the Aviation Industry	N/A	English	Global	Narrative	Virtual reality Augmented reality Training Maintenance Economy	Aviationpros website / article
Woodrow Bellamy III |	2017	9 Companies Using Augmented and Virtual Reality in Aviation	N/A	English	Global	Narrative	Design and manufacturing Maintenance Entertainment Training Aumented Reality Virtual reality Safety Airline/Helicopter/Aerospace	Aviation Today

***Table 2**. Literature selected - Search B*

EXECUTIVE SUMMARY

This thesis aims to identify and clarify the environmental impacts and opportunities offered by applying digital reality technologies in the aviation sector. After a profound literature review of the current global interest in sustainability challenges and digital trends, the topic was chosen with the collaboration of Leonardo S.p.A, a multinational Aerospace & Defence industrial leader company in the Dow Jones Sustainability Index. Due to the lack of availability of similar studies, the methodology adopted was a systematic review to select relevant evidence and extract and assess the data to bring a logical response to the research question: Is Digital Reality a good ally against the current environmental challenges of aviation?

The first chapter of this research presents the current sustainability background. The literature review aims to understand the main pillars that integrate Sustainable Development, the current challenges, and their relevance in today's reality. Moreover, it searches to understand the crucial role of investors and corporations in achieving those goals.

The second chapter introduces Digital Technologies and their potential capability to accelerate the transition to a sustainable economy. It shows how the current pandemic of Covid- 19 has impacted the organisation's adoption of digital technologies and the current benefits and barriers. Finally, it describes virtual and augmented reality technologies showing their expected growth in the following years and highlighting potential benefits and challenges for organisations.

The third chapter seeks to clarify the evidence base available around the relationship between virtual reality technologies used in the aviation sector and their impacts on the sustainable development goals linked to the environment. The evidence was selected and analysed through a systematic review of the scientific papers published during the last two years, company reports, journals and interviews with experts in the field of study. This chapter reports a description of the different steps of the methodology adopted to analyse the evidence and descriptive synthesis, exposition and discussion of the findings.

Through this, it was possible to conclude that those technologies could positively impact climate change. Most of the environmental benefits of those technologies founded in this research were associated with pilot training simulators. Nevertheless, there are not enough studies available about the environmental impacts of those technologies. Moreover, it would be necessary to fully study the entire cycle of each digital reality application to confirm a positive impact in each specific case. Therefore, further research is needed about the environmental impacts of aviation emissions and the digital reality technologies used by different organisations to effectively communicate the climate benefits of the new technologies applied in this sector. As a result, responsible investments decisions will be facilitated by collaborating to achieve a sustainable future.

CHAPTER 1: SUSTAINABILITY FRAMEWORK

1.1 Historical framework and definitions

Sustainable development is defined as the ability to meet the needs of current generations without compromising the ability of future generations to meet their needs and aspirations. Sustainability integrates economic, environmental, and social factors. Economic factors give the framework in which decisions are made, including all the development and transactions of knowledge, competencies, resources, and skills relevant to economic growth. Environmental factors recognise the interdependence and diversity within our ecosystems. Finally, social factors refer to the interactions between institutions and people and their function to protect human values, well-being, ethical issues and aspirations. Sustainability is a constant challenge of every epoch, and it is essential to understand that innovative technological solutions from today's sustainability issues could become a problem for tomorrow.

1.2 International Framework to tackle sustainability issues

The following table summarises some of the international trends to decarbonise our economy aggressively.

Paris Agreement	The 2030 Agenda for Sustainable Development	European Green deal
In 2015 the Paris Agreement, a legally binding international treaty on climate change, seeks to avoid the dangerous effect of climate change limiting global warming below 2°C and pursuing efforts to limit it to 1.5°C.	In 2015, the United Nations member states set The 2030 Agenda with the 17 Sustainable Development Goals (SDGs) and 169 targets to end poverty, protect the planet, and improve everyone's lives and prospects.	In 2019, the European Commission launched The European Green Deal. It is a set of policies to make the European economy sustainable, with a broad goal of net-zero carbon emissions by 2050 and a 50% cut in emissions by 2030.

1.3 Responsible Investments

To achieve the sustainability goals proposed by the Paris Agreement, the 2030 Agenda and the European Green Deal, governments and public institutions should work together with the private sector. In this segment, following the "Recommendation of the Task Force on Climate-related Financial Disclosures" report issued in 2017, some climate-related financial risks, opportunities, and their financial impacts have been summarised.

Environmental risks	Environmental opportunities	Financial Impacts
Risks linked to the transition to a low-carbon economy are policy and legal, technological and reputation risks and the physical impacts resulting from climate change.	Some areas and opportunities driven by the efforts to mitigate and adjust to the environmental changes are resource efficiency, energy source, product and services, new markets and resilience to change.	The environmental-related risks and opportunities can have a financial impact on revenues, expenditures, assets, liabilities and capital expenditures.

1.4 Corporate sustainability: the role of companies to achieve SDGs

It is essential to understand that governments alone cannot successfully address the SDGs. Private business organisations and industries play a crucial role in the transformation to achieve sustainable development. This section has addressed the reason for integrating sustainability into a business, some of the best practices to manage sustainability and highlight the need to accelerate the change taking disruptive solutions to accomplish with the SDGs, Paris Agreement and European Green Deal.

To conclude, there is a common belief that digital technologies could also be the accelerators that we are searching for. However, history has shown that technologies bring powerful and exponential benefits but also exponential risks. Therefore, a sustainable consciousness and an understanding of the challenges seems to be the best path to help industries use technology innovation for our benefit and future generations' benefit.

CHAPTER 2: DIGITAL SOLUTIONS FOR ENVIRONMENTAL CHALLENGES

2.1 Digital Evolution: key concepts and characteristics

Nowadays, many observers believe that we are traversing a new revolution, the fourth one. It has been labelled as Industry 4.0, and it is characterised by the emergence of digital technologies. German chancellor Angela Merkel defined it as 'the comprehensive transformation of the whole sphere of industrial production by merging digital technology and the internet with conventional industry'.

Digitisation is defined as the conversion or representation of something non-digital such as identity cards, papers, health, songs, and photographs into a digital format (bits and bytes) used by a computing system for multiple purposes. An example is when we took physical information, a paper document, and digitised it using a document scanner. However, digitisation can be defined as a process applied to societies and, principally, economies. It is the conversion of interactions, business functions, business models and communications into digital. A final step is Digital transformation. It comprises the incorporation of digital technologies into every aspect of a business. The acceleration of technology adoption and change leads to an entirely new market, customer and business realities, opportunities and challenges, that drive a new economy. Fundamentally, it leads to a change of culture and how the company operates to create value.

2.2 Digital acceleration

Nowadays, we are traversing a global pandemic produced by the virus Covid- 19. Standard tools that most government and scientific communities have suggested to combat the pandemic are related to social distancing policies. Many companies have been forced to change their way of interacting inside and outside the firm. Those circumstances seem to create the perfect scenario for accelerating the digitalisation of their business and economies. According to a new McKinsey Global Survey of executives, their firms have accelerated the digitisation of their customer and supply-chain interactions and their internal operations by three to four years.

The European Commission's Green Deal chief Frans Timmermans has assured that "every euro" spent on economic recovery measures after the pandemic Covid 19 would be linked to the green and digital transition. The following graph synthesis some of the expected benefits and challenges from those changes:

Benefits of Digital Technologies	Barriers of Digital Transformation
Productivity: The increase of quality and reduced errors is a powerful tool to use the resources and reduce cost, enhancing competitiveness efficiently. **Flexibility:** digitalisation will enable increasing the workforce's flexibility, allowing workers to perform specific tasks remotely. **Business models:** Digitalisation is influencing customer relationships, the value proposition and the management infrastructure. The shift from a product perspective to a service perspective is opening new markets and an opportunity to increase revenues for companies.	**Investments:** Industry 4.0 requires considerable investments in new technologies, infrastructure, research and skills. **Security and legal issues:** All companies want to be protected from risks because they can cause significant damages for a company and even, in some cases, their bankruptcy. Another challenge arising more in the courts is Intellectual Property Issues. **Employment and skills development:** The new revolution will shift several manual or simple labour for machines. Several employees risk becoming replaceable, and at the same time, the market will require new skills and capabilities.

Digitalisation's sustainable benefits can be understood not as a unique technology or industry but as an interconnected system that interplays many fields. Even if the global greenhouse gases emissions that correspond to the ICT sector are approximately 1.4% of the overall global emission, the potential benefits of digitalisation could outperform the negative impact decreasing other sector emissions by up to 15-20%. Moreover, according to *"Digital with Purpose: Delivering a SMARTer 2030"*, a report by the Global Enabling

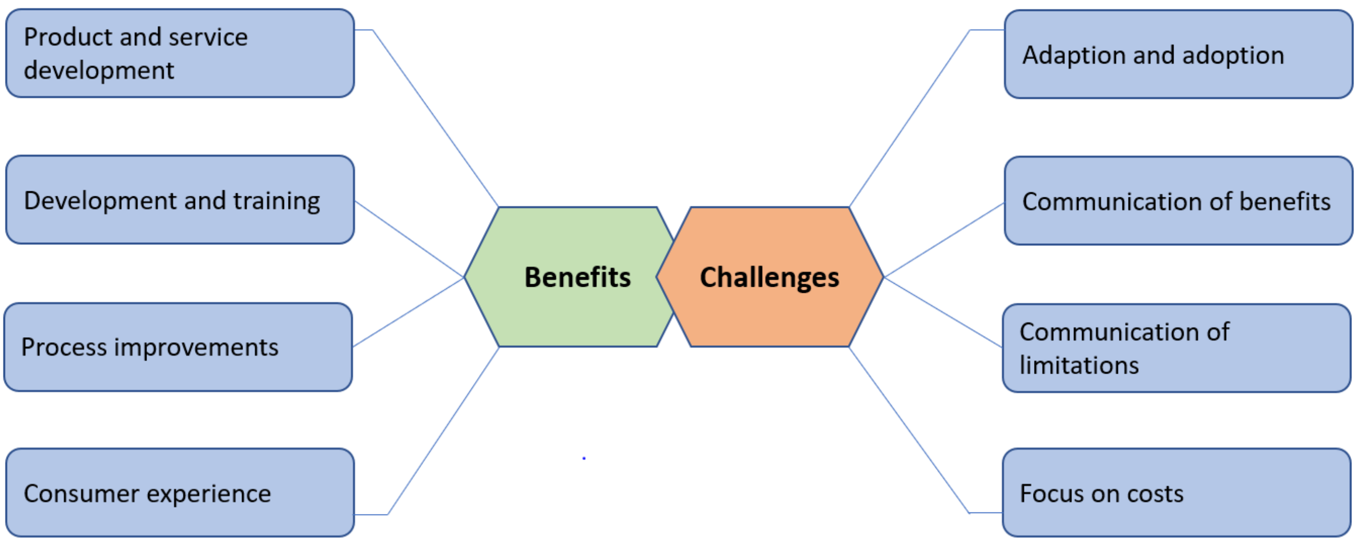
Sustainability Initiatives (GeSI) and Deloitte, supported by the EIT Climate -KIC; Digitalization could accelerate the progress toward the Sustainable Development Goals by 22%.

The *"Digital with Purpose: Delivering a SMARTer 2030"* report also identifies some prominent digital technologies groups with global and cross-industry impact during the following years. Those are Cloud technologies, Digital Access, Cognitive, Blockchain, Fast Internet, Internet of Things (IoT) and Digital reality. The seven technologies vary significantly in maturity. Each of them has plenty of opportunities to scale in terms of deployment, and consequently, in terms of impact. This thesis focuses on the impacts of the digital reality group.

2.3 Digital reality technologies

Digital reality technologies is a growing and expanding market over the last following years. This section introduces digital reality technologies, such as virtual reality (VR) and augmented reality (AR). VR can replace your real-world environment with a virtual one. This environment can be computer-generated or filmed in 360-degree video. It also takes full advantage of the body- and motion-tracking capacities, with many claiming that this leads to a superior sense of presence and involvement. Instead, AR can deliver an interactive experience of a real-world environment where the objects that belong to the real world are enhanced by computer-generated perceptual information. These objects can appear as a flat graphical overlay or can behave as actual 3D elements.

An economic impact assessment conducted by PwC economists estimates that VR and AR technologies can deliver a $1.5 trillion boost to the global economy by 2030. In the following graph, there is a summary of some potential benefits and challenges for those technologies.



CHAPTER 3: SYSTEMATIC REVIEW – ENVIRONMENTAL IMPACTS OF DIGITAL REALITY APPLICATIONS IN AVIATION

3.1 Sustainable Development in the Aviation Sector

Aviation is a growing sector that currently is facing multiple environmental challenges. In 1999, an Intergovernmental Panel on Climate change reported that aviation accounted for near 2% of global greenhouse gas emissions due to human activity. Additionally, it was highly thought that aviation emissions are particularly challenging due to the chemical interactions at high altitude. This has increased the spotlight on aviation, and consequently, the market participants have been affected by a variety of targets, regulations, possible solutions, and practices that emerged during the last years.

In 2009, the International Air Transport Association (IATA) presented to the United Nations Framework Convention on Climate Change a strategy to reduce carbon emissions. The targets proposed were:

- From 2009 to 2020, an average improvement in fuel efficiency of 1.5%.
- From 2020, a carbon-neutral growth.
- By 2050, a reduction in net aviation CO_2 emissions of 50% relative to 2005 levels.

Moreover, from a Market Research Report Record, it has been projected that the augmented and virtual reality market in aviation will grow from USD 78 million in 2019 to USD 1375 million by 2025, an annual growth rate of 61,2%. This survey will investigate the environmental impacts of the aviation industry and how digital reality technologies on the aviation sector could help fight against climate change, giving the companies in this sector the opportunity to create new value for all the stakeholders involved. Considering the novelty of the topic, the methodology adopted was a compilation of existing evidence through a systematic review. In addition, interviews have been done with the specialist in the aircraft and sustainability divisions of Leonardo S.p.A. company, one of the world's major players in Aerospace, Defence and Security, to complement the systematic literature research with a practical case.

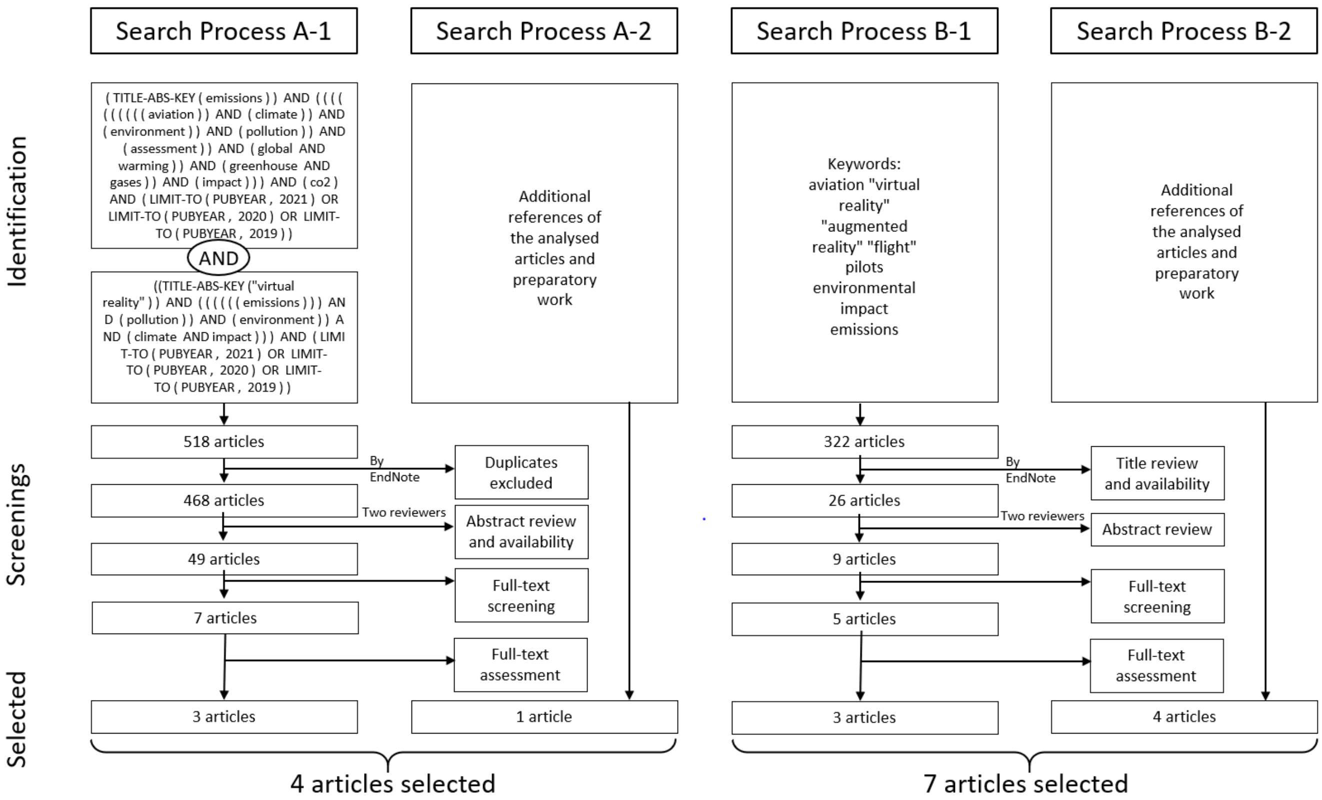
3.2 Review Methodology

A systematic research procedure was applied to address the objective of this thesis, minimise the risk of bias during the search, and find an answer to the following research questions:

- Which are the environmental impacts of the aviation sector?
- What is the utility of digital reality technologies in aviation?
- Are virtual reality technologies good to reduce the environmental impacts on the aviation sector?

3.2.1 Identification of studies

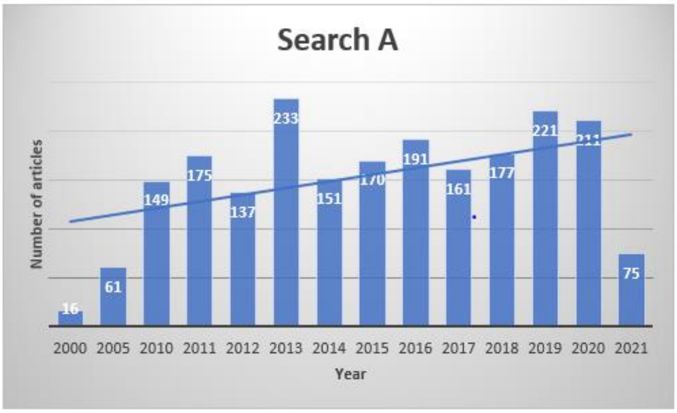
Based on the research questions and the theoretical framework, appropriate keywords were identified. Nevertheless, the combination of all of them does not lead to any result. For that reason, it was decided to divide into two search strings illustrated below. Searches were performed using search queries in different data sources. Leading data sources were Scopus (https://www.scopus.com), Google Scholar (https://scholar.google.com/) and Summon Luiss (https://luiss. summon.serialssolutions.com/). Apart from searching these databases, newspapers and related reports of public and private organisations were also studied, and interviews with experts in the field of study were also conducted.

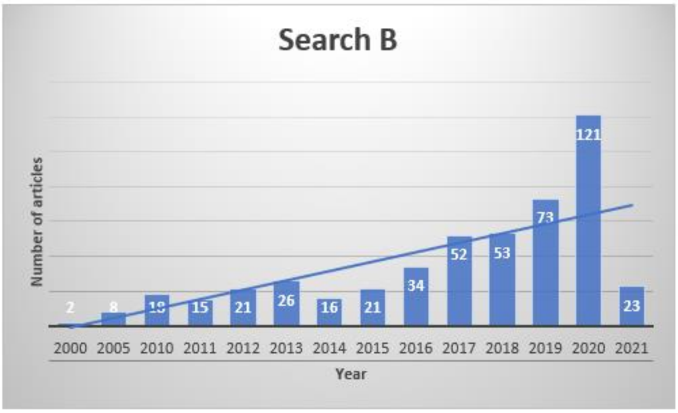


3.2.2 Selection criteria

The results from the different database searches were analysed in a structured screening process. First, language criteria were applied to include articles that were written in English. In addition, publication date criteria were also applied. For Search A articles published from 2019 to April 2021. For Search B the time period was extended from 2017 to April 2021. Then, the abstracts of the remaining articles were analysed by two reviewers and took into consideration their relevance, originality and availability.

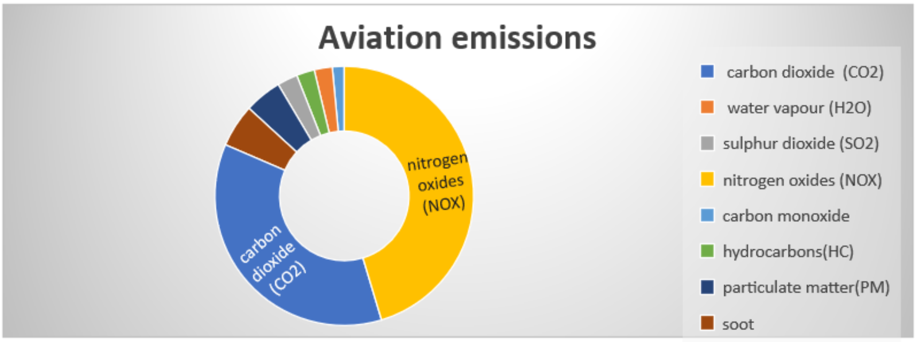
3.2.3 Statistical analysis publication over time

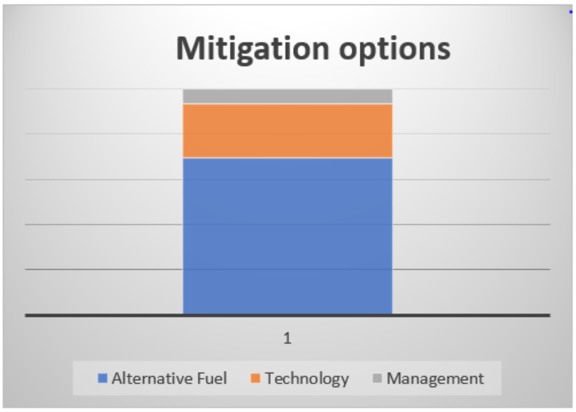


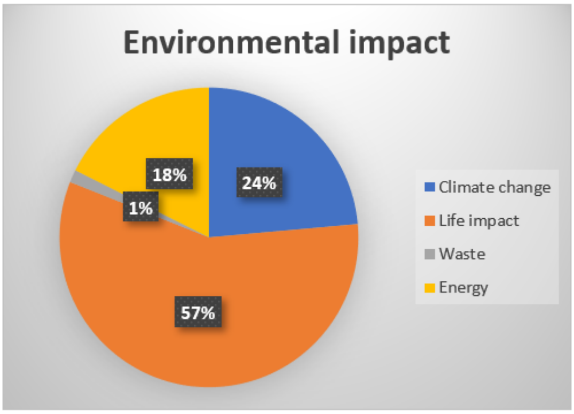


For a first overview, the distribution of the publication output over time is analysed. In their totality, these literature analyses by publishing year seem to demonstrate that the interest in researching the environmental impact of the aviation sector is higher than the research on the application of digital reality technologies in the same sector. Nevertheless, observing only the last 10 years, the growth rate of interest in VR and AR technologies in the aviation sector is almost double of environmental impact. Therefore, it could be estimated that with time, more research will be done in this area, simplifying for investors and organisations the understanding and communication of the sustainable impacts of the application on those technologies in the aviation industry.

3.2.4 Contents analysis of the selected literature

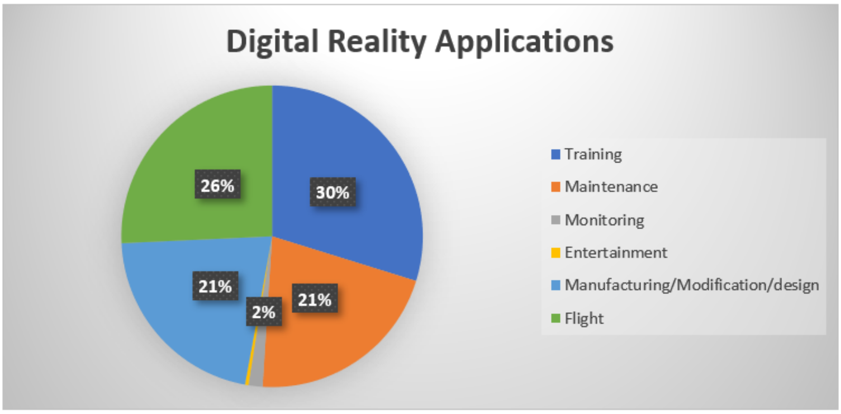


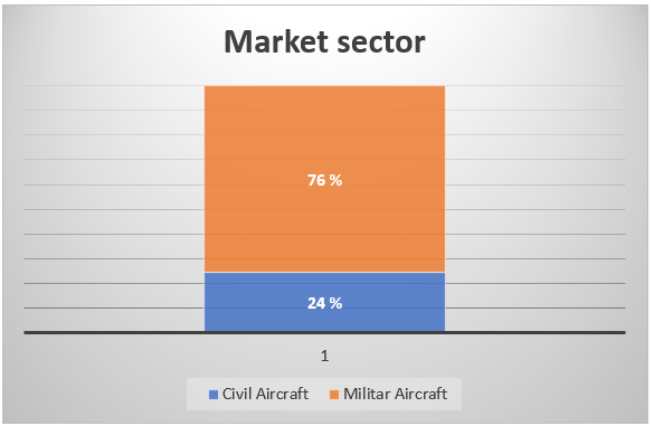


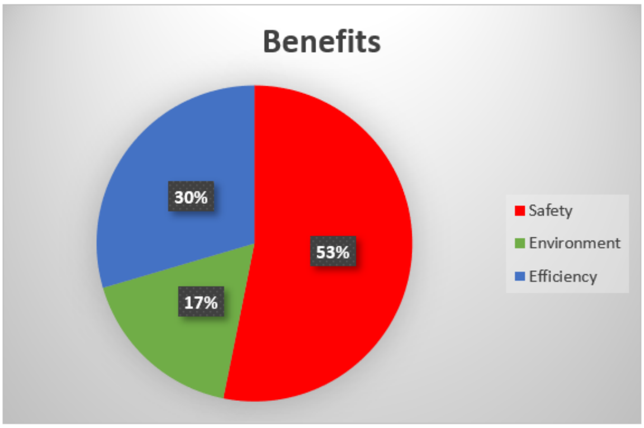


The graphic above compares the frequency of terms correlated with aviation emissions, mitigation options, and types of environmental impacts mentioned in Search A. This comparison was made to identify the trends and research focus of the selected articles.

As well as in Search A, through the identification of keywords on articles selected in Search B it was possible to understand the different utilities of these technologies in the aviation industry. Then, between the different repeated keywords, it was also possible to identify that these studies focused on different market sectors with different characteristics and requirements. Finally, some benefits of the use of these technologies in aviation were identified in the literature .







3.3 Detailed analysis and key insights

Climate change is a relevant risk for the aviation industry that will grow in the following years. Hence stakeholders need to contemplate them on their planning process, risk assessment evaluations and future investments. The impact of climate change will be variable depending on the geographic locations and particular circumstances. Some of the increasing physical risk highlights in the literature are:

- Heat damages in infrastructure,
- More uncertainty in climate modelling will increase delays, re-routings and consequently, an increment of fuel burn.

- Climate change will also raise clear air turbulence in frequency and strength.
- Higher and extreme temperatures limit the departures for colder times of the day, changing schedules and reducing payloads.
- The rise of sea levels and natural disasters will create a permanent or temporary loss of airport capacity and network disruptions in the long term.

Similarly, policy and legal risks also need to be taken into consideration. The literature study showed the possibility to apply in the following years a charge on the total NOx emissions and also the possibility to include them in the EU Emissions Trade System (ETS). The vital need to reduce carbon emissions has prompted a Carbon Offsetting and Reduction Scheme for the aviation industry (CORSIA). CORSIA is an offsetting scheme that allows compensating the emissions reductions that cannot be achieved in the aviation sector, with cuts in other sectors where the potential for faster reductions is larger, and the linked costs are lower.

Finally, it is essential to consider the reputational risks and to take into account that the current projection shows that if the sector does not apply any changes, the total Effective Radiative Forcing consumed by the aviation sector will be 51.6% of the world ERF budget in 2050 for 1.5ºC. Those numbers could have a negative impact on customers and organisations' perception of this sector.

Therefore, the environmental risks and the significant contribution of greenhouse gases emissions of aircraft have encouraged stakeholders to search for innovative solutions that could help in the reduction of impacts. As a result, different applications of AR and VR technologies in aviation have been studied to identify how they could contribute to the fight against climate change.

- **Cutting flight hours**

The report "CAE 2020 Airline and Business Jet Pilot outlook update" published by the company CAE estimates that the civil aviation market will require between 2020 to 2029 around 264,000 new pilots for airline flights and business jet flights. Moreover, the average emission of CO_2 that we can find on the internet by an hour of flight is approximately 3.08 tonnes. Depending on the type of license, the pilots will need around 40 hours of flight for a Private Pilot License, 250 hours for a Commercial Pilot Certificate and 1,500 hours Airline Pilot Transport License. If we decide to simplify 250 hours of training by pilot, it is possible to calculate around 203 Mt of CO_2 avoided by flight simulators, which represents around 22% of the aviation CO_2 emissions in 2019.

This quick estimation has been done only to illustrate the capacity of emission reduction using flight simulators. Further research will need to be done to estimate accurately avoided emissions numbers, considering civil aviation and military flights, CO_2 and non- CO_2 emission by aircraft models, and pilots' percentage worldwide training hours. Therefore, the possibilities of reduction of emission by use of flight simulators might be much higher.

- **Reducing flight and operational inefficiencies**

The literature shows that in 2017 the gate-to-gate actual trajectories of all the European flights compared with their unimpeded trajectories produce an extra of 5.8% gate-to-gate CO_2 emissions at the European level. Also, there are airport inefficiencies where a significant variation of the average additional Arrival Sequencing and Metering Area (ASMA) time can be appreciated. In 2017, inefficiencies in the arrival flow at the top 30 airports in Europe caused 8.33 million minutes of additional ASMA time.

These inefficiencies result from multiple factors such as adverse weather, avoiding dangerous areas, need to maintain minimum separation, pilot's ability, management and coordination issues, among others. VR simulations could help optimise flight routes, and AR is a significant support to improve pilots' awareness and performance during flights. In the literature selected, there is a comparison between the times needed in a Landing and Take-off test (that involves each phase of flight: taxi, approach, take-off, and climb) in an actual airport and a flight simulator. The results of those experiments indicate that CO, NOx, HC and PM emissions were lower through flight simulation in ranges between 14% to 54%. This study showed that flight simulation could positively affect pilot efficiency and consequently reduce emissions.

- **Improving environmental awareness**

AR and VR technologies have shown to be powerful tools to provide information, creating awareness, helping users improve their performance in an efficient and didactic way. Although the literature does not mention this specific application, we find that it could be helpful to add the number of emissions inside the AR data transmitted to pilots during flights, to improve the emissions flight performance.

Another suggestion from this research has been inspired by airlines' experimental use of VR as an entertainment tool. It could be helpful to take advantage of the educational benefits of those technologies, allowing passengers to experiment and appreciate the amount of air pollutants in the atmosphere during their flights and the effects of those greenhouse gases in climate change and earth life. Similar tests have been carried out using simulators to create ecological awareness in other sectors such as ocean life or the Amazon forest. As a result, they have a positive effect on changing environmentally negative behaviours and increasing economic cooperation for combating those effects.

- **Social and economic benefits**

Apart from the above-mentioned environmental benefits, digital technologies have a powerful impact on other Sustainable Development Goals such as quality Education, good health and well-being, and decent work and economic growth. A review of the literature shows there were approximately 907 deaths during the period between 2017 to 2019 due to airline crashes and failures. Consequently, the safety benefits of AR and VR technologies identified in Figure 19 could be essential to ensure workplace security and decrease considerable cost from those accidents. In addition, digital reality technologies seem to be powerful educational tools that could be applied to efficiently train employees in various activities. To conclude, it is important not to forget that during the phases of development, assessment and maintenance of aircraft, significant waste, time and cost savings could be achieved.

3.4 Study case: Digital reality solutions for the military aviation sector – Leonardo S.p.A

During an interview with Leonardo's current Head of Simulation & Training, it was possible to obtain a description and comparison between the simulation technology applied in the military and civil sectors. While in civil aviation, the pilots have to repeat a limited number of manoeuvres, in the military sector, pilots learn how to fly during different missions, which entails different manoeuvres, higher speed, higher risks, and a continuous training process to improve their skills and preparation from different missions. Those differences made it currently impossible for military aviation to achieve 100% fidelity or Zero Flight Time as in the civil aviation segment.

Despite the difficulties, Leonardo has developed an innovative training system that allows the substitution of around 50% to 60% of the military pilot flight training hours. In the following years, it expects to accomplish 70% of fidelity. The technology behind those simulators included a Live, Virtual and Constructive Simulation (LVC). Those technologies permit that simulators in the ground interact with the pilots in the air, during the same training missions, through augmented reality applications. Therefore, this complex technology creates a safety scenario avoiding accidents caused by aircraft collisions and improves training efficiency, giving pilots the possibility to simulate situations that would be too costly or risky to simulate in reality.

The International Flight Training school is a collaboration between Leonardo and the Italian Air Force that has reduced actual flight hours through full mission simulators, providing 26,000 hours of virtual training and avoiding around 116,000 tonnes of CO_2 emissions since 2018. Those emissions are equivalent to the carbon sequestered by 142,121 acres of US forest in one year.

The potential environmental emissions saved by digital reality technologies in the military sector could be significant if it is taken into consideration for continuous pilot training requirements and a large amount of GHG emissions coming from this sector. In the meantime, further research of the amount of CO_2 non-CO_2 emissions created by those sectors and their respected climate effects is needed; those data could be crucial to understand and expand the digital reality applications for the fight against climate change.

CONCLUSIONS

The transition towards a greener economy is strongly related to a change in society and organisational behaviour toward sustainability and digital solutions. There exists a strong belief that digitalisation could be a key ally for economic and sustainable recovery. Although some studies report that digital solutions could decrease an average between 15% to 20% of the global CO_2 emissions, there needs to be further study into the particular environmental benefits and challenges that they represent for each industry.

In this work, a general framework of the overall sustainability challenges and digitalisation evolution has been presented. Then, it was decided to analyse the environmental impacts and opportunities of digital reality technologies on the aviation sector. Consequently, due to the topic's novelty, a systematic review of the scientific literature, organisational reports, and company experiences was conducted. By compiling the evidence available by a methodical process, it was possible to identify the potential benefits of Virtual and Augmented reality technologies to reduce aviation environmental impacts.

Through a scientific literature review, this survey has found that aviation contributes to around 2.6% of the worldwide CO_2 emissions. This number could be considered slow, but pondering that aviation is also responsible for other greenhouse gas emissions whose warming effects seem to be higher to those from CO_2 emissions, it is not the best parameter to measure aviation impacts on climate change. A better parameter to determine the greenhouse effect of aviation could be Effective Radiative Forcing, which is the difference between solar irradiance absorbed by the Earth and energy radiated back to space. According to ATAG estimations, aviation could consume 51.6% of the world ERF budget in 2050 for 1.5ºC. However, even if it could be a better indicator, there are still many doubts about the actual impacts of those gases because, depending on the altitude and the chemical background, their warming or cooling effects change considerably.

So, the aviation sector is conscious of those numbers and principally of the risks and costs that climate change signified for the industry. Infrastructure damages, an increase of accidents and schedule changes and delays are only some examples of the physical environmental risks with which aviation stakeholders need to deal with. For that reason, they are invested in disruptive solutions. The EU has invested approximately €5 billion over the last decade to support various programmes and measures, such as Clean Sky, SESAR, CORSIA, to transform the aeronautics industry to become more environmentally-friendly.

At the beginning of this research, the objective was to identify the opportunities of VR and AR technologies in the aviation fight against climate change and measure those impacts through some common indicators. However, difficulties finding existing and comparable articles to approach this issue has led to division of the systematic review into two parts. The first one, a search to understand the environmental aviation challenges and, the second one, to find the VR and AR applications in the aviation sector. This methodological path to approach the topic leads us to understand that one of the main problems of the aviation sector is the lack of a clear understanding of the climate impacts of their emissions. Therefore, it would be more challenging to understand the possible solutions if one cannot understand the problem. Nevertheless, this leads to the first conclusions: the necessity to establish a KPI for the aviation sector that serves as a parameter to understand and compare the environmental benefits of different technological solutions. The standardisation of comparable indicators is essential to facilitate green investment decisions.

Secondly, the systematic review concluded that the main environmental benefits of VR and AR technologies in aviation are indirect effects linked to their educational advantages. Consequently, those technologies have allowed flight simulators with Zero Flight Times, which means no more emissions due to civil pilot training. Due to the complexity of the military sector, the flight simulators combined virtual and augmented reality technologies allowing a reduction of around 50% to 60% of the actual flight training hours. Moreover, those technologies help to improve the efficiency of the whole aviation system operations. Considering the studies that show around 6% of the aviation emissions are linked to systems inefficiencies, the support of those technologies could be significant. Finally, we also believe that their immersive characteristics could be helpful to develop educational programmes during the flight that allowed to increase climate awareness and support green initiatives.

Apart from the described research outcome, the results of this work show that even if there is a lot of information available about different sustainable and innovative initiatives, there is a limited amount of work or literature available assessing the environmental impacts of those technologies. Further research about aviation emissions effects will be needed to measure and report the ecological benefits and challenges of digital solutions in the aviation sector. In retrospect, the primary purpose of this work has been to explore the digital reality environmental benefits and opportunities that are not often considered, searching to increase awareness in the aviation stakeholders and scientific community, and create a direct reference of the existing works for the future.